SPEECH ANALYSIS AND SYNTHESIS OF THE PUNJABI LANGUAGE

A Thesis
submitted in fulfillment of the requirement
for the award of the degree of

DOCTOR OF PHILOSOPHY
in
COMPUTER SCIENCE

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CANDIDATE'S DECLARATION

Certified that the thesis entitled, **"SPEECH ANALYSIS AND SYNTHESIS OF THE PUNJABI LANGUAGE"**, which is being submitted by **Dr. Surinderpal Singh Dhanjal** (Registration No. 9051453), in the fulfillment of the requirements for the award of the degree of **DOCTOR OF PHILOSOPHY** (in Computer Science), to the School of Mathematics and Computer Applications, Thapar University, Patiala, comprises of entirely my own research work carried out under the supervision and guidance of **Dr. Satvinder Singh Bhatia** during the period from August 2005 to June 2014, and that the ideas and references cited herein have been duly acknowledged.

(Dr. Surinderpal Singh Dhanjal)

Attestation by Supervisor

(Dr. Satvinder Singh Bhatia)
Professor
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INDIA

DEDICATED TO

MY PARENTS
Late Rala Singh Dhanjal (Father) and Late Nand Kaur Dhanjal (Mother)

MY BROTHERS
Late Malkit Singh Kundan (eldest Brother) and Late Mrs. Tej Kaur Dhanjal
Late Amarjit Singh Dhanjal M.A., B.Ed. (elder Brother) and Mrs. Manjit Kaur Dhanjal
Amritpaul Singh Dhanjal M.A., LL.B. (elder Brother) and Mrs. Mandip Kaur Dhanjal

MY SISTERS
Late Amar Kaur Sond (eldest Sister) and Late Mr. Harjit Singh Sond
Late Ranjit Kaur Ghattaurha (elder Sister) and Mr. Gurcharan Singh Ghattaurha
Harbans Kaur Ghattaurha (elder Sister) and Late Mr. Bhagwan Singh Ghattaurha
Gurcharan Kaur Dhiman (younger Sister) and Mr. Ranjit Singh Dhiman

MY WIFE
Balbir Kaur Dhanjal B.Sc.N.

and

MY ONLY CHILD
Ms Samta Dhanjal B.A. (Math and Bus. Mgmt.), Post-Bac Teaching Diploma (TESL)

I DO NOT KNOW WHAT I MAY APPEAR TO THE WORLD, BUT TO MYSELF I SEEM TO HAVE BEEN ONLY LIKE A BOY PLAYING ON THE SEA-SHORE, AND DIVERTING MYSELF IN NOW AND THEN FINDING A SMOOTHER PEBBLE OR A PRETTIER SHELL THAN ORDINARY, WHILST THE GREAT OCEAN OF TRUTH LAY ALL UNDISCOVERED BEFORE ME.

- ***ISAAC NEWTON (1642-1727)***

WHAT WE KNOW IS NOT MUCH,
WHAT WE DO NOT KNOW IS IMMENSE.

- ***PIERRE-SIMON LAPLACE (1749-1827)***

IF WE KNEW WHAT IT WAS WE WERE DOING, IT WOULD NOT BE CALLED RESEARCH, WOULD IT?

- ***ALBERT EINSTEIN (1879-1955)***

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August 25, 2014

(Surinder Dhanjal)

ABSTRACT

The present thesis entitled "**Speech Analysis and Synthesis of the Punjabi Language" embodies the investigations carried out** by me at the School of Mathematics and Computer Applications (SMCA), under the supervision of Dr. Satvinder Singh Bhatia (Professor, SMCA, Thapar University, Patiala).

The quality of the synthesized speech, also known as (*aka*) synthetic speech, has been an important issue for speech researchers. This project is an attempt to address this important issue of synthesizing high quality speech in the Punjabi language. The Punjabi language is a modern Indo-Aryan language. The Punjabi language has been ranked amongst the top 15 spoken languages of the world. Over the years, this ranking has varied between 10 and 18. With more than 90 million native speakers, and more than 140 million speakers in 150 countries of the world, the Punjabi is considered amongst the world's 10 most influential languages, and is respectfully included in an article by the same name, "The World's 10 Most Influential Languages" by George Weber. Andronov reports that the Institute of Oriental Studies of the Russian Academy of Sciences has prepared and preserved dozens of reports on the Punjabi language. Any research on the Punjabi language, therefore, assumes an international significance.

There are many dialects of the Punjabi language mainly written in the two scripts. Punjabi University (Patiala, India) published a list of 31 dialects of the Punjabi language. In the Punjab state of India, the Punjabi Language is written in the Gurmukhi script, whereas in the Punjab state of Pakistan, the Punjabi language is written in the Persian (or Shahmukhi) script. It will be an enormous task to deal with all dialects of both scripts of the Punjabi language. This research work, therefore, concentrates only on one dialect (the *Malwai* dialect) and one script (the *Gurmukhi* script) of the Punjabi language.

This research work has been carried out with the following *three* objectives in view as set in the Institute Research Board (IRB):

(i) To design a new phonetic alphabet for speech processing in the Punjabi language consistent with the **ARPAbet** *because at present, the symbols consistent with the ARPAbet phonetic transcription do not exist in the Punjabi Language.*

(ii) To develop a new text and speech corpus for the Punjabi language *because no computer database/corpus exists in the Punjabi language, where the representative speech sentences concentrate on a specific dialect (the* ***Malwai*** *dialect) of the Punjabi language.*

(iii) To conduct the linear prediction analysis and synthesis (*aka* Linear Predictive Coding or LPC) of the Punjabi speech sentences *because no work has so far been*

reported in the literature where the Punjabi speech has been analyzed/synthesized using the linear prediction model of speech production.

The *first* issue is the actual representation of the phonemes. In linguistics, the International Phonetic Alphabet (IPA) designed by the International Phonetic Association is used to represent the phonemes. However, the major limitation of this representation is that it needs some special symbols that are not readily available on computer keyboards. In this work, a new phonetic alphabet consistent with the ARPAbet phonetic transcription of the Punjabi language has been developed in CHAPTER II. This newly designed scheme called ***PUNJARPAbet*** has been graphically presented in CHAPTER VI. This achieves our first objective set for this study.

The *second* issue is to develop a new corpus suitable for achieving the third objective. A new text and speech corpus with several original features has been developed in CHAPTER IV. The contents of this chapter meet the second objective set for this research. The new corpus has at least *twenty* original features such as ***complete sentences*** (rather than *words* only), some lines of the folk songs in the *original* form and the *modified* form, some single line folk songs (***bolis***), some newly-written ***bolis,*** some slowly fading words of the Punjabi language, and some *ṭheṭh pendu shabads* (rustic words). In the corpus developed in this work, the speech sentences have been *recorded* in the *Malwai* dialect of the Punjabi language, and the sentences have been *written* in the Gurmukhi script. The fact that the new corpus is very rich and versatile due to a wide variety of its linguistic and cultural features makes it an ideal corpus for any serious speech processing work in the Punjabi language.

The *third* issue is to analyze and synthesize the Punjabi speech. No work has so far been reported in the literature where the Punjabi speech has been analyzed/synthesized using the Linear Predictive Coding (LPC). This work investigated the linear prediction analysis and synthesis of the Punjabi speech for the first time. The linear prediction technique is rated very high in the broad field of speech processing. This technique has been chosen because of its popularity, sound mathematical properties, simplicity, and its effectiveness as evidenced by the SPEECH UNDERSTANDING RESEARCH (SUR) project of the Advanced Research Projects Agency (ARPA) started in early 1970s. The third objective set for this project has been accomplished in CHAPTER V and graphically presented in CHAPTER VI.

The present thesis consists of *seven* chapters, and *five a*ppendices. The work carried out in this thesis can be described as follows:

Chapter I is introductory and it presents the basic concepts required in this thesis. **Chapter II** introduces the main concepts required to understand the broad field of Linguistics so that one can understand the corpus designed in Chapter IV. A new phonetic alphabet (called ***PUNJARPAbet***) consistent with ARPAbet is designed in this chapter. This chapter achieves objective 1 set for this research. **Chapter III** prepares the reader for the linear prediction speech analysis and synthesis of the Punjabi language to be conducted in Chapter V. In **Chapter IV**, a new text and speech corpus has been designed. It covers objective 2 set for this study. **Chapter V** describes in detail the mathematical concepts involved in the Linear Prediction analysis and synthesis of the Punjabi speech sentences. It accomplishes objective 3 set for this project. In **Chapter VI**, the *spectrographic analysis* is conducted by using Praat and MATLAB where the graphs for *formant frequencies, intensity, pitch, V/UV contours, and the Fast Fourier Transform (FFT)* of the speech waveforms have been plotted to gain additional insight into the results obtained in Chapter V. The graphical analysis evaluating the newly-designed coding scheme ***PUNJARPAbet*** is also included in Chapter VI. **Chapter VII** summarizes the whole work, highlighting the original contribution of this project. This chapter concludes by stating the *future directions.*

The thesis also includes five Appendices. **Appendix A** and **Appendix B** include the Text Corpus developed in this project. **Appendix A** includes about 200 sentences and single line folk songs (*bolis*) while **Appendix B** includes more than 100 *bolis*. In both appendices, the complete corpus has been transcribed both in the IPA and the newly developed phonetic alphabet ***PUNJARPAbet***. **Appendix C** describes the Levinson-Durbin algorithm to efficiently solve the Normal Equations resulting from the Autocorrelation Method for the linear prediction analysis. **Appendix D** includes the SIFT algorithm for computing the V/UV decision and the pitch extraction. **Appendix E** lists twenty-five Punjabi speech sentences synthesized in the present study.

The thesis concludes by listing the **Bibliography** of various publications and websites cited in this work.

■

PUBLICATIONS AND PRESENTATIONS

The following papers have been published in refereed International/National Journals. Presentations have been given at **six** different organizations/universities in Canada and India based on the work completed during this project.

Papers Published (Refereed Journals and International Conferences):

1. Surinder Dhanjal and Satvinder Singh Bhatia; "PUNJARPAbet: A New Phonetic Alphabet for Speech Processing in the Punjabi Language"; *Journal of Circuits, Systems, and Computers*, World Scientific Publishing Co.; Vol. 23, No. 5, June 2014 (DOI: 10.1142/S0218126614500704) (SCI)

2. Surinder Dhanjal and Satvinder Singh Bhatia; "Punjabi Speech Processing: LP Analysis and Synthesis"; *4th World Conference on Innovation and Computer Sciences* (INSODE-2014), Rome, Italy; April 11-13, 2014 (accepted for publication in *AWERProcedia Information Technology and Computer Science*).

3. Surinder Dhanjal and Satvinder Singh Bhatia; "Development of a Standard Text and Speech Corpus for the Punjabi Language"; *16th International Oriental COCOSDA / Conference on Asian Spoken Language Research and Evaluation (CASLRE) 2013 Conference*, KIIT Gurgaon, India; Nov 25-27, 2013.
   - (IEEE Xplore Digital Library DOI: 10.1109/ICSDA.2013.6709891)
   - Shortlisted by Department of Electronics and Information Technology (DeitY), MC&IT, Government of India for upload on TDIL (Technology Development for Indian Languages) Data Center (http://tdil-dc.in) portal*.

4. Surinder Dhanjal and Satvinder Singh Bhatia; "Computerization of the Punjabi Language: L.P. Analysis and Synthesis"; *PARKH (biannual Journal)*, Panjab University, Chandigarh, India; Vol. I, Jan-June 2013, pp. 179-188.

5. Surinder Dhanjal and Satvinder Singh Bhatia, "A New Corpus for the Punjabi Speech Processing", *International Symposium on Frontiers of Research on Music and Speech* (FRSM-2012); Kamrah International Institute of Technology (KIIT), Gurgaon, India; Jan 18-19, 2012; pp. 223-227.

6. Surinder Dhanjal and Satvinder Singh Bhatia, "Computerization of the Punjabi Language", *2nd World Punjabi Conference*; Panjab University, Chandigarh; Feb 24-25, 2009.

7. Surinder Dhanjal and Satvinder Singh Bhatia, “Punjabi Bhasha da Takneekee Bhavikh (Technical Future of the Punjabi Language)”; published in hard cover text *Punjabi Bhasha, Sahit Te Sabhyachar: Samkall Atey Bhawikh* (Editor: Dhanwant Kaur); Punjabi University, Patiala, India; ISBN: 81-302-0177-1; 2010; pp. 218-238.

8. Surinder Dhanjal and Satvinder Singh Bhatia, “Punjabi Bhasha da Takneekee Bhavikh (Technical Future of the Punjabi Language)”; *Silver-Jubilee International Punjabi Development Conference*, Punjabi University, Patiala, India; Feb 3-5, 2009.

Presentations/Seminars:

1. **Invited Presentation:** “A New Corpus in the Punjabi Language”, *International Lecture Series, Kamrah International Institute of Technology (KIIT), Gurgaon, India* presentation on March 19, 2013
2. **Invited Presentation:** “Digital Speech Processing: English and Punjabi”, *International Lecture Series, Kamrah International Institute of Technology (KIIT), Gurgaon, India* presentation on February 27, 2013
3. **Invited Presentation:** “Computerized Analysis and Synthesis of the Punjabi Language”, *Computer Science & Technology Lecture Series, Vancouver Island University Nanaimo, B.C., Canada* presentation on January 15, 2013
4. **Invited Presentation:** “Digital Speech Processing of English and Punjabi”, *Computer Science Colloquium Series, IEEE Northern British Columbia and University of Northern British Columbia, Prince George, B.C., Canada* presentation on October 11, 2011
5. **Invited Presentation:** “Computer Analysis and Synthesis of the Punjabi Language”, *South Asian Lecture Series (Centre for Indo-Canadian Studies), University of the Fraser Valley, Abbotsford, B.C., Canada* presentation on November 8, 2010
6. **Invited Presentation:** “Digital Speech Processing: Problems & Challenges”, *Mathematics, Statistics and Physics Unit Colloquium Series, UBC Okanagan, Kelowna, B.C., Canada* presentation on November 18, 2009
7. **Invited Presentation:** "Digital Speech Processing", *Canadian Information Processing Society (CIPS), Kamloops Chapter, B.C., Canada* presentation on March 13, 2008

** TDIL Data Center (http://tdil-dc.in) is an initiative of Department of Electronics and Information Technology (DeitY), MC&IT, Government of India for creating a national repository of Indian language tools, technologies, research papers and many more.* ■

CONTENTS

CHAPTER I
INTRODUCTION

The purpose of this chapter is to introduce the basic concepts involved in this work. These basic concepts include: Official Languages of India, Punjabi language, Dialects of the Punjabi Language, Importance of Dialects, Malwai Dialect, Digital Signal/Speech Processing, Biometrics and Speech Processing, Linear Prediction, Need of a New Corpus, Computerization of the Punjabi Language, Objectives of the Study, and the Thesis Organization.

1.1. OFFICIAL LANGUAGES OF INDIA

The 8th Schedule to the Constitution of India, as of May 2008 lists 22 languages as the **official languages of India**. Out of the thousands of languages and dialects of India, 29 languages have more than a million native speakers, 60 languages have more than 100,000 speakers and 122 languages have more than 10,000 native speakers as per the most recently available census of India (2001). The 22 official languages with the most recent number of the native speakers in millions, written in brackets, are listed below [141]:

1. Hindi (258-422)
2. Bengali (83)
3. Telugu (74)
4. Marathi (72)
5. Tamil (61)
6. Urdu (52)
7. Gujarati (46)
8. Kannada (38)
9. Malayalam (33)
10. Oriya (33)
11. Punjabi (29)
12. Maithili (12-32)
13. Assamese/Axomiya (13)
14. Santhali (6.5)
15. Kashmiri (5.5)
16. Konkani (2.5 -7.6)
17. Nepali (2.9)
18. Sindhi (2.5)
19. Dogri (2.3)
20. Manipuri *or* Meitei *or* Meithei (1.5)
21. Bodo (1.4)
22. Sanskrit (0.01)

Most of these languages (***15*** to be exact) belong to a family of languages known as the *Indo-Aryan* languages (a sub-branch of the Indo-European family, spoken by 74% of Indians), the Punjabi language being one of these 15 languages. The following ***four*** languages, spoken by 23% of Indians, belong to another family of languages known as the *Dravidian languages*: Tamil, Telugu, Kannada, and Malayalam. The *Tibeto-Burman* family includes these ***two*** languages namely: Manipuri (or Meitei or Meithei), and Bodo. ***One*** language (Santhali) belongs to the *Munda* family, and thus totaling to 15+4+2+1=22.

1.2. <u>PUNJABI LANGUAGE</u>

The Punjabi language is a modern Indo-Aryan language. The Punjabi language has been ranked amongst the top 15 spoken languages of the world. Over the years, this ranking has varied between 10 and 18. With more than 90 million native speakers, and more than 140 million speakers in 150 countries of the world, the Punjabi is considered amongst the world's 10 most influential languages, and is respectfully included in an article by the same name, "The World's 10 Most Influential Languages" by George Weber [130]. The most recent confirmation is an inset published by the daily newspaper *Hindustan Times*, New Delhi, India (one day after the *International Mother Tongue day 2013* on Friday; February 22, 2013; pp. 16) under the title *LANGUAGES WORLD SPEAK MOST* where Punjabi has been ranked number 10 as follows: Mandarin (14.1%), Spanish (5.85%), English (5.25%), Hindi (4.46%), Arabic (4.24%), Portuguese (3.08%), Bengali (3.05%), Russian (2.42%), Japanese (1.92%), and Punjabi (1.44%). Andronov [6] reports that the Institute of Oriental Studies of the Russian Academy of Sciences has prepared and preserved more than three dozen reports on the Punjabi language. Any research on the Punjabi language, therefore, assumes an international significance.

1.3. <u>DIALECTS OF THE PUNJABI LANGUAGE</u>

The Punjabi was the native language of the Punjab state of undivided India. In 1947, when the British rulers partitioned India into two countries (India and Pakistan), the Punjab state was also bifurcated into two states: East Punjab (in India), and West Punjab (in Pakistan). There are many dialects of the Punjabi language in both countries. Punjabi University (Patiala, India) published a list of ***31** dialects* of the Punjabi language [142] as follows: Awankari, Baar di Boli, Banwali, Bhattiani, Bherochi, Chacchi, Chakwali, Chambiali, Chenavri, Dhani, Doabi, Dogri, Ghebi, Gojri, Hindko, Jatki, Jhangochi/Jhangi, Kangri, Kachi, Lubanki, Malwai, Majhi, Pahari, Pothohari/Pindiwali, Powadhi/Puadhi, Punchi, Peshori/Peshawari, Rathi, Swaen, Thalochri, Wajeerawadi.

1.4. <u>IMPORTANCE OF DIALECTS</u>

The importance of studying and computerizing various dialects of a language should not be underestimated. Many researchers from all-over the world have emphasized the importance of dialects. Three representative examples showing their importance are given as under:

(A) In the famous text *Linguistic Atlas of the Punjab* [43, pp. v], André Martinet's comments about *dialect* are noteworthy:

1. “A dialect is not the language plus a few appendages; it is a whole that deserves to be considered and studied as such.”
2. “ ‘Dialect’ is one of *the* most ambiguous-terms in the field of linguistics. Etymologically and originally, it is used in reference to varieties of the same language. In old Greece, Athenians, Boeotians and Spartans were all supposed to speak Greek, but with a number of serious differences which however did not seem to prevent mutual understanding.”
3. “There is no form of the language that is not a dialect.”

(B) An article “A simple introduction to the importance of studying dialects and language” published by Rhodes University [143] describes the importance of ***language, dialect and identity*** as follows: “Language says a lot about our identity. Americans, Australians, New Zealanders and South Africans all speak differently. When we meet somebody from a different part of the country, they may use different words, sounds or grammatical structures. A *dialect* is a variety of language that is characteristic of a certain area. For instance, in the Northern Cape, people refer to older people as *grootmense* and paper as *pampier* whereas in Pretoria they are called *oumense* and *papier*. If you hear coloured people from Cape Town speaking Afrikaans, they sound different to Afrikaans spoken elsewhere. People from Natal speak English in different ways to people from Johannesburg etc. So often, the way we speak says a lot about where we are from, who we are and what we care about. So studying dialects is one way of validating people's identities and ways of life.”

The same article [143] establishes a strong connection between ***dialects and computers*** as follows: “Over the last ten years or so, computational linguists have managed to get computers to understand human language -- to a limited degree. But computers are pretty dumb -- they can learn to understand one person but when they hear another variety of language, they tend to get confused. One way of solving this would be to let computers listen to many different varieties and dialects of a language. If the computer listens long enough, it can learn to recognize many different people speaking many different languages. Of course, this can only happen if we study dialects and record people who speak them.”

(C) The importance of language varieties and regional dialects can be understood better when we come across a host of varieties of the English language. The following varieties have been frequently mentioned in literature: American English, British English, Australian English, Canadian English, Indian English, Jamaican English, New Zealander English, South African English, Mexican English, French English, Chinese English, Russian English, German English, and Italian English.

Dialects affect many *characteristics* of the human beings including the *pronunciation/accent, spellings, vocabulary, and grammar* of the speakers and authors. The differences of the *pronunciation/accent* amongst various people are obvious in the real world scene, where the *pronunciation/accent* of any two speakers of the same language is rarely the same. Some examples of some of the other *characteristics* (spellings, vocabulary, and grammar) are given here. As far as ***spellings*** are concerned, various authors spell the same words differently. Some examples are: *Programme / Program, Honor / Honour, Color / Colour*. Various speakers use different ***vocabulary*** to describe the same items. Some examples are: Truck / Lorry, Elevator / Lift, Soccer / Football.

Different people use different ***grammar (or*** grammatical structure) to describe the same situation. Some examples are:

1. Call him / Give him a call / Phone him / Ring him / Ring him up.
2. You don't need to fix that car / You needn't fix that car.
3. I have three children / I've got three children.

Similar examples can be found in various dialects of other languages. These examples convincingly prove that it is important to study various *dialects* of a language.

1.5. MALWAI DIALECT

The main dialects of the Punjabi language [142] in India *are: Malwai, Majhi, Doabi, and Puadhi*, and the main dialects in Pakistan *are: Multani, Pothohari, and Lehndi*. In the Punjab state of India, the Punjabi language is written in the *Gurmukhi* script, whereas in the Punjab state of Pakistan, the Punjabi language is written in the *Persian* (or *Shahmukhi*) script. It will be an enormous task to design a corpus that can completely describe all dialects in both scripts of the Punjabi language (Simply stated, a *corpus* is a large body of text in the *natural state* as recorded speech or written text). This work, therefore, concentrates only on one dialect of the Punjabi language: the *Malwai* dialect. The ***Malwai*** dialect has been chosen because of the following major reasons:

1. At present, there are ***twenty-two*** districts in the Punjab state [144]. According to Wikipedia, *Malwa* makes up the majority of the Punjab region [145], consisting of 11 districts (Barnala, Bathinda, Faridkot, Fazilka, Ferozepur, Ludhiana, Mansa, Moga, Muktsar, Patiala, Sangrur) and parts of the 12th district named Fatehgarh Sahib.
2. Thapar University (formerly Thapar Institute of Engineering & Technology), where this project is being completed is located in the city of Patiala. The city of Patiala belongs to the *Malwa* region.
3. The Language Department Punjab and Punjabi University are both also located in the city of Patiala. (*Punjabi University Patiala* is world's *second* university to be named after a language name, the *first* one being the Hebrew University of Israel [146]).
4. The *Sahitya Academy Award* is the highest literary award of India bestowed *annually* on an author for his outstanding contribution to literature, one for

each Modern Indian Language. So far, ***seventeen*** out of the ***fifty-two*** winners of this award in the Punjabi literature [147] belong to the *Malwa* region (clearly demonstrating that *Malwai* authors are not lagging behind in this area).

5. The *author* was born and raised in a small village in the *Malwa* region of the Punjab state, and therefore, is more familiar with the *Malwai* dialect than any other dialect.

The *Malwai* dialect in the Punjab state of India is written in the *Gurmukhi script* [140]. Therefore, in the corpus designed in this thesis (Chapter IV), the speech sentences have been *recorded* in the *Malwai* dialect of the Punjabi language, and the sentences have been *written* in the *Gurmukhi* script.

1.6. DIGITAL SIGNAL/SPEECH PROCESSING

Digital signal processing [11-12, 15, 20, 24-25, 79, 83, 85-90, 99-102] has been successfully applied to many types of signals including telecommunications signals, audio signals, image processing, radar signals, sonar signals, signals in geophysics, and speech signals. Digital speech processing includes many fields. Some of these *fields* of on-going research interest include:

- Speech analysis, e.g., linear prediction (LP) analysis [11-12, 52, 74-76]
- speech synthesis, e.g., LP synthesis, text-to-speech (TTS) synthesis [126]
- speech enhancement or noise cancellation [87-89]
- speech coding *or* speech storage and transmission [23, 47, 65, 77, 82]
- speaker separation [79, 83, 99]
- speaker identification [79, 83, 99]
- language identification [59, 92-94]
- automatic speech recognition (ASR) which also includes continuous speech recognition (CSR), discrete utterance recognition, and keyword spotting [79, 83, 99]
- pitch and formant estimation [90, 99]
- aids-to-the handicapped [79, 83, 99]

This list can be enhanced to include many more *fields*. This thesis concentrates on the topic *Speech Analysis and Synthesis of the Punjabi Language.* The quality of the synthesized speech (*or* synthetic speech) has been an important issue for speech researchers. The following comments by Bruce Sherwood (a multi-dimensional researcher knowledgeable in Engineering Science, Physics, Softwave design, Linguistics, and several languages including Spanish, Italian, French, Russian, Persian, and Esperanto) in his article *The Computer Speaks* [101, pp. 18] are true even today: “Synthetic speech of good quality is hard to achieve because of dynamic properties of the human-speech mechanism that have to be simulated. Research, which is on-going, has thus far yielded mixed results. The basic principles of what components are needed to generate human speech are known (*IEEE Spectrum*, October 1970, pp. 22-45), and the quality of synthetic speech has been increasing in laboratories. But synthetic speech is still unacceptable to critical human ears. Listeners are not comfortable hearing plastic talk, and so methods have yet to be devised for a good human-speech synthesizer."

This project is an attempt to address this important issue of producing high quality *synthesized speech* or *synthetic speech* in the Punjabi language.

1.7. BIOMETRICS AND SPEECH PROCESSING

Some forms of the human identification, such as one's physical traits are very difficult to be faked or imitated. *Biometrics* is the science of measuring individual body characteristics. *Biometrics* uses some of those physical characteristics or traits of a person in security devices, which are 'not easily fakable' by any other person. ***Voice/speech*** is amongst the most important physical traits and biological characteristics used in the biometric security devices. Other such biological characteristics used in these devices include the lips, the handprints, the fingerprints, the blood vessels in the back of the eyeball, and *even* one's entire face [50, pp. 14.25]. Biometric systems are used in lieu of typed passwords to identify the people authorized to use a computer system [50, pp. 3.20]. According to Etter [35, pp. 220-221], the most common biometrics include *fingerprints, face, iris, DNA*, and ***speech***, whereas other biometrics include *bones, hand recognition*, and *handwriting*. The fact that the ***speech analysis and synthesis*** is extensively used in the Biometric systems enhances the significance of the present thesis.

1.8. LINEAR PREDICTION

Linear prediction technique is also known as *Linear Predictive Coding* or *LPC* [Rabiner and Schafer, 89, pp. 473]. Almost every book on *Speech Processing* includes a chapter on *Linear Prediction*, and usually starts by attesting the simplicity, power, and the popularity of this technique. Markel and Gray Jr. have written the book *Linear Prediction of Speech* [76] that includes a number of comments about the merits of this technique including speed, popularity, simplicity, and stability. In addition to *speech processing*, linear prediction (LP) is a fundamental tool in many diverse areas such as adaptive filtering, system identification, economics, geophysics, and spectral estimation [15, pp. 121].

This work concentrates on the Linear Prediction Analysis and Synthesis of the Punjabi language because

1. no such work has so far been reported in the literature, and
2. we have been active in this area of research [26-31] since early 1980s.

In addition to these two reasons, two more extremely important reasons, namely *popularity* and *Speech Understanding Research (SUR) Project)*, are detailed below.

1.8.1. POPULARITY

The linear prediction technique is rated very high in the broad field of speech processing as evidenced by many famous speech researchers. Some representative quotations are given below:

> "(one of) the most popular parametric representations in use today" [Allen et al., 4, pp. 10];
>
> "linear prediction plays a fundamental role in all aspects of speech." [Benesty et al., 15, pp. 121];
>
> "The (linear prediction) technique has been the basis for so many practical and theoretical results that it is difficult to conceive of modern speech technology without it" [Deller et al., 24, pp. 266];
>
> "the most powerful analysis method in every respect" [Lass, 67, pp. 484];
>
> "an extremely powerful technique for the digital analysis of speech" [Oppenheim, 79, pp. 156];
>
> "probably the most powerful tool in the speech-processor's armamentarium" [Parsons, 83, pp. 345];
>
> "One of the most powerful speech analysis techniques is the linear predictive analysis…The importance of this method lies both in its ability to provide extremely accurate estimates of the speech parameters, and its relative speed of computation." [Rabiner and Schafer, 88, pp. 396];

"Linear prediction is a powerful tool in speech processing. Linear prediction is widely used in speech applications (recognition, compression, modeling, etc.)" [Markel and Gray, 76, pp. 271]

In his recent article *The History of Linear Prediction* [11], Atal states that "the introduction of linear prediction techniques started a new era in speech processing about 40 years ago. Since then, these techniques have found numerous applications."

Based on linear predictive coding, Texas Instruments introduced a toy named "Speak and Spell" in 1978. The toy enjoyed a high level of popularity for several years.

1.8.2. LINEAR PREDICTION AND SPEECH UNDERSTANDING RESEARCH (SUR) PROJECT

The Advanced Research Projects Agency (ARPA) of USA started its famous Speech Understanding Research (SUR) Project in early 1970s with a 5 year time limit (1971-76) for achieving the following specific goals in the area of continuous speech recognition. A large number of speech research groups participated in the ARPA SUR project. Rabiner and Juang [15, pp. 527] conclude that *eight* technological contributions came out of this five-year project. Out of these *eight*, the first *three* prominently revolve around Linear Predictive Coding (LPC), or *simply* linear prediction, as follows:

1. Use of LPC as the front-end spectral processor became the standard for speech recognition systems [Atal and Hanauer (12), Itakura and Saito (15, 52), Makhoul (74)].

2. Methods for reliably estimating vocal tract areas and vocal tract length from LP representations [Wakita, 15].

3. Use of the LPC residual as a sound similarity measure [Itakura (15, 52)]

The above discussion proves that the linear prediction technique is hugely popular. Therefore, it makes sense to conduct the speech analysis and synthesis of the Punjabi language by using the classical linear prediction technique, and to design new speech processing techniques similar to LPC.

1.9. <u>NEED FOR A NEW CORPUS</u>

In very simple words, a *corpus* is a large body of text in the *natural state* as recorded speech or written text. Designing databases and corpora is generally considered the first major step in speech processing. The quality of the corpora and databases play a decisive role in determining the quality of the speech processing work tested and based on these corpora and databases.

This work concentrates on the Linear Prediction Analysis and Synthesis of the Punjabi language. Since no such work has so far been investigated in the literature, it is evident that no corpus suitable to be used in conjunction with this technique exists in the Punjabi language.

The corpus designed in this work will be one of the most suitable corpora to be used in the Digital Speech Processing techniques which make use of the ***complete sentences*** (rather than *words* only) for analyzing and synthesizing speech (e.g., the classical linear prediction analysis and synthesis technique of the Punjabi language in this thesis).

1.10. COMPUTERIZATION OF THE PUNJABI LANGUAGE

The Computerization of the Punjabi Language is a relatively new field of research. This field of research started attracting the attention of the research scholars towards the end of the twentieth century. Several organizations and individuals have been actively pursuing the research in this field throughout the world. In 2004, Agrawal, Samudravijaya and Arora [3, pp. 25] compiled a preliminary list of the on-going activities, and the institutes, active in the text and speech corpora development in Indian Languages. We have updated this list specifically for the activities in the Punjabi Language. At present, the following **institutions** are active in the field of the computerization of the Punjabi Language:

1. Thapar University (*formerly* TIET), Patiala, India. [2, 63, 120, 68-70]
2. Punjabi University (Advanced Centre for Technical Development of Punjabi Language, Literature and Culture), Patiala, India. [2, 62-63, 68-70, 120]
3. Central Institute of Indian Languages (CIIL), Mysore, India. [2, 34]
4. Northern Regional Language Centre (NRLC), Patiala, India. [2, 34]
5. Centre for Development of Advanced Computing (CDAC), Ministry of Communications & IT (Govt. of India), Noida, India. [2, 120]
6. CFSL, Chandigarh, India. [2]
7. CSIO, Delhi, India. [2]
8. Kamrah International Institute of Information Technology (KIIT), Gurgaon, India. [2-3, 7, 32]
9. Thompson Rivers University, Kamloops, BC, Canada [26-30, 63].

In addition to the researchers associated with the above **institutions** having research funding, the following **individuals** are known to be very seriously active in the field of computerization of the Punjabi Language *on voluntary basis* without externally supplied research funding:

1. Dr. Kulbir Singh Thind (USA). [62-63, 127]
2. Janmeja Singh Johl (Ludhiana, India). [54-55, 62-63]
3. Kirpal Singh Pannu (Canada). [62-63, 80-81]
4. Baba Baljinder Singh (Rara Sahib, India). [62-63, 107-108]
5. Dr. Baldev Kandola (UK). [62-63]

Their activities include many diverse areas such as Punjabi font development, keyboard standardization, font conversion, transliteration between the Gurmukhi script and the Shahmukhi (Persian) script, word processor development including spell checker and thesaurus, search engine development, availability of the original text of Sri Guru Granth Sahib and other prominent Sikh scriptures along with their translations on the internet, optical character recognition, text-to-speech (TTS) synthesis, dictionary development, machine translation, Unicode implementation, speech processing and many more.

Lehal [62-63, 68-70, 115], and Singh [63, 70], both currently working with Punjabi University Patiala, have authored more papers on a wide variety of topics, than any other researcher mentioned above, in the fast growing field of the computerization of the Punjabi language.

Computer-related books have also been published recently. Kamboj [60-61] started publishing his computer-related books (e.g., [61]) in June 2003, followed by Juneja [58] in 2004, and Pannu [81] in February 2009.

The above-mentioned list is a preliminary list, and a very brief overview of the activities to the best of our present knowledge. There may be other institutions and individuals actively involved in this field. Considering the fact that the computerization of the Punjabi Language is still at its initial stage of problems, struggles, controversies, and challenges, it is our sincerest hope and belief that the other researchers and authors will continue to update our preliminary list in a fact-based scientific and unbiased professional manner.

1.11. OBJECTIVES OF THE STUDY

In specific terms, the objectives of this study are as under:

(i) To design a new phonetic alphabet for speech processing in the Punjabi language consistent with the **ARPAbet** *because at present, the symbols consistent with the ARPAbet phonetic transcription do not exist in the Punjabi Language.*

(ii) To develop a new text and speech corpus for the Punjabi language *because no computer database/corpus exists in the Punjabi language, where the representative speech sentences concentrate on a specific dialect (the* ***Malwai*** *dialect) of the Punjabi language.*

(iii) To conduct the linear prediction analysis and synthesis (*aka* Linear Predictive Coding or LPC) of the Punjabi speech sentences *because no work has so far been reported in the literature where the Punjabi speech has been analyzed/synthesized using the linear prediction model of speech production.*

1.12. THESIS ORGANIZATION

The aim of the present thesis is to investigate **speech analysis and synthesis of the Punjabi language** using the *linear prediction* technique (*aka* Linear Predictive

Coding *or* LPC). The present thesis consists of *seven* chapters, and *five a*ppendices. Each chapter is divided into various sections, subsections, and sub-subsections on an as-needed basis. The numbers like 5.2.1.1 indicate sub-subsection 1 of subsection 1 of section 2 of Chapter V. The numbers in square brackets refer to the references cited in this work (Books, Journals, Dictionaries, Encyclopaedias, and Internet websites) from the Bibliography. The work carried out in this thesis can be described as follows:

CHAPTER I is introductory. It presents the basic concepts required in this thesis to provide sufficient background for later chapters. In this chapter notations and terminology to be used in the sequel is presented. A resume of the hitherto known results interrelated with our results along with a brief plan of our results has also been given in this chapter. It introduces the following items: Official Languages of India, Punjabi Language, Dialects of the Punjabi Language, Importance of Dialects, Malwai Dialect, Digital Signal/Speech Processing, Biometrics and Speech Processing, Linear Prediction, Need for a New Corpus, Computerization of the Punjabi Language, Objectives of the Study and Thesis Organization. Some of the basic concepts covered in this chapter will be repeated occasionally in various chapters for the sake of completeness.

CHAPTER II introduces the main concepts required to understand the broad field of Linguistics so that one can understand the corpus to be designed in CHAPTER IV. After the brief introduction, it discusses the Phonetics with reference to the English Language, The Punjabi Language and Gurmukhi Script, The Punjabi Speech Sounds, Classification of the Punjabi Sounds, and Phonetic Coding Schemes. The new phonetic alphabet (consistent with ARPAbet), called ***PUNJARPAbet*** is designed in this chapter This chapter achieves objective 1 set for this research.

CHAPTER III deals with the Speech Signal, the Speech Sound and Speech Processing, and various Speech Production Models including the Linear Speech Production Model, the Digital Model of speech Production, and the Linear Prediction Model of speech Production (to be used in CHAPTER V), Speech Signal Processing: A Grand Challenge, followed by the conclusion.

In CHAPTER IV, a new text and speech corpus has been designed. It describes the Corpus Design, Examples of the corpus, Overview of the New Corpus, Recording of the New Corpus, and Technical Considerations. This chapter concludes by describing the Original Features of the new Corpus. This chapter accomplishes objective 2 set for this study.

CHAPTER V describes in detail the mathematical concepts involved in the LPC of the Punjabi speech. The topics addressed in this chapter include Linear Prediction Analysis of Speech, Linear Prediction Coefficients (Autocorrelation method and Covariance method), Gain factor, V/UV Decision and Pitch Extraction, Linear Prediction Synthesis of Speech; Pitch, Speech Synthesis, and Tones, Speech Processing Considerations, Analysis and Synthesis Considerations, Analysis and Synthesis

(Combined), Computational Savings, and the Punjabi Sentences Synthesized. The speech synthesis results achieved in this chapter using software programs *MATLAB* and *Praat* are described in the Conclusion. This chapter fulfills objective 3 set for this project.

CHAPTER VI includes the graphical analysis of the results obtained in the previous two chapters: (a) Spectrographic analysis of speech waveforms of Chapter V (b) Graphical evaluation of the new phonetic coding scheme ***PUNJARPAbet*** designed in CHAPTER II. The graphs for *formant frequencies*, *intensity, pitch,* and *V/UV contours* are presented in this chapter. Additional insight into the results obtained in CHAPTER V has been provided by the *spectrographic analysis* conducted using Praat and MATLAB where the Fast Fourier Transform (FFT) of the speech waveforms has been plotted. Some of the features of the corpus designed in CHAPTER IV and transcribed using ***PUNJARPAbet*** designed in CHAPTER II, have also been graphically evaluated in this chapter.

CHAPTER VII summarizes the whole work, highlighting the original contribution of this project. This chapter concludes by stating the *future directions.*

The thesis also includes five Appendices as follows: APPENDIX A and APPENDIX B include the Text Corpus developed in this project. APPENDIX A includes about 200 sentences and single line folk songs (*bolis*) while APPENDIX B includes more than 100 *bolis*. In both appendices, the complete corpus has been transcribed both in the IPA and the newly developed phonetic alphabet ***PUNJARPAbet***. APPENDIX **C** describes the Levinson-Durbin algorithm to efficiently solve the Normal Equations resulting from the Autocorrelation Method for the linear prediction analysis. APPENDIX **D** includes the SIFT algorithm for computing the V/UV decision and the pitch extraction. APPENDIX E lists twenty-five Punjabi speech sentences synthesized in the present study.

The thesis concludes with the **Bibliography** section. The Bibliography section has been organized in five groups as follows:

1. All Books and Journals [1-130]
2. All Dictionaries and Encyclopaedias [131-140]
3. Internet Websites [141-160]
4. All Punjabi References (*alphabetical order* in English) [1-78]
5. All Punjabi References (*alphabetical order* in Punjabi) [1-78]

The references in group 1, 2, and 4 are listed in the alphabetical order based on the last name of the first author according to the *English* language (Roman alphabet). The internet websites (group 3 above) are listed in the order they are cited in the thesis. The fifth group consisting of all Punjabi references is listed in the alphabetical order based on the last name of the first author according to the *Punjabi* language (Gurmukhi alphabet).

■

CHAPTER II
LINGUISTICS AND PUNJARPAbet[1]

In this chapter, a new phonetic alphabet consistent with the **ARPAbet** phonetic transcription or coding of the corpora in the Punjabi language has been developed. A number of coding schemes have been used for international as well as Indian languages in literature. The need for a new coding scheme becomes obvious when we investigate the existing coding schemes such as IPA, ARPAbet, ISCII, SAMPA (and its extended versions X-SAMPA and SAMPROSA), INSROT and wx-Roman. The laborious, irritating, and time-consuming necessities for dealing with the special symbols for vowels, nasalization, tones, and inserting diacritical marks in most of these schemes (especially where two diacritical marks over the ten vowel signs are needed for the Punjabi language in Gurmukhi script) confirm the need for a new coding scheme which has been designed in this chapter.

Before designing the new scheme called ***PUNJARPAbet***, we need to study several essential concepts leading to our objective. These concepts include linguistics, phonetics, Punjabi language and Gurmukhi script, speech sounds, Punjabi speech sounds, and the existing coding schemes.

2.1. <u>INTRODUCTION</u>

The study of the rules of a language, which govern the arrangement of the sounds or symbols, is the domain of *Linguistics*. The speech signals are constituted of a sequence of distinctive sounds known as *phonemes*. Most languages are described and studied in terms of phonemes. Consequently, the study and the classification of the speech sounds is known as *Phonetics*. Phonetics of a language can be studied in number of ways. Each phoneme represents the smallest unit of speech information, and is therefore, characterized by a unique combination of many underlying speech feature values. For the purpose of digital speech processing of a language, it is sufficient to study the following *three* most important features of the phonemes: the place of articulation, waveforms, and spectrographic characterization. The first feature is studied in this chapter, whereas the remaining two features are studied in Chapter VI.

Before we study the phonetics with reference to the Punjabi language, it is appropriate to study the phonetics with reference to the English language. It is interesting to note that as a particular language grows, the number of phonemes in that language also

[1] The work reported in this chapter has been published in **Journal of Circuits, Systems, and Computers (JCSC), Volume 23, No. 5, June 2014 (SCI).**

keep on growing. This simple and interesting fact will be confirmed as we study the phonetics with reference to the English and the Punjabi language.

The first issue for the Punjabi speech processing is the actual representation of the phonemes. In linguistics, the International Phonetic Alphabet (IPA) designed by International Phonetic Association is used to represent the phonemes. However, the need for some special symbols that are not readily available on computer keyboards is the major limitation of this representation [15, pp. 801].

To simplify this problem, ARPAbet representation came into existence as a result of the ARPA SUR project [15, pp. 527-529]. A website [148] describes ARPAbet as follows: **"**ARPAbet is a phonetic transcription code developed by Advanced Research Projects Agency (ARPA) as a part of their Speech Understanding Project (1971–1976). It represents each phoneme of General American English with a distinct sequence of ASCII characters. ARPAbet has been used in several speech synthesizers, like SAM for the Commodore 64, SAY for the Amiga and TextAssist for the PC… It is also used in the CMU Pronouncing Dictionary. In ARPAbet, every phoneme is represented by one or two capital letters. Digits are used as stress indicators and are placed at the end of the stressed syllabic vowel. Punctuation marks are used like in the written language, to represent intonation changes at the end of clauses and sentences." There are three stress values: 0, 1, and 2 signifying "no stress", "primary stress", and "secondary stress" respectively.

2.2. <u>PHONETICS</u>

Rabiner and Schafer (1978) state that: "for American English, there are about 42 phonemes including **vowels, diphthongs, semivowels and consonants."** However, in the Table 3.1 [88, pp. 43], they list only 41 phonemes (11 Vowels, 6 Diphthongs, 4 Semivowels, 20 Consonants).

Rabiner and Schafer in their second book (2007) state that: "the number of phonemes depends upon the language and the refinement of the analysis. For most languages the numbers of phonemes is between 32 and 64." The authors have presented a set of 39 phonemes [87, Table 2.1, pp. 18-19] which is used in the CMU Pronouncing Dictionary [149] under the title "Condensed list of ARPAbet phonetic symbols for North American English."

The same authors in their third book (2011) state that "for American English, there are somewhere between 39 and 48 phonemes" and have given a standard list of 48 phonemes [89, Table 3.3, pp 87] under the title "Condensed list of phonetic symbols for American English." This Table is reproduced here as **Table 2.1**. This Table is very valuable because it includes the IPA representation, and the ARPAbet representation, along with an example of a word where the phoneme appears. This table, thus, represents the latest approach of representing phonemes in the speech processing literature.

Table 2.1: Condensed list of phonetic symbols for American English

IPA Phoneme	ARPAbet	Example	IPA Phoneme	ARPAbet	Example
/i/	IY	beet	/ŋ/	NX	sing
/I/	IH	bit	/p/	P	pat
ɚ	AXR	butter	/t/	T	ten
/ɛ/, /e/	EH	bet	/k/	K	kit
/æ/	AE	bat	/b/	B	bet
/a/	AA	Bob	/d/	D	debt
/ʌ/	AH	but	/g/	G	get
/ɔ/	AO	bought	/h/	HH	hat
/o/	OW	boat	/f/	F	fat
/ʊ/	UH	book	/θ/	TH	thing
/u/	UW	boot	/s/	S	sat
/ə/	AX	about	/ʃ/, /sh/, /š/	SH	shut
/ɨ/	IX	roses	/v/	V	vat
/ɝ/	ER	bird	/ð/	DH	that
/e^y/	EY	bait	/z/	Z	zoo
/*a*^{w}/	AW	down	/ʒ/, /zh/, /ž/	ZH	azure
/*a*^{y}/	AY	buy	/tʃ/, /č/	CH	church
/ɔ^y/	OY	boy	/dʒ/, /j/	JH	judge
/y/	Y	you	/ʍ/	WH	which
/w/	W	wit	/*l*/	EL	battle
/r/	R	rent	/*m*/	EM	bottom
/l/	L	let	/*n*/	EN	button
/m/	M	met	/Γ/	DX	batter
/n/	N	net	/ʔ/	Q	(glottal stop)

We have used the similar approach in representing the Punjabi speech sounds in the next sections **(Table 2.2).**

It is a well-known fact that the vowels have the longest duration in natural speech [89, pp. 89]. It is interesting to note that although the **vowels** (the most well-defined sounds of a language) play a decisively major role in speech (the spoken language), it is the **consonants** that contain a lot more information in the written version of the speech sentence. The vowels convey very small linguistic information as far as the orthography of the spoken sentence is concerned. Consider two sentences, *one* with all vowels removed:

ਕਣ ਹ ?

and the *other* with all consonants removed:

ੋ ੀ ੈ ?

It will be much easier for a native speaker to reproduce the complete original sentence:

ਕੋਈ ਹੈ ?

in the first case as compared with the second case.

2.3. THE PUNJABI LANGUAGE AND GURMUKHI SCRIPT

In the present work, we have developed a new phonetic alphabet for the *Punjabi language* in the *Gurmukhi script*. Therefore, before discussing the design methodology of the new alphabet, it makes sense to develop the basic understanding of the *Punjabi language* and its *Gurmukhi script*.

The *Punjabi alphabet* in the *Gurmukhi script* consists of 35 letters (because thirty-five in Punjabi is known as **ਪੈਂਤੀ *(pɛ̃ti),*** therefore, the Gurmukhi alphabet is also known as ***pɛ̃ti***), and 6 letters with dot (਼), known as ਬਿੰਦੀ (*bĨdi)*, below a letter symbol. Therefore, at present, there are 35 + 6 = 41 letters in the Gurmukhi alphabet. The complete alphabet is given below:

ਵਰਣਮਾਲ਼ਾ (ਪੈਂਤੀ)

ੳ ਅ ੲ ਸ ਹ

ਕ ਖ ਗ ਘ ਙ

ਚ ਛ ਜ ਝ ਞ

ਟ ਠ ਡ ਢ ਣ

ਤ ਥ ਦ ਧ ਨ

ਪ ਫ ਬ ਭ ਮ

ਯ ਰ ਲ ਵ ੜ

ਸ਼ ਖ਼ ਗ਼ ਜ਼ ਫ਼ ਲ਼

Out of these **41 letters**, the *first* **three letters** (ੳ, ਅ, ੲ) are known as *swər* or *vowel forms* or *vowel consonants* or *semi consonants* or *matra vahək* and the *remaining* **38 letters** are known as *vIə̃jəns* (consonants). There are **ten** vowel symbols. A vowel symbol is known as a *ləga/matra (*or just *matra)* or a *diacritical mark* or an *accessory* *sign* or *a vowel sign*. These vowel symbols also include *mukta* (no symbol). Using these **ten** vowel symbols (*matras*), the *first* **three letters** (ੳ, ਅ, ੲ) of the Gurmukhi script generate the following **ten non-nasalized vowels** in the Punjabi language:

ਉ, ਊ, ਓ, ਔ, ਅ, ਆ, ਐ, ਏ, ਇ, ਈ

In other words, the *first* **three letters** use or 'carry' or 'drive' the *matras* to generate *vowels*. *Vahək* means a *driver* or a *carrier*. That is why the *first three letters* (uṛa, ɛṛa, and iṛi) are known as *matra vahək* or *vowel forms* [66]. There are **two symbols,** ਬਿੰਦੀ (ਂ = *bĨdi*) and ਟਿੱਪੀ (ੰ = *ṭIppi*) for *nasalization* of sounds. Using these two symbols, the *first three letters* generate the following **ten nasalized vowels** in the Punjabi language:

ਉਂ, ਊਂ, ਓਂ, ਔਂ, ਅਂ, ਆਂ, ਐਂ, ਏਂ, ਇੰ, ਈਂ

There is **one symbol** (ੱ = *ədək*) for the *reduplication* of the sound of a consonant. The *reduplication* produces the sound of *long* consonants. According to Bahri [13, pp. 5], "Long (or double) consonants have an overhead crescent sign, called *adhak*, before them" as in the words ਸੱਪ (means *snake*), ਅੱਧਾ (means *half*), and ਪੱਤਾ (means *leaf*).

After the first **three** letters (ੳ, ਅ, ੲ), the next **two** consonants (ਸ, ਹ) are the *root class consonants*. Out of the remaining **36** consonants, the next **25** letters are grouped into five *ṭoli*s (groups) of five letters each (*kavarg, cavarg, ṭavarg, tavarg, and pavarg ṭoli*), according to their overall phonetic characteristics (the place of origin, pronunciation, participating articulators: lips, jaws, lungs, mouth, nose, tongue, palate, and throat). The next group of **five** letters (yəya, rara, ləlla, vava, ṛaṛa) is called the *ə̃ṭIm (*means *last) ṭoli*. The last group of **six** consonants is a special group with a dot (*bĨdi)* below the letter. It is called the *nəvin* (means *new*) *ṭoli*. The first five of these consonants (ਸ਼ ਖ਼ ਗ਼ ਜ਼ ਫ਼) were introduced in the previous century *mainly* to accommodate the words from the languages such as English, Sanskrit, Arabic and Persian, while the sixth and the last consonant (ਲ਼) is an original sound from the Punjabi culture. It is important to note that the existence of the phoneme [ਲ਼] = [ḷ] has been mentioned in literature long before 70s of the previous century, but the character ਲ਼ was officially introduced in 1979 in the 2nd edition of *Punjabi Praveshka* (the text book for Grade I students) published by the *Punjab School Education Board* in 1979 [84, pp. 15]. The 1st edition of *Punjabi Praveshka* published in 1978 [pp. 15] had *only* the first five of these consonants (ਸ਼ ਖ਼ ਗ਼ ਜ਼ ਫ਼) of the *nəvin ṭoli*. In other words, the first-ever batch of the Grade I students to officially learn the existence of

ਲ਼ was the batch starting *Grade I* in the year 1979. To the best of our knowledge, this fact (verified by the author with considerable effort in finding an old Grade I text) is being stated in any *document in print* for the first time.

There are three **conjunct consonants** (or half-letters): h, r, v (੍ਹ, ੍ਰ, ੍ਵ). Lot more *conjunct consonants* are spoken, but not written [13, pp. 5] at present. The most authentic example is *Guru Granth Sahib* (The Holy Manuscript of Sikhism), compiled by the fifth guru (Guru Arjun Dev) of Sikhs in 1604, which has at least the following four more conjunct consonants: c, ṭ, t, n (੍ਚ, ੍ਟ, ੍ਤ, ੍ਨ). *Guru Granth Sahib* includes the writings of three dozen spiritual poets (six gurus who lived between 1469 and 1675, fifteen *bhagats* who lived before *gurus*, and fifteen contemporaries of different gurus). The description of all of the thirty-five letters of the *Gurmukhi* script as we know today can be found in print in *Guru Granth Sahib* in the writings of the first guru (Guru Nanak Dev), and Bhagat Kabir (The word *guru* means *teacher*, and the word *bhagat* means *meditator*).

2.4. SPEECH SOUNDS

The details of the Punjabi language and Gurmukhi script described in the previous section, concepts of speech sounds described in this section, and the classification of the Punjabi speech sounds described in the next sections are mainly based on the pioneering works referenced in Jain [53], Arun [10], Gill [43], Gill and Gleason, Jr. [42,46], Sandhu [95-97], Joga Singh [43, 84], Dulai and Koul [34], Bahri [13], Agnihotri [1], Joshi [43,56-57], Harkirat Singh [43, 110-111, 139], Tej Bhatia [18-19], Bhardwaj [16-17] Prem Prakash Singh [43, 116-117], and Surjeet Singh [43, 119].

Speech sounds in a language are generally classified in two broad categories: *segmental* and *suprasegmental*. For the purpose of speech analysis and synthesis, we need to understand both: segmental sounds and suprasegmental sounds as described below:

2.4.1. Segmental Sounds

The Segmental sounds are further divided into *vowels* and *consonants*.

2.4.1.1. Vowels

Sandhu [95, pp. 35] summarizes the production of vowels as follows: "For the production of all the vowels, vocal cords vibrate and in the Panjabi language, there are no voiceless vowels like sounds." While producing vowels, the air stream coming from the lungs passes through the oral cavity without any obstruction. Different parts of the tongue move to different heights within the oral cavity; and the shape of the lips is modified. The movement of the different parts of the tongue (like front, central or back), the shape of the lips, and the heights to which a specific part of the tongue is raised play a decisive role in the production of different vowels. In the production of vowels, vocal cords may vibrate to produce the *voiced vowels*. The nasal passage remains closed when the *non-nasal or oral vowels* are produced and it remains open allowing the air stream to pass through the nasal cavity thus producing *nasalized vowels* [34].

Besides a broad classification of vowels into *nasal and non-nasal* categories, the vowel sounds can be classified on the basis of the part of the tongue used in the articulation, the height of the tongue, and the position of the lips [34].

Based on the part of the tongue used in the process of articulation, vowels are classified as *front vowels, central vowels and back vowels*. On the basis of the height of the tongue in the articulation of vowels, the vowels are classified as high, lower-high, mid, mid-low and low vowels. Based on the posture of lips during the production of vowels, vowels can be classified as *rounded and unrounded vowels,* or *Short and long vowels*.

2.4.1.2. Consonants

In the production of the consonants the air current coming from the lungs is stopped or impeded at different points of articulation (POI). The shape of the chambers through which the air passes is also modified accordingly. In the broad field of *Phonetics*, consonants have been classified as *stops, affricates, nasals, laterals, trills, flaps, fricatives, and semi-vowels* based on Manner of Articulation (MOA) as described below:

Air stream coming from the lungs is blocked at some point or other in the oral cavity and the nasal passage gets closed while producing **stops**. The contact is released suddenly with Explosion. For example, [p] and [b] are known as **plosives**. Stops are sometimes produced by sucking the air in. As Punjabi stops are not implosives, so the process of articulation for implosives is not discussed in this work [34].

The air stream coming from the lungs is stopped in the oral cavity, but the contact is withdrawn slowly causing friction when the air escapes in the production of **affricates**. Its examples are: [c], and [j].

On producing **nasals**, the air stream coming from the lungs is directed into nasal cavity by lowering the soft palate. When the contact of the articulator is released the air passes through the nasal cavity, the oral cavity is in most of the cases fully closed. Its examples are: [m], and [n].

While producing **laterals**, the air stream coming from the lungs is blocked in the middle of mouth by raising the mid surface of the tongue and then the air is allowed to escape from the sides of the tongue. An example is: [l].

A rapid vibration of the tip of the tongue against the teeth ridge occurs *while* producing **trills**. [r] is one of its example.

The tip of the tongue approaches the hard palate but does not make a contact *in* the production of **flaps**. The air escapes between the tip of the tongue and palate. One of its examples is: [ṛ].

As far as the production of **fricatives** is concerned, the air stream is pushed through a narrow opening which causes friction. Two examples are: [f], and [s].

While producing **semi-vowels** (also known as **frictionless continuants**), the position of the speech organs remains same as in the case of fricatives but there is a weaker breath force so that no audible friction is heard. Two of its examples are: [y], and [v].

Based on the **points of articulation (POA),** *consonants* can be classified as *bilabials, dentals, alveolars, retroflexs, palato-alveolars, palatals, velars, and glottals*. While producing various speech sounds just mentioned here, the air flow coming from the lungs is checked or impeded at these points [34].

2.4.2. Suprasegmental Sounds

The Suprasegmental or nonsegmental Punjabi sounds can be understood in terms of the following features: nasality, gemination, stress, vowel-length, duplication, three tones (low, mid, high), five intonations (falling pitch, high rising pitch, high level pitch, low rising pitch, mid level pitch), style (e.g., formal, informal), tempo (e.g., slow, fast), juncture, and three conjunct consonants (h, r, v).

2.5. THE PUNJABI SPEECH SOUNDS

2.5.1. Punjabi Alphabet

The complete Punjabi alphabet is reproduced here once again for the sake of completeness, and to maintain continuity:

ਵਰਣਮਾਲ਼ਾ (ਪੈਂਤੀ)

ੳ ਅ ੲ ਸ ਹ

ਕ ਖ ਗ ਘ ਙ

ਚ ਛ ਜ ਝ ਞ

ਟ ਠ ਡ ਢ ਣ

ਤ ਥ ਦ ਧ ਨ

ਪ ਫ ਬ ਭ ਮ

ਯ ਰ ਲ ਵ ੜ

ਸ਼ ਖ਼ ਗ਼ ਜ਼ ਫ਼ ਲ਼

The segmental speech sounds of the Punjabi language have been classified in two broad categories of *vowel phonemes* and *consonant phonemes* as outlined in the next two sub-sections.

2.5.2. Vowel phonemes

(i) Non-nasalized vowels:

front unrounded vowels:
[i], [I], [e], [ɛ]
central vowels:
[A], [a]
back rounded vowels:
[u], [U], [o], [O]

(ii) Nasalized Vowels:

Ten non-nasalized vowels described above are present in nasalized form also:
[ĩ], [Ĩ], [ə̃], [ã], [ẽ], [ɛ̃], [ũ], [Ũ], [õ], [ɔ̃]

These ten vowels have also been classified as short and long vowels as follows:

Short vowels:
[I], [U], [A]
Long vowels:
[i], [e], [ɛ], [a], [u], [o], [O]

2.5.3. Consonant Phonemes

Stops:

[ਪ] = [p], [ਫ] = [ph], [ਬ] = [b]

[ਤ] = [t], [ਥ] = [th], [ਦ] = [d]

[ਟ] = [ṭ], [ਠ] = [ṭh], [ਡ] = [ḍ]

[ਕ] = [k], [ਖ] = [kh], [ਗ] = [g]

Affricates:

[ਚ] = [c], [ਛ] = [ch], [ਜ] = [j]

Nasals:

[ਮ] = [m], [ਨ] = [n], [ਣ] = [ṇ]

Laterals:

[ਲ] = [l], [ਲ਼] = [ḷ]

trill:

[ਰ] = [r]

Flap:

[ੜ] = [ṛ]

Fricatives:

[ਸ] = [s], [ਸ਼] = [š], [ਜ਼] = [z], [ਫ਼] = [f],

[ਖ਼] = [x], [ਗ਼] = [g̣], [ਹ] = [h]

Semi-vowels:

[ਯ] = [y], [ਵ] = [v]

The results of the discussion regarding the English speech sounds, and the Punjabi speech sounds can be summarized in **Tables 2.2 and 2.3** (based on Rabiner and Schafer [87-89], and Dulai and Koul [34] respectively). It should be noted that the English language (Roman script) has 26 letters leading to 42-48 phonemes, whereas the Punjabi language (Gurmukhi script) consists of 56 items (35 letters, 6 supporting letters with a dot in the foot, 3 conjunct consonants (half-letters), 9 supporting symbols, 3 reduplication/nasality symbols) leading to many phonemes by using different permutations and combinations. The following sounds, and phonemes (e.g., *nasals:* ਙ, ਞ, ਣ; *tonemes:* ਘ, ਝ, ਢ, ਧ, ਭ; *stops:* ਤ, ਖ; *flap:* ੜ; *lateral:* ਲ਼) do not exist in the English language (*Phonemes* involving tones in a language are known as *Tonemes*). Several other sounds with conjunct consonant ਹ (e.g., ਨ੍ਹ, ਮ੍ਹ, ਰ੍ਹ, ਲ੍ਹ, ੜ੍ਹ) also don’t exist in the English speech sounds (see **Table 2.5** for details). **Tables 2.4 and 2.5** are based on Sandhu [97], and Bahri [13] respectively. These tables have been added here to confirm the simple fact that no two authors in the Punjabi language agree on the classification of the Punjabi consonants and Punjabi speech sounds. ***These important observations make the Speech Processing projects in the Punjabi language much more different and challenging than the similar projects in the English language.***

Table 2.2: ENGLISH SPEECH SOUNDS (based on Rabiner and Schafer [87-89])
[26 letters, 41 phonemes: 42(1978), 39(2007), 48(2011)]

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1. Vowel phonemes (11)
    - Front vowels: [IY], [I], [E], [AE]
    - Mid vowels: [A], [ER], [UH], [OW]
    - Back vowels: [OO], [U], [O]
2. Diphthongs(6)
    - [AI], [OI], [AU], [EI], [OU], [JU]
3. Semi-vowels (4)
    - Liquids: [R], [L]
    - Glides: [W], [Y]
4. Consonants (6 + 2 + 3 + 8 + 1 = 20)
    - Stops: voiced: [B], [D], [G] unvoiced: [P], [T], [K]
    - Affricates: [DZH], [TSH]
    - Nasals: [M], [N], [NX]
    - Fricatives: voiced: [V], [TH], [Z], [ZH]
      unvoiced: [F], [THE], [S], [SH]
    - Whisper: [H]

Table 2.3: PUNJABI SPEECH SOUNDS (based on Dulai and Koul [34])
[56 items: 35 letters, 6 supporting letters, 3 half-letters,
9 supporting symbols, 3 gemination/nasality symbols]

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1. Vowels
    - Short vowels: [I], [U], [A]
    - Long vowels: [i], [e], [ɛ], [a], [u], [o], [O]
2. Consonants
    - Stops: [p], [ph], [b]
      [t], [th], [d]
      [ṭ], [ṭh], [ḍ]
      [k], [kh], [g]
    - Affricates: [c], [ch], [j]
    - Nasals: [m], [n], [ṇ]
    - Laterals: [l], [ḷ]
    - trill: [r]
    - Flap: [ṛ]
    - Fricatives: [s], [š], [z], [f], [x], [g̣], [h]
    - Semi-vowels: [y], [v]

Table 2.4: Consonantal Phonemes (Sandhu [97], pp. 8)

	Labial	**Dental**	**Retroflex**	**Palatal**	**Velar**
Voiceless unaspirated stops	p	t	ṭ	c	k
Voiceless aspirated stops	ph	th	ṭh	ch	kh
Voiced unaspirated stops	b	d	ḍ	j	g
Nasals	m	n	ṇ		
Laterals		l	ḷ		
Trills		r	ṛ		
Fricatives		s		s’	h
Semi vowels	w			y	

Table 2.5: Panjabi Consonants (Bahri [13], pp. 11)

	1. Stops				**2. Affricate Stops**				**3. Nasal Stops**		**4. Fricatives**		**5. Laterals**		**6. Rolled**		**7. Flapped**		**8. Semi-Vowels**
VL/V →	**VL**		**V**		**VL**		**V**		**V**		**VL**		**V**		**V**		**VL**		**V**
U/A→	**U**	**A**	**U**	**A**	**U**	**A**	**U**	**A**	**U**	**A**	**U**	**A**	**U**	**A**	**U**	**A**	**U**	**A**	**U**
Velars	ਕ	ਖ	ਗ	ਘ*					ਙ			ਹ							
Palatals																			ਯ
Palato-alveolars					ਚ	ਛ	ਜ	ਝ*	ਞ		ਸ਼								
Cerebrals	ਟ	ਠ	ਡ	ਢ*					ਣ								ੜ	ੜ੍ਹ	
Alveolars									ਨ	ਨ੍ਹ*	ਸ		ਲ	ਲ੍ਹ*	ਰ	ਰ੍ਹ*			
Dentals	ਤ	ਥ	ਦ	ਧ*															
Labio-dentals																			
Labials	ਪ	ਫ	ਬ	ਭ*					ਮ	ਮ੍ਹ*									ਵ

VL = Voiceless (aka Unvoiced), V = Voiced; U = Unaspirated, A = Aspirated
* Voiced aspirates

2.6. PHONETIC CODING SCHEMES

At present, a major problem in the area of Punjabi speech processing is that *the symbols consistent with the ARPAbet phonetic transcription do not exist in the Punjabi Language.* Consequently, different authors are using different notations.

In the present work, a new phonetic alphabet consistent with the **ARPAbet** phonetic transcription/coding of the corpora in the Punjabi language has been developed **in Table 2.7 (objective 1).** A number of coding schemes have been used in literature for different international languages [130] as well as the official languages of India [141]. The need for a new coding scheme for the Punjabi language becomes obvious when we investigate the existing coding schemes. Some of the major phonetic coding schemes are briefly discussed below.

2.6.1. International Phonetic Association: IPA (1888)

The International Phonetic Alphabet (IPA) was created in 1888 by a group of prominent European phoneticians as an effort to facilitate and standardize language transcription **[The International Phonetic Alphabet (IPA): 1989 (Das Mandal), 1886 (LSI)].** Even today, the IPA is most widely accepted and used [24, 9]. Because there are enough entries to handle phonemes in almost all the languages of the world, the IPA is considered most appropriate for handwritten work. However, the following problems arise when one tries to use IPA for the computerized speech processing [Deller et al., 24 pp. 117]:

1. The IPA cannot be typed on a "conventional typewriter or a computer keyboard."
2. Different books make use of the different symbols or notations for the elements implying the possible difference in notation even within the IPA. As an example, see **Table 2.6,** where three different books use three different notations.

2.6.2. Advanced Research Projects Agency (ARPAbet)

As a solution to this problem, the United States Advanced Research Projects Agency (ARPA) developed the phonetic alphabet known as **ARPAbet**, with two versions (Single-letter version and upper-case version) suitable for typing:

1. *Single-letter notation*: This notation uses single-letter symbols. It is a mixture of lower case letters, upper-case letters, and non-alphabet symbols [24].
2. *Upper-case notation*: This notation uses upper-case symbols only. Inevitably, it uses some double-letter designators [24, 89].

At present, a major problem in the area of Punjabi speech processing is that *the symbols consistent with the* **ARPAbet** *phonetic transcription do not exist in the Punjabi language.*

2.6.3. Indian Script Code for Information Interchange (ISCII)

ISCII-88 is an 8-bit code slowly developed by the year 1988 focusses on the bilingual nature (one Indian script and the Roman script being used by ASCII) of the linguistic scenario in India [128]. The earlier versions of ISCII were 7-bit codes. ISCII-88 is an 8-bit code because 7-bits are required to represent each of the two code sets (7-bit ISCII code and 7-bit ASCII code). After about 3 years work, the Center for Development of Advanced Computing (C-DAC) modified ISCII-88 and proposed an improved version known as ISCII-91 as the national standard for Indic scripts [120]. This document was accepted by the Bureau of Indian Standards (BIS) and published by BIS in 1991 as **ISCII-91** (IS 13194:1991). An eleven column table consisting of the eleven scripts and the corresponding languages ISCII-91 can handle is given as Annexure-1 in [120, pp. 320-323]. The contents of the several pages long table are summarized below. The languages that make use of these eleven scripts are given in brackets (e.g., Devanagari or DEV script is employed by nine languages as described in item 2. below):

1. RMN = Roman (English)
2. DEV = Devanagari (Dogri, Hindi, Kashmiri, Konkani, Maithili, Marathi, Nepali, Sanskrit, Sindhi)
3. PNJ = Gurmukhi (Punjabi)
4. GJR = Gujarati (Gujarati)
5. ORI = Oriya (Oriya)
6. BNG = Bangla (Bengali)
7. ASM = Assamia (Assamese/Axomiya, Bodo)
8. TLG = Telugu (Telugu)
9. KND = Kannada (Kannada)
10. MLM = Malayalam (Malayalam)
11. TML = Tamil (Tamil)

It should be noted that Sindhi and Kashmiri languages can be written in Devanagari as well as Urdu scripts. ISCII code is considered suitable for the coding of most of the Indian languages and Indic Scripts due to its capabilities to represent matras, vowels, consonants, numerals, and diacritical marks. That is one of the major reasons why Unicode representation of different coding sets for representing Indic Scripts is based on ISCII-88.

2.6.4. Speech Assessment Methods Phonetic Alphabet (SAMPA)

SAMPA is an ASCII coding scheme particularly developed for European languages as well as for some Asian languages. It is a machine readable phonetic alphabet. Consequently it has been successfully used for many speech processing applications [8-9]. **X-SAMPA** is a variation of SAMPA to cover the entire IPA. **SAMPROSA** is a parallel system of prosodic notation (keeps prosodic and segmental transcriptions distinct from one another). SAMPROSA is a limited scope scheme with its scope limited only to the phonemic transcription. Both X-SAMPA and SAMPROSA are considered the extended versions of SAMPA [9].

2.6.5. Indian Script to Roman Transliteration (INSROT)

INSROT is a limited scope coding scheme. It was designed for the transcription of Indian language contents in the Roman alphabet [8]. INSROT uses lower case letters only. Consequently, it is not case-sensitive so as to support the case-insensitive search.

2.6.6. wx-Roman

This scheme is a limited-objective (or special purpose) scheme designed to transliterate Devanagari to Roman script. The single most important salient feature of wx-Roman is, that it makes use of a single keystroke for each consonant or vowel in the Devanagari script [8]. SAMPA, INSROT and wx-Roman have been employed to represent the Hindi and Punjabi languages. Arora *et al.* [8] have attempted to make use of SAMPROSA, the extended version of SAMPA, in order to represent the tonal variations in the Punjabi language because a prosodic notation is required to represent the special tonal features in the Punjabi language. However, they have concluded that "the five voiced aspirates are firm in Hindi but are absent in Punjabi". The same limitation becomes more obvious in Annexure I [9] where five Punjabi tonemes (ਘ, ਝ, ਢ, ਧ, ਭ) are missing.

It is clear that each of the ***six coding schemes*** discussed above has its merits, but none of these have proven suitable for the phonetic representation of the Punjabi language because of the following reasons:

1. These schemes were designed with different foci, different languages, and different objectives in mind.
2. Most of these schemes cannot be typed on a conventional typewriter or a computer keyboard.
3. Most of these are inconsistent (different books make use of the different symbols or notations for the elements implying the possible difference in notation even within the IPA).
4. Some of these coding schemes are limited-objective schemes only.
5. The laborious, irritating, and time-consuming necessities for dealing with the special symbols for vowels, nasalization, tones, and inserting diacritical marks in most of these schemes (especially where two diacritical marks over the ten vowel signs are needed for the Punjabi language in Gurmukhi script) further confirm the need for a new coding scheme as designed in this chapter. **Tables 2.6 and 2.7** provide a different insight into the necessity of the new coding scheme.

Table 2.6: Condensed list of phonetic symbols for Punjabi

Symbol (form)	GILL and GLEASON, Jr.[43]		DULAI and KOUL[34]		BAHRI[13]	
	Value	Name	Value	Name	Value	Name
ੳ		uṛa		-	u	ooṛá
ਅ		ɛṛa		-	a	āiṛá
ੲ		iṛi		-	i	iṛi
ਸ	s	səssa	s	səssa	s	sassa
ਹ	h	háha	h	haha	h	háhá
ਕ	k	kəkka	k	kəkka	k	kakká
ਖ	kh	khəkkha	kh	khəkkha	kh	khakkhá
ਗ	g	gəgga	g	gəgga	g	gaggá
ਘ	k̀, ǵ, g̀	kə̀gga	k̀, ǵ, g̀	kə̀gga	gh	kaghá
ਙ	ŋ	ŋəŋa	-	-	ṅ	ṅaṅa
ਚ	č	čəčča	c	cəcca	ch	chachchá
ਛ	čh	čhəčča	ch	chəccha	chh	chhachhá
ਜ	j	jəjja	j	jəjja	j	jajjá
ਝ	č̀, ʝ́, j̀	čə̀jja	c̀, ʝ́, j̀	cə̀jja	jh	cajhá
ਞ	ñ	ñəñña	ṅ	ṅəṅa	ñ	ñañá
ਟ	ṭ	ṭɛ̃ka	ṭ	ṭɛ̃ka	ṭ	ṭāinká
ਠ	ṭh	ṭhəṭṭha	ṭh	ṭhəṭṭha	ṭh	ṭhaṭhṭhá
ਡ	ḍ	ḍəḍḍa	ḍ	ḍəḍa	ḍ	ḍaḍḍá
ਢ	ṭ̀, ḍ́, ḍ̀	ṭə̀ḍḍa	ṭ̀, ḍ́, ḍ̀	ṭə̀ḍḍa	ḍh	ṭaḍha
ਣ	ṇ	ṇáṇa	ṇ	ṇaṇa	ṇ	ṇáṇá
ਤ	t	tətta	t	tətta	t	Tattá
ਥ	th	thəttha	th	thətha	th	thaththá
ਦ	d	dədda	d	dədda	d	daddá
ਧ	t̀, d́, d̀	tə̀dda	t̀, d́, d̀	tə̀dda	dh	tadha
ਨ	n	nənna	n	nənna	n	nanná
ਪ	p	pəppa	p	pəpa	p	pappá
ਫ	ph	phəppha	ph	phəppha	ph	phaphphá
ਬ	b	bəbba	b	bəbba	b	babbá
ਭ	p̀, b́, b̀	pə̀bba	p̀, b́, b̀	pə̀bba	bh	pabhá
ਮ	m	məmma	m	məmma	m	mammá
ਯ	y	yəya	y	yəya	y	yayyá
ਰ	r	rára	r	rara	r	rárá
ਲ	l	ləlla	l	ləlla	l	lallá
ਵ	w	wáwa	v	vava	v	vává
ੜ	ṛ	ṛáṛa	ṛ	ṛaṛa	ṛ	ṛáṛá

Table 2.6 ***(Continued)***

ਸ਼	š		š	šəšša	sh	
ਖ਼	*kh*		x	xəxxa	<u>kh</u>	
ਗ਼	*gh*		g̣	gəgga	G	
ਜ਼	z		z	zəzza	z	
ਫ਼	f		f	fəffa	f	
ਲ਼			ḷ	ḷəḷḷa		

2.7. <u>NEW PHONETIC ALPHABET DEVELOPMENT: *PUNJARPAbet*</u>

As pointed out in earlier sections 2.1 and 2.2 of this chapter**,** a major problem in the area of Punjabi speech processing is that *at present, the symbols consistent with the* **ARPAbet** *phonetic transcription do not exist for the Gurmukhi alphabet in the Punjabi Language.* Consequently, different authors are using different notations. For example, see **Table 2.6**, where three different books by Gill and Gleason, Jr. [43], Dulai and Koul [34], and Bahri [13] use different notations. **ARPAbet** notation has gained popularity amongst computerized speech researchers due to simplicity and the credibility of the agency ARPA itself. Therefore, in this chapter, we have concentrated on developing a notation based on **ARPAbet.**

In this section, a new phonetic alphabet (invariably called *coding scheme* or *new scheme* or 'just' *scheme* hereafter) has been designed to encode the Punjabi corpus. Since the new scheme is based on the ARPAbet, let us call it ***Punjabi ARPAbet*** to begin with. Combining **PUNJ** and **ARPAbet**, we derive the name ***PUNJARPAbet*** same way as the name of the PUNJAB state has been derived from the combination of the two words **PUNJ** (five) + **AAB** (water). The name ***Punjab*** literally translates to *five waters* [150]; representing the fact the undivided Punjab state (before partition in 1947) was the land of the five rivers: Jhana (Chenab), Jhelum, Ravi, Beas, Sutlej. The ***PUNJARPAbet*** is an *all upper-case* coding scheme. It is consistent with the all upper-case version of the famous ARPAbet scheme. The existing schemes (e.g., IPA) almost always require special symbols. It is not an easy task to find these symbols, or to combine the appropriate diacritical marks to these symbols. While transferring data consisting of these symbols from one computer to another, it is not unusual to face the portability problems. Consequently, dealing with these symbols is laborious, irritating, and time-consuming.

However, the new coding scheme designed in this work is very easy to follow and is the most suitable scheme for the ordinary computer keyboard as well as an ordinary typewriter. **Table 2.7** summarizes the new coding scheme. **Table 2.7** consists of six columns and 58 rows. Ten non-nasalized vowels, ten nasalized vowels, and 38 consonants add up to 58 and each item occupies one row. Column 1 has 58 Gurmukhi symbols. Column 2 has corresponding **IPA** symbols. Column 3 has two sub-columns for **ARPAbet**: one each for *Single Symbol Version* and *Upper Case Version*. Column 4 has corresponding **SAMPA** symbols. Column 5 consists of the newly designed ***PUNJARPAbet*** symbols: the original contribution of this work. Column 6 has two sub-columns for examples in English and Punjabi. The **sixteen** blank boxes in two sub-columns under **ARPAbet** in **Table 2.7** mean that at present there are no symbols in the **ARPAbet** to represent these sixteen Punjabi speech sounds (and the corresponding letters of the Gurmukhi script). These sixteen Punjabi speech sounds/Gurmukhi letters are:

ਖ, ਖ਼, ਗ਼, ਘ, ਛ. ਝ, ਞ, ਠ, ਢ, ਣ, ਤ, ਧ, ਫ, ਭ, ਲ਼, ੜ

kh, x, g̣, k /g, ch, c/j, ɲ / ň, ṭh, ṭ /ḍ, ṇ, t, t / d, ph, p / b, ḷ, ṛ

In this work, new symbols have been designed for the above 16 Punjabi speech sounds to transcribe the newly designed text and speech corpus. These symbols can be found in column 5 of **Table 2.7**. A complete template of ***PUNJARPAbet*** including newly designed symbols is given in **Table 2.8**.

PUNJARPAbet is a coding scheme that uses only *uppercase* English letters to represent the Punjabi speech sounds. Hence the ***PUNJARPAbet*** is consistent with the *all uppercase* version of the famous *ARPAbet* scheme. It uses three lowercase letters ***n, h*** and ***l*** to represent nasalization, high tone and low tone respectively. The other two symbols used in the ***PUNJARPAbet*** to represent the following seven Punjabi speech sounds or phonemes (ਟ, ਠ, ਡ, ਢ, ਣ, ਗ਼, ਲ਼) are underline (_) and colon (:). The new scheme is very easy to use since all the symbols used in this scheme are readily available on an ordinary computer keyboard as well as on an ordinary typewriter. Consequently, the ***PUNJARPAbet*** is the most suitable coding scheme for transcribing the Punjabi language speech and text corpora. The evaluation of this scheme requires an appropriate corpus. This corpus is designed in Chapter IV, and the ***PUNJARPAbet*** coding scheme is thoroughly evaluated in Chapter VI. The complete corpus using the newly designed ARPAbet-compatible Phonetic Coding Scheme ***PUNJARPAbet*** is given in the Appendices C and D.

Table 2.7: New Phonetic Coding Scheme for the GURMUKHI Script

Gurmukhi	IPA Symbol	ARPAbet		SAMPA	PUNJAR-PAbet	Examples	
		Single Symbol Version	Upper Case Version			English	Punjabi
ਅ	ə / ʌ	A	AH	a	AH	un	ਅਨ, ਅਸਰ
ਆ	a	a	AA	a:	AA	all	ਆਲ, ਆਦਤ
ਇ	I	I	IH	I	IH	it	ਇਟ, ਚਿਰ
ਈ	i	i	IY	i	IY	eat	ਈਟ, ਚੀਰ
ਉ	U	U	UH	U	UH	push	ਪੁਸ਼, ਸੁਰ
ਊ	u	u	UW	u	UW	tool	ਟੂਲ, ਸੂਰ

Table 2.7 ***(Continued)***

ਏ	e	e	EY	e	EY	ate	ਏਟ, ਸੇਰ
ਐ	ɛ/æ	@	AE	E	AE	at	ਐਟ, ਸੈਰ
ਓ	o	o	OW	o	OW	oat	ਓਟ, ਮੋਰ
ਔ	ɔ	c	AO	O	AO	odd	ਔਡ, ਮੌਰ
ਅੰ, ਸੰ	ə / ʌ	A	AH	a	AHn	under	ਅੰਡਰ, ਅੰਤ
ਆਂ, ਸਾਂ	ã	a	AA	a:	AAn	auntie	ਆਂਟੀ, ਆਂਦਰ
ਇੰ, ਸਿੰ	Ĩ	I	IH	I	IHn	ink	ਇੰਕ, ਹਿੰਸਾ
ਈਂ, ਸੀਂ	ĩ	i	IY	i	IYn		ਆਈਂ, ਨੀਂਦ
ਉਂ, ਸੁੰ	Ũ	U	UH	U	UHn		ਉਂਗਲ਼, ਸੁੰਦਰ
ਊਂ, ਸੂੰ	ũ	u	UW	u	UWn		ਊਂਘ, ਗੂੰਦ
ਏਂ, ਸੇਂ	ẽ	e	EY	e	EYn	saint	ਸੇਂਟ, ਗੇਂਦ
ਐਂ, ਸੈਂ	ɛ̃/æ̃	@	AE	E	AEn	and	ਐਂਡ, ਹੈਂਕੜ
ਓਂ, ਸੋਂ	õ	o	OW	o	OWn		ਓਂਕਾਰ, ਹੋਂਦ
ਔਂ, ਸੌਂ	ɔ̃	c	AO	O	AOn		ਸੌਂ, ਸ਼ੌਂਕਣ
ਸ	s	s	S	s	S	seat	ਸੀਟ, ਸਨੇਹ
ਸ਼	ṣ / ʃ	S	SH	S	SH	sheet	ਸ਼ੀਟ, ਸ਼ਬਦ
ਹ	h	h	HH	h	H	heart	ਹਰਟ, ਹਿਰਨ
ਕ	k	k	K	k	K	keep	ਕੀਪ, ਕਰਤਾ
ਖ	kh			k_h	KH		ਖੱਟਾ, ਖੱਚਰ
ਖ਼	x			X	X	xuda	ਖ਼ੁਦਾ, ਖ਼ੂਨ
ਗ	g	g	G	g	G	great	ਗ੍ਰੇਟ, ਗਰਮ
ਗ਼	g̣			G	<u>G</u>		ਬਾਗ਼, ਗ਼ੁਲਾਮ
ਘ	k / g			g_h	GH		ਘਰ, ਖੰਘ
ਙ	ŋ / ṅ	G	NX	N	NX	sing	ਮੀਂਙਣ, ਕੰਙਣ
ਚ	c / tʃ	C	CH	tS	CH	church	ਚਰਚ, ਚਾਰ
ਛ	ch			tS_h	CHH		ਛਾਤੀ, ਛੱਤ
ਜ	j / dʒ	J	JH	dZ	J	jeep	ਜੀਪ, ਜੀਭ
ਜ਼	z	z	Z	z	Z	zero	ਜ਼ੀਰੋ, ਰਾਜ਼
ਝ	c / j			dZ_h	JH		ਝੂਠ, ਝੰਡਾ
ਞ	ɲ / ň			J	NJ		ਜੰਞ, ਇੰਞ

Table 2.7 ***(Continued)***

ਟ	ṭ / t	t	T	t`	T:	team	ਟੀਮ, ਟੀਸੀ
ਠ	ṭh			t`_h	TH:		ਠੰਢ, ਠੀਕ
ਡ	ḍ / d	d	D	d`	D:	drama	ਡਰਾਮਾ, ਡਰ
ਢ	ṭ / ḍ			d`_h	DH:		ਢਿੱਡ, ਢੰਗ
ਣ	ṇ			n`	N:		ਪੌਣ, ਪਾਣੀ
ਤ	t			t	T		ਤਨ, ਤੀਰ
ਥ	th / θ	T	TH	t_h	TH	thing	ਥਿੰਗ, ਥਾਂ
ਦ	d / ð	D	DH	d	D	that	ਦੈਟ, ਦੁਲਹਨ
ਧ	t / d			d_h	DH		ਧਰਮ, ਪੰਧ
ਨ	n	n	N	n	N	neat	ਨੀਟ, ਨਾਮ
ਪ	p	p	P	p	P	para	ਪੈਰਾ, ਪੀੜ
ਫ	ph			p_h	PH	phone	ਫੋਨ, ਫਸਣਾ
ਫ਼	f	f	F	f	F	five	ਫ਼ਾਈਵ, ਫ਼ਰਸ਼
ਬ	b	b	B	b	B	book	ਬੁੱਕ, ਬੁੱਧੂ
ਭ	p / b			b_h	BH		ਭਾਰਾ, ਭੂਮੀ
ਮ	m	M	EM	m	M	mother	ਮਦਰ, ਮੋਰ
ਯ	y / j	y	Y	j	Y	yard	ਯਾਰਡ, ਯਾਰ
ਰ	r	r	R	r	R	rat	ਰੈਟ, ਰਾਤ
ਲ	l	l / L	L / EL	l	L	love	ਲਵ, ਲਿਖਣਾ
ਲ਼	ḷ				L		ਗਲ਼, ਗੋਲ਼
ਵ	V	v	V	v	V	victory	ਵਿਕਟਰੀ, ਵੇਚਣਾ
ੜ	ṛ			r`	RH		ਸੜਕ, ਫੜ

2.8. CONCLUSION

In this Chapter, a new phonetic coding scheme has been designed to encode the ***Punjabi*** corpus. Since the new scheme is based on the ***ARPAbet***, therefore, we have called it ***Punjabi ARPABet*** to begin with. Combining PUNJ and ARPAbet, we have derived the name ***PUNJARPAbet*** in the same way as the name of the PUNJAB state has been derived from the combination of the two words PUNJ (five) + AAB (water). ***PUNJARPAbet*** is a coding scheme that uses only *uppercase* English letters to represent the Punjabi speech sounds. Hence the ***PUNJARPAbet*** is consistent with the *all uppercase* version of the famous *ARPAbet* scheme.

The idea of the new scheme originated to address the four issues. *Firstly*, the existing schemes (e.g., IPA) almost always require special symbols. It is not an easy task to find these symbols, or to combine the appropriate diacritical marks with these symbols. *Secondly,* while transferring data consisting of these symbols from one computer to another, it is not unusual to face the portability problems. Consequently, dealing with these symbols is laborious, irritating, and time-consuming. *Thirdly*, no two authors agree on the representation of the Punjabi speech sounds as shown in **Table 2.6** consisting of Gill & Gleason, Bahri, and Dulai. *Lastly*, the symbols for at least 16 letters of the Punjabi language/Gurmukhi script do not exist in the ARPAbet. These 16 letters (ਖ, ਖ਼, ਗ਼, ਘ, ਛ. ਝ, ਞ, ਠ, ਢ, ਣ, ਤ, ਧ, ਫ, ਭ, ਲ਼, ੜ) have been identified in red colour in **Table 2.8**. **Table 2.7** summarizes the new coding scheme. **Table 2.8** gives the complete template of the new coding scheme ***PUNJARPAbet.*** The new scheme is very easy to use since all the symbols used in this scheme are readily available on an ordinary computer keyboard as well as on an ordinary typewriter. Consequently, the ***PUNJARPAbet*** is the most suitable coding scheme for transcribing the Punjabi language text corpora.

Table 2.8: PUNJARPAbet TEMPLATE

ਅ	ਆ	ਇ	ਈ	ਉ	ਊ	ਏ	ਐ	ਓ	ਔ
AH	AA	IH	IY	UH	UW	EY	AE	OW	AO
ਸ	ਸ਼	ਹ	ਕ	ਖ	ਖ਼	ਗ	ਗ਼	ਘ	ਙ
S	SH	H	K	KH	X	G	G	GH	NX
ਚ	ਛ	ਜ	ਜ਼	ਝ	ਞ				
CH	CHH	J	Z	JH	NJ				
ਟ	ਠ	ਡ	ਢ	ਣ					
T:	TH:	D:	DH:	N:					
ਤ	ਥ	ਦ	ਧ	ਨ					
T	TH	D	DH	N					
ਪ	ਫ	ਫ਼	ਬ	ਭ	ਮ				
P	PH	F	B	BH	M				
ਯ	ਰ	ਲ	ਲ਼	ਵ	ੜ				
Y	R	L	L	V	RH				

■

CHAPTER III
SPEECH SIGNAL PROCESSING[2]

3.1. INTRODUCTION

In this chapter, all essential concepts required for developing the speech production models for linear prediction analysis and synthesis of the Punjabi speech are discussed. These concepts include speech signal, speech sound and speech processing, speech production models, and the challenges presented by the speech signal processing. The term "speech" conveys an entirely different meaning to different people, in different context and environment, and in different professional fields. It might mean speech related *medical* issues such as stuttering to a *doctor* or a *patient*, *clarity of thoughts* of the speaker conveyed to a *layman* or a *political worker*, and an *acoustic waveform* to a *speech scientist* or an *IT professional*. A speaker perceives the speech at a linguistic level in his/her brain, generates it via mouth and nose at the physiological level, and conveys it at the acoustic level. The listener's (and speaker's own) ears receive it at the physiological level before decoding and understanding it at the linguistic level. This phenomenon or activity, generally called the *Speaker Chain* [Rabiner and Schafer, 89, pp. 5, pp. 125] is summarized in **Fig. 3.1**.

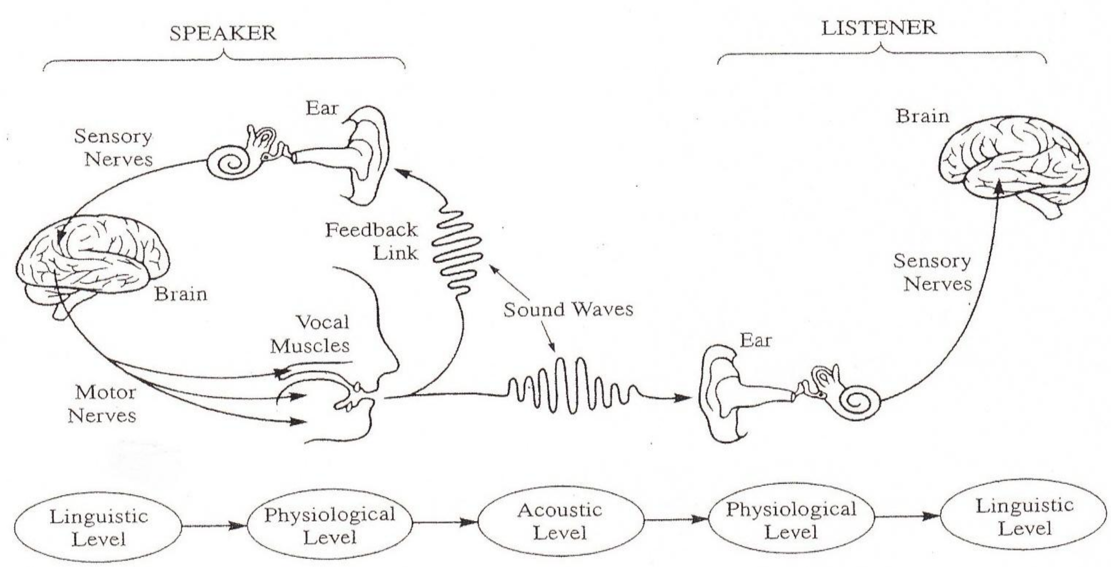

Figure 3.1: The Speaker Chain: from message, to speech signal, to understanding [due to P. B. Denes and E. N. Pinson (1993, 2nd edition)]

[2] The partial contents discussed in this chapter have been published in a book of **Punjabi University (ISBN: 81-302-0177-1), 2010** and in the International Journal **PARKH, Vol. I, Jan-June 2013, pp. 179-188.** Some contents of this chapter were presented in the international conferences including **World Punjabi Conference (WPC-2009), Punjab University, India** and **International Punjabi Development Conference (IPDC-2009), Punjabi University, India**.

Using the communication systems technology, the speaker or talker is the *transmitter* and the listener is the *receiver*, and the speech signal is the *message* of interest.

3.2. SPEECH SIGNAL

The purpose of speech is communication of ideas expressible in some language. As Edward Sapir [116, pp. 17] said, "Speech is so familiar feature of our daily life that we rarely pause to define it. It seems as natural to man as walking, and only less so than breathing." Mario Pei [116, pp. 17] confirms the same fact from a different angle by stating that the "systems of communication not based on speech, while extremely useful on specific occasions, are generally inferior to the spoken tongue as meaning-conveyors."

In the signals and systems theory, speech is represented as an acoustic pressure waveform, i.e., as a signal carrying the information or message.

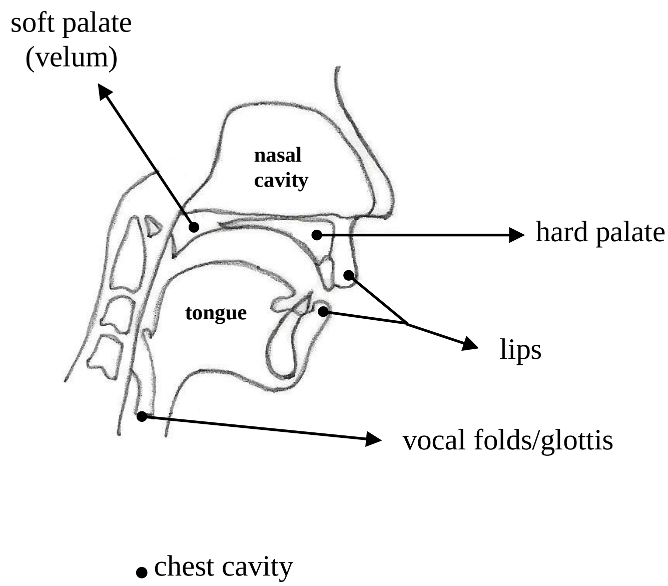

Figure 3.2: Cross-sectional view of the human vocal tract mechanism showing some of the major articulators in speech production (due to Markel and Grey [76])

The representation of a speech signal based on its acoustic waveform, or some parametric model based on the waveform has been found to be most useful and helpful in practical applications, and in understanding the complex structure of the waveform.

The acoustic speech waveform is an acoustic pressure wave which originates from voluntary physiological movements of the major parts of anatomical structure involved in speech generation as shown in **Fig. 3.2**.

The organs of speech involved in the production of various speech sounds [34] may be classified into two categories: 1. Articulators, and 2. Points of Articulation. The articulators are those movable organs in the speech tract, which move towards the points of articulation when sounds are produced. The articulators are lower lip, tip of the tongue, blade of the tongue, center of the tongue and back of the tongue. The points of articulation are relatively stationary organs of speech, such as upper lip, tip of teeth, ridge, hard palate, soft palate, and uvula (full name is the *palatine uvula*).

The vocal cords play an important role in the production of speech sounds. The air stream coming from the lungs passes through the wind pipe. The Larynx is the uppermost part of the wind pipe. It contains two lip-like elastic membranes known as *vocal cords*. The vocal cords vibrate, when brought very near to each other and when air current passes through them. This gives rise to voicing. Speech sounds which are produced in this manner are called **voiced sounds**. In case the vocal cords are not brought near to each other and remain apart, the air current passes through them noiselessly, and the speech sounds thus produced are called **unvoiced (or voiceless) sounds** [34].

A schematic diagram of the human speech production mechanism (based on Flanagan [40]) is shown in **Fig. 3.3**. More specifically, speech is produced by the actions of nose, mouth, jaws and throat upon the entire *breath system*. In normal speech production, the chest cavity expands and contracts and forces the air from the lungs out through trachea past the glottis (the opening between the vocal folds is called *glottis*). Depending upon the position of the trap door velum, the air stream is expelled either through the mouth cavity or through the nasal cavity or both and perceived as speech.

The vocal tract is a non-uniform acoustic tube which extends from the glottis to the lips and is about 17 cm long for an average adult male. Vocal tract varies in shape and size as a function of time. This time-varying change is caused by the continuously changing positions of the various articulators (the major anatomical components participating in speech production, e.g., lips, tongue, jaw and velum, have already been described in Section 2.1). As an example, the cross-sectional area of vocal tract varies from 0 to 20 sq. cm. depending upon whether the lips are closed, or mouth and jaws are wide open.

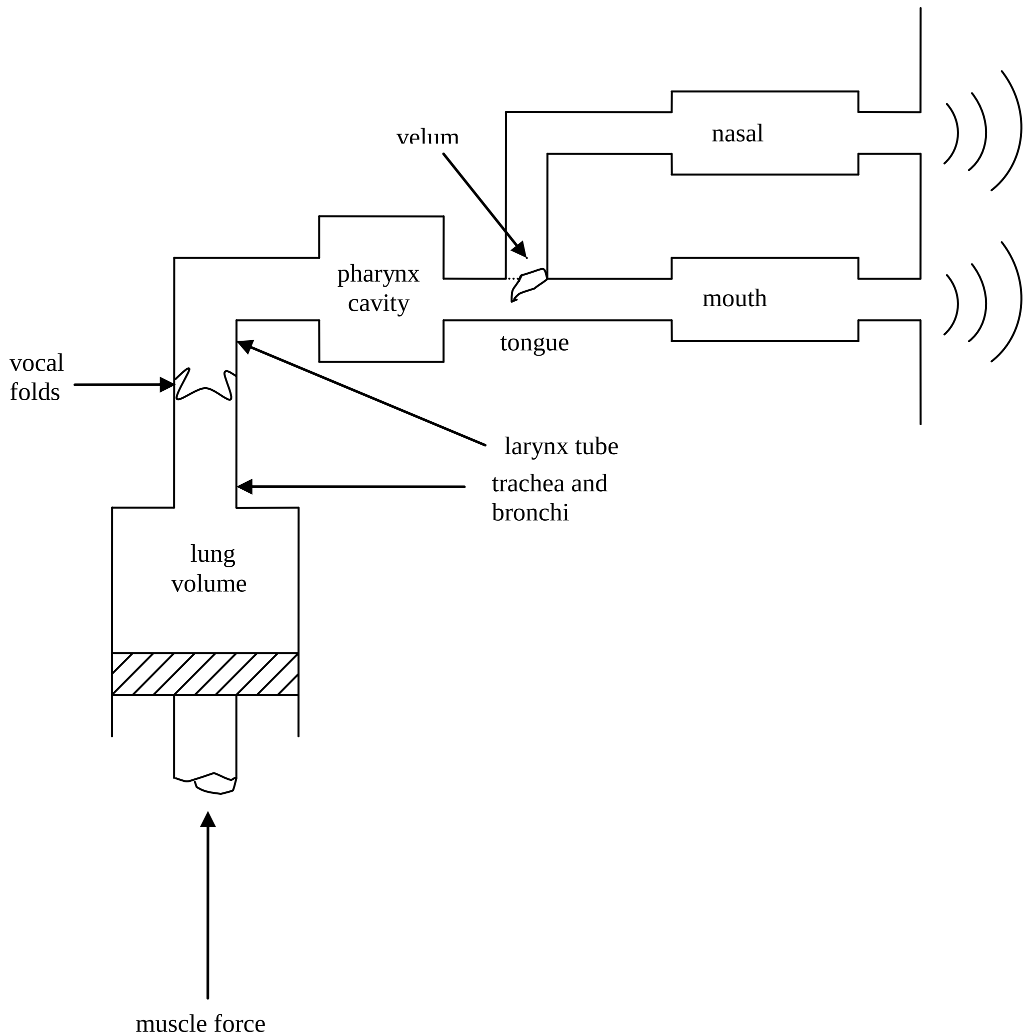

Figure 3.3: Schematic diagram of the Human Speech Production Mechanism (due to Flanagan [40])

3.3. SPEECH SOUNDS AND SPEECH PROCESSING

In order to conduct speech analysis and synthesis in any language, the speech sounds must be understood in terms of the vocal tract system, so that an appropriate computer model can be developed. This section deals with the vocal tract system so that we can start developing the appropriate speech production model in the next section.

The speech signals are constituted of a sequence of sounds and the sets of these distinctive sounds in a language are called *phonemes*. These sounds and the transitions between these sounds form the symbolic representation of the information.

The Punjabi speech sounds have been described in Section 2.5 where *phonemes* were classified into vowels, diphthongs, semivowels or consonants. These four main classes are further broken down to sub-classes depending upon the manner and place of articulation of the sounds within the vocal tract.

There are **three** primary modes for exciting the vocal tract system. Based on these three primary modes, the speech sounds can be classified into three distinct classes as follows:

i) Voiced sounds
ii) Unvoiced or voiceless sounds
iii) Plosive sounds

For **voiced sounds**, the source of excitation is at the glottis and the sounds are generated by broad-band quasi-periodic puffs of air produced by the vibrating vocal cords. Typical examples of these sounds are *voiced consonants, nasal consonants, vowels and semi-vowels.*

For **unvoiced or voiceless sounds**, the source is at some point of constriction in the vocal tract, anywhere from glottis to the lips. The vocal cords are spread apart (no voicing) and the sounds are produced by turbulent quasi-random airflow. Typical examples of unvoiced or fricative sounds are *non-nasal consonants.*

For **plosive sounds**, the source is at the point of closure, and the sounds are produced by suddenly releasing the air pressure built up behind the total constriction. *Unvoiced stop consonants* are the examples of such sounds.

3.4. SPEECH PRODUCTION MODELS

Sound waves are generated by vibration and are propagated in air or other media by vibrations of the particles of the media (It is important to note that *sound waves* cannot travel through *vacuum* because sound needs a medium such as air, any liquid (e.g., water), or any solid to travel along). Since a *vacuum* does not contain any particles, the sound will not be able to *propagate through* or be *heard*. A set of partial differential equations describing the motion of air in the vocal system can be obtained (Fant [38-39], Flanagan [40]) but the solution of these equations is very difficult. A detailed acoustic theory must consider the effects of many complicated physical processes [76-77, 79, 99] associated with speech production, including the following: the position of the tongue, changes in the length, shape and contour of the vocal tract, the resonance of the vocal cords, the mass and elasticity of the muscles along the vocal tract walls, dental effects, the viscosity of the mucus in the vocal tract, the position of the velum, and subsequent coupling with the nasal tract, radiation effects at the lips, losses due to heat conduction, and temperature gradients [24, 38-40, 82-83, 85-89]. A major concern in the area of speech processing has been, and still remains, that a detailed acoustic theory incorporating all the above processes and effects is still not available completely.

Many models have been proposed to describe the complicated process of speech production. None of these models, alone, can account for all of the observed characteristics of human speech (as described above); nor is it probably desirable to postulate such a model due to its inevitable complex structure.

However, for convenience, it is desired to have models that are linear as well as time-invariant. But speech production mechanism is neither linear nor time-invariant. On the contrary speech is a continuous but slowly time-varying, non-stationary, quasi-periodic waveform. Also, the fact that the glottis is coupled to the vocal tract results in non-linear characteristics [24-31, 87-89, 99].

All speech models make **two** basic assumptions thereby reducing some complexity at the cost of accuracy:

(i) The vocal tract system and the source of excitation are independent such that the vocal tract system can be excited by any of the possible sources of excitation. **This assumption becomes invalid in the case of transient sounds like 'p' in 'pot', voiced fricatives, nasals, and whisper**. The validity of this assumption is quite good for the majority of the cases of interest.

(ii) The characteristics of speech are time-invariant over short segments of time (approximately 15 to 25 milliseconds). It implies that in order to represent the slowly time-varying characteristics of speech indicating a new configuration of the vocal tract, the control parameters of the model require to be updated only for the *new speech segment*, and not for *each speech sample*.

Based on these **two** main assumptions, many speech production models have been proposed by various research scientists (e.g., Fant [38-39], Flanagan [40], Schafer [99, 87-89], Atal and Hanauer [11-12], Itakura and Saito [52]) throughout the world to describe major characteristics of speech. Although many models have been attempted, the following three speech models are noteworthy for this project:

1. Linear speech production model [38-39, 40]
2. Digital model of speech production [87-89, 99]
3. Linear prediction model of speech production [11-12, 52, 74-76]

These models are introduced in the next three sections.

3.4.1. LINEAR SPEECH PRODUCTION MODEL

This model shown in **Fig. 3.4** was developed by Fant [38-39, 99] in the late 50's (1960). Fant covered the assumptions in detail later on elaborated by Flanagan [40]. Flanagan presented the results of some carefully conducted experiments on acoustic radiation supporting Fant's justification as well as the mathematical derivation of this model.

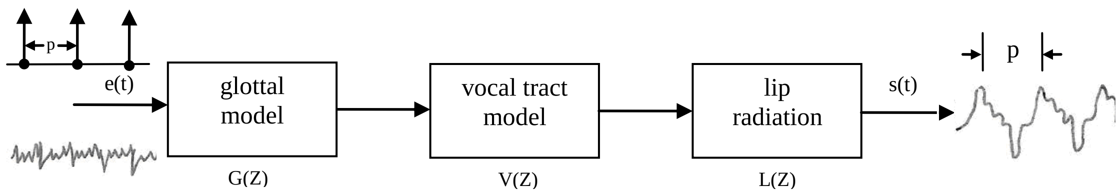

Figure 3.4: Linear speech production model (due to Fant [38-39])

In this model vocal tract system is simulated as three different low pass filters one each for glottal model, vocal tract model and lip and flat spectrum random noise for unvoiced sounds. The impulses simulating the initiation of puffs of air for voiced sounds are spaced P samples apart where **P** is the **pitch period** (the rate of oscillation of vocal cords is called the pitch frequency or fundamental frequency F_0 for the particular speech segment and its reciprocal l/F_0 is known as the **pitch period P**). The random noise simulates the pressure buildup waveform and the quasi- random turbulence for unvoiced sounds.

The linear speech production model in Z-transform terminology can be described as:

$$S(Z) = E(Z)\ G(Z)\ V(Z)\ L(Z) \qquad (3.1)$$

where

$$S(Z) \leftrightarrow s(kT) = s(t)|_{t = kT} \qquad (3.2)$$

$$E(Z) \leftrightarrow e(t)|_{t=kT} \qquad (3.3)$$

3.4.2. DIGITAL MODEL OF SPEECH PRODUCTION

Schafer [87-89, 99] presented the ideas of the previous section in digital form (**Fig. 3.5**) and probably in a little more sophisticated manner than Fant, and Flanagan [38-40]. The digital model of speech production suggests that vocal tract system can be represented in a single time-varying digital filter excited either by an impulse train generator (for **voiced sounds**) or by a random number generator (for **unvoiced sounds**). A gain parameter between the excitation sources and the excited system (digital filter) allows some flexibility in the output acoustic level and the digital output corresponds to the sampled speech waveform.

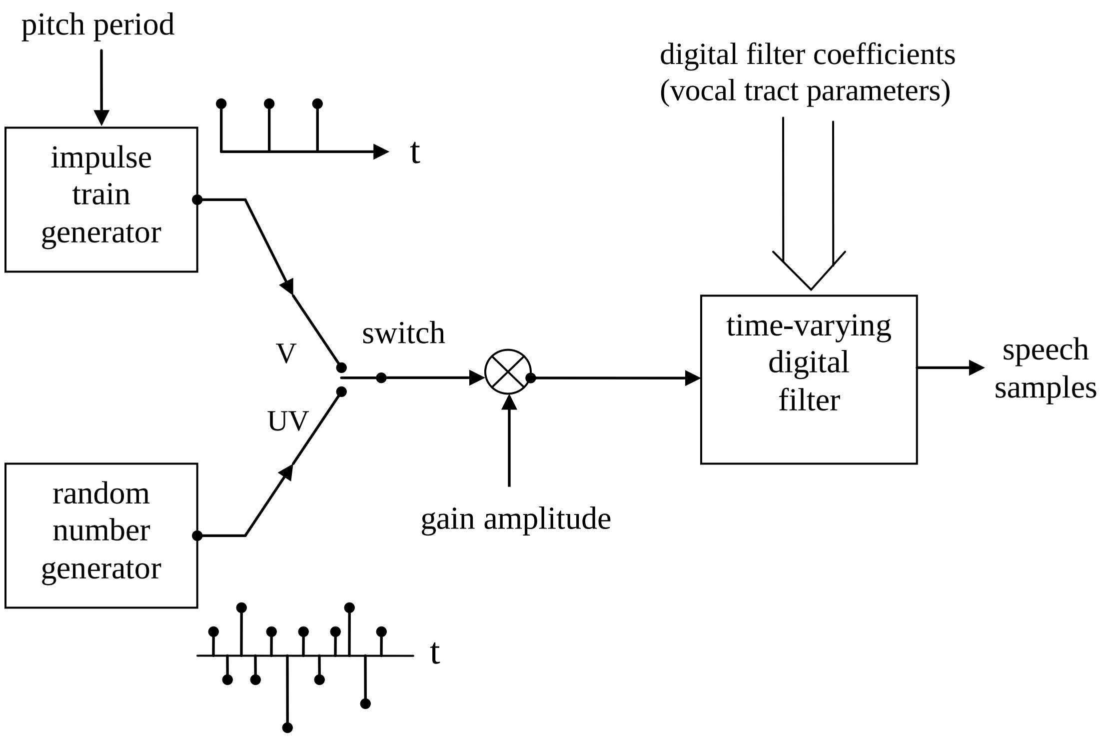

Figure 3.5: Digital model of speech production (due to Schafer [87-89, 99])

3.4.3. LINEAR PREDICTION MODEL OF SPEECH PRODUCTION

The linear speech production model, the digital model of speech production, and the following two conclusions of Fant, Flanagan, Schafer [38-40, 87-89, 99]:

i) transfer function of the vocal tract has no zeroes for non-nasal speech sounds and the vocal tract can be adequately represented by an all-pole filter for these sounds;

ii) zeroes required by the vocal tract transfer function for nasals and unvoiced sounds lie within the unit circle in Z-plane and therefore each factor representing zeroes in the numerator of the transfer function can be approximated by multiple poles in the denominator;

and other speech researchers lead Atal and Hanauer [11-12] to develop the linear prediction model of speech production (**Fig. 3.6**). This model has the following distinct features:

a) The four control parameters of the model i.e., linear prediction coefficients (**a_j's**), position of the voiced/unvoiced (**V/UV**) switch, **pitch period P** of the voiced frame, and **gain G** (r.m.s. value of the speech samples) give complete representation of the speech waveform for a particular frame (speech segment during which the vocal tract configuration is assumed to be time-invariant is generally called *frame*).

b) The effects of the glottal flow, the vocal tract and the lip radiation are combined in a single all-pole recursive filter. If number of poles (**p**) is high enough, then this simplified all-pole model gives a good representation of almost all speech sounds. The additional advantage of the *all-pole model* is that all the control parameters of the model can be evaluated accurately and directly from the speech wave in a very straightforward and computationally efficient manner.

c) The all-pole model in the frequency-domain means that the current speech sample is *approximated* (or *predicted*) as a *linear combination* of the past **p** speech samples in the time-domain using the *linear prediction coefficients* as the *weighting* coefficients (This is where the name *linear prediction* comes from).

d) Speech can be encoded in terms of the four control parameters and can be synthesized from the control parameters in the same manner by a linear prediction synthesis model (L.P. Synthesizer, **Fig. 5.2,** Chapter V) proposed by Atal and Hanauer [11-12].

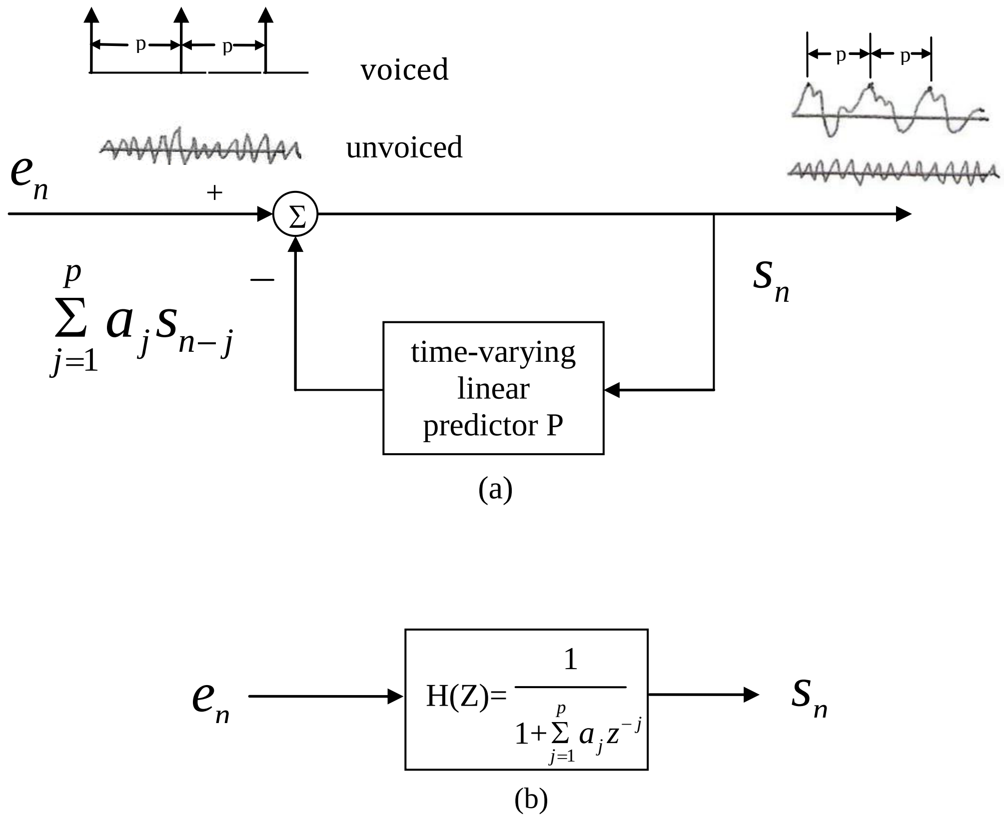

Figure 3.6: Linear prediction model of speech production
(a) Time-domain representation (b) Frequency-domain representation
(due to Atal and Hanauer [11-12, 74-76])

3.5. <u>SPEECH SIGNAL PROCESSING: A GRAND CHALLENGE</u>

Speech signal processing has been declared as one of the most interesting challenges by many authors in this field. Two representative examples are quoted here:

(1) According to Yegnanarayana [129, pp. 551], "Communicating with a machine in a natural mode such as speech brings out not only several technological challenges, but also limitations in our understanding of how people communicate so effortlessly. The key is to understand the distinction between speech processing (as is done in human

communication) and speech signal processing (as is done in a machine). When people listen to speech, they apply their accumulated knowledge of speech in relation to a language to capture the massage. In this process, it is interesting to note that the input speech is processed selectively using the knowledge sources acquired over a period of time such as sound units, acoustic-phonetics, prosody, lexicon, syntax, semantics and pragmatics. This processing varies from person to person, and it is difficult for any individual to articulate the mechanism he/she is using in processing the input speech. This makes it difficult to write a program to perform the task of extracting message in speech by a machine. It should be noted that, for a machine, only the speech signal is available in the form of a sequence of samples, the rest of the mechanism involving identification of knowledge sources and invoking them on the input signal is a scientific challenge. **Thus speech signal processing is one of the most interesting challenges** that arouse curiosity among different scientific groups, such as linguists, phoneticians, (psycho) acousticians, electrical engineers, computer scientists and application engineers."

(2) The Office of Science & Technology Policy (Washington, D.C., USA) has identified a group of fundamental problems in science and engineering as *Grand Challenges* for high performance computing. *Computerized Speech Understanding* is one of those grand challenges. Etter [36, pp. 8-10] covers at least five of these challenges as given below:

- Computerized Speech Understanding
- Human Genome or DNA (DeoxyriboNucleic Acid) Project
- Weather, Climate, and Global Change Prediction
- Vehicle Performance Improvement
- Enhanced Oil and Gas Recovery

It is with this background and understanding of one of the *most interesting challenges* and one of the *grand challenges* in mind that we are approaching Speech Signal Processing in the Punjabi Language.

3.6. CONCLUSION

The *Linear Prediction Model of Speech Production* has been specifically chosen for this project because of its merits and relatively simple characteristics as explained in this chapter, as well as explained earlier in the previous chapter (Section 1.7). Using this model, we have synthesized the Punjabi speech sentences in Chapter V.

■

CHAPTER IV
A NEW CORPUS IN THE PUNJABI LANGUAGE[3]

Digital signal processing [11-12, 15, 24-25, 79, 83, 85-90, 99-102] has been successfully applied to many types of signals including telecommunication signals, audio signals, image processing, radar signals, sonar signals, signals in geophysics, and speech signals. Digital speech processing includes many fields: (a) Speech analysis, e.g., linear prediction (LP) analysis [11-12, 52, 74-76] (b) Speech synthesis, e.g., LP synthesis, text-to-speech (TTS) synthesis (c) Speech enhancement or noise cancellation (d) Speech coding (speech storage and transmission) (e) Speaker separation (f) Speaker identification (g) Language identification (h) Automatic speech recognition (ASR) which also includes continuous speech recognition (CSR), discrete utterance recognition, and keyword spotting (i) Pitch and formant estimation (j) Aids-to-the handicapped, and many more. Most of these applications require reliable speech and text corpora as the starting point. In this chapter, a new text and speech corpus in the Punjabi language has been developed.

4.1. INTRODUCTION

Corpus plays the main role in any speech processing work (e.g., Speech Analysis and Synthesis, Language Engineering, Computational Linguistics, Cross-language Information Retrieval, Speech Recognition, Speech Translation, Multi-Lingual Lexicography, Developing Language-Learning tools). A *corpus* is a large body of text in the *natural state* as recorded speech or written text. The corpora in the *machine-readable form* are considered more useful and versatile than the corpora in their natural state because the machine-readable form of the corpora can be used, processed and manipulated in a variety of ways that are not possible with the natural formats. However, it is obvious that the *machine-readable form* of the corpora is derived from the corpora in the *natural state*, but not the other way around.

In this chapter, a new corpus for the Punjabi language has been designed.

The Punjabi was the native language of the Punjab state of undivided India. In 1947, when the British rulers partitioned India into two countries (India and Pakistan), the Punjab state was also bifurcated into two states: East Punjab (in India), and West Punjab (in Pakistan). Like any other language of the world, there are many dialects of the Punjabi language in both countries. Punjabi University (Patiala, India) published a list of 31 *dialects* of the Punjabi language (see Section 2.1.). The main dialects of the Punjabi language in India *are: Malwai, Majhi, Doabi, and Puadhi*, and the main dialects of the

[3] The results obtained in this chapter have been published in **International COCOSDA-2013 / CASLRE-2013 (Conference on Asian Spoken Language Research and Evaluation (**indexed and published in **IEEE Xplore),** and **International Symposium on Frontiers of Research on Speech and Music (FRSM-2012)**, Jan 2012, pp. 223-227.

Punjabi language in Pakistan *are: Multani, Pothohari, and Lehndi*. It will be an enormous task to design a corpus that can completely describe all dialects of the Punjabi language. This work, therefore, concentrates only on one dialect of the Punjabi language: the ***Malwai*** dialect.

The *Malwai* dialect has been chosen because of the five major reasons described in Chapter 1.

In the Punjab state of India, the Punjabi language is written in the *Gurmukhi* script, whereas in the Punjab state of Pakistan, the Punjabi language is written in the *Persian* (or *Shahmukhi*) script. Since the *Malwai* dialect in the Punjab state of India is written in the *Gurmukhi* script, consequently in the corpus designed in this chapter, the speech sentences have been *recorded* in the *Malwai* dialect of the Punjabi language, and the sentences have been *written* in the *Gurmukhi* script.

4.2. CORPUS DESIGN

Designing databases and corpora is generally considered the first major step in speech processing.

Corpora are generated by recording optimal set of textual words/sentences spoken by the native speakers of a particular language. We have used high quality microphones for the recordings of selected words and sentences. We have also maintained a pronunciation vocabulary by mapping each word to a sequence of sound units. The spoken language not only carries the linguistic information, but also conveys many features related to the nonlinguistic information such as the speaker’s emotions, gender, age, social status and cultural background.

The quality of the corpora and databases play a decisive role in determining the quality of the speech processing work based or tested on these corpora and databases. The speech processing work can be considered as a *building* constructed on the *foundation* of these corpora and databases. Apparently, a strong *building* cannot be constructed on a weak *foundation*. Many important attempts have been described in literature on the corpora design of Indian Languages.

Examples quoted in the literature, and published during the last 10 years are included in this work to convey the latest trends in the corpus design [2, 9, 51, 106, 120]. Out of the literature published on the corpus design, 16 representative papers are listed here:

five articles in [120]: V. N. Shukla (pp. 87-94); G. S. Lehal and Meenu Bhagat (pp.128-141); S. Chanda, S. Sinha and U. Pal (pp. 244-247); Om Vikas (pp. 280-300); Om Vikas (pp. 305-330);

five articles in [2]: S. S. Agrawal, K. Samudravijaya and Krunesh Arora (pp. 21-27); Sunita Arora, Krunesh Arora and S. S. Agrawal (pp. 122-126); Sunita Arora, Garima Sinha, Rohit Parashar and S. S. Agrawal (pp. 127-131); Deepak Dhiman, Samita Tayal, S. S. Agrawal and N. K. Sharma (pp. 303-305); Vijay K. Gugnani, Krunesh K. Arora, V. N. Shukla, Sunita Arora and Mohan Gour (pp. 317-322);

four articles in [51]: Shyam S. Agrawal, Karunesh K. Arora, Sunita Arora and Krishan K. Goswami (pp. 20-23); Shyam S. Agrawal, Karunesh K. Arora, Sunita Arora and K. Samudravijaya (pp. 94-97); Karunesh K. Arora, Sunita Arora and Shyam S. Agrawal (pp. 330-333); Sunita Arora, Karunesh K. Arora and Shyam S. Agrawal (pp. 176-179);

One article [9]: Krunesh Arora, Sunita Arora, Somi Ram Singla and S. S. Agrawal;

One article [106]: Paramjit Singh Sidhu.

4.3. EXAMPLES OF THE CORPORA

Some examples of the corpora in the Indian languages found in the literature [2, 9, 51, 106, 120] are included in this section. Two broad categories of corpora have been described in literature: (a) Text Corpora, and (b) Speech Corpora / Databases.

Amongst many other examples, the major examples of the ***text corpora*** include: Kolhapur Corpus of Indian English (KCIE), Technology Development for Indian Languages (TDIL) corpora project (Govt. of India), *E*nabling *Mi*nority *L*anguage *E*ngineering (EMILLE) corpus, Central Institute of Indian Languages (CIIL) corpus, GyanNidhi corpus of C-DAC, Department of Information Technology (DIT) consortia projects, and the *Hindi Samgraha* project of Mahatma Gandhi International Hindi University (MGIHU).

The major examples of the ***speech corpora / databases*** include the corpora developed at C-DAC (Centre for Development of Advanced Computing), C-DAC and Central Scientific Instruments Organization (CSIO), Indian Institute of Technology (IIT), Indian Institute of Science (IISc), International Institute of Information Technology (IIIT) and HP Labs, Central Electronics Engineering Research Institute (CEERI) and Tata Institute of Fundamental Research (TIFR), Central Forensic Science Lab (CFSL) and Centre for Artificial Intelligence and Robotics (CAIR), Kamrah International Institute of Information Technology (KIIT), Thapar University, and Punjabi University.

These representative examples discussed below have influenced many new corpora such as the one designed in this work.

4.3.1. Text Corpora

Several major examples of the ***text corpora*** are briefly discussed here.

1. Kolhapur Corpus of Indian English (KCIE)

This corpus is unanimously considered the first corpus in an Indian language. It was developed in 1988 at Shivaji University Kolhapur, India. It consists of One million words of Indian English.

2. TDIL corpora project (DIT)

The Govt. of India Department of Information Technology (DIT) has originated a large corpora design (more than one million machine-readable words for all major Indian languages) under its Technology Development for Indian Languages (TDIL) program in 1991.

3. Enabling Minority Language Engineering (EMILLE) corpus

This corpus has been developed as a result of a joint project between two countries, India and UK: CIIL Mysore (India) and the Lancaster University (UK). The complete details of this corpus can be found on the internet [151].

4. Central Institute of Indian Languages (CIIL) Corpus

CIIL, in addition to collaborating for developing the famous three component (monolingual, parallel, annotated) corpora project EMILLE [151] for the Indian Languages, has designed and collected linguistic material on dialects, dictionaries, grammars, phonetic readers, for approximately 120 languages, speech varieties, major languages, tribal languages, and relatively less known languages.

5. GyanNidhi Parallel Corpus

This corpus has been developed by the Centre for Development of Advanced Computing (C-DAC), Noida, India. It consists of more than one million pages of text in a total of twelve languages. The Punjabi language is one of these twelve languages. The other eleven languages *in alphabetical order* are Assamese, Bengali, English, Gujrati, Hindi, Kannada, Malayalam, Marathi, Oriya, Tamil, and Telugu.

6. Consortia Projects of Dept of IT (MoCIT DIT consortia projects)

Ministry of Communications and Information Technology (MoCIT), Govt. of India through its Department for Information Technology (DIT), has been organizing monolingual and parallel text corpora under various consortium projects.

7. The *Hindi Samgraha* project

This is a mega project originated by the Mahatma Gandhi International Hindi University (MGIHU).

4.3.2. Speech Corpora / Databases

Several major examples of the ***speech corpora /databases*** are briefly discussed here.

1. Centre for Development of Advanced Computing (C-DAC)

C-DAC is a dynamic organization sponsored by the Govt. of India. Operating from its headquarters in Pune, a total of ten centers of C-DAC located at (in alphabetical order) Bangalore, Chennai, Hyderabad, Kolkata, Mohali, New Delhi, Noida, Pune and Trivandrum have been actively engaged in speech and text corpora/database development.

C-DAC Noida has been working on the development of speech corpora in several languages including Hindi, Punjabi (a joint project in collaboration with CSIO) and Marathi languages. Using a statistical analyzer tool known as Vishleshika, C-DAC Noida has collected different categories of thousands of the most frequent words sets, phonetically rich sentence sets and prosodically representative sentence sets for natural language and speech processing projects in speech synthesis systems.

C-DAC Noida has collaborated with many other organizations, agencies, and institutions actively engaged in speech corpora development and related activities. CSIO, ELDA and DRDO can be quoted as three prime examples. C-DAC Noida has collaborated with Central Scientific Instruments Organisation (CSIO) Chandigarh for a versatile speech corpora development in the Punjabi language. It has collaborated with a France-based organization Evaluation and Language resources Distribution Agency (ELDA) to generate a 2000-speaker database in Hindi language recorded in different environments (e.g., homes, streets, public places, offices and moving vehicles), different age groups, different genders, different regions and different dialects. It has collaborated with SAG of DRDO (the Scientific Analysis Group of the Defence Research and Development Organization) to develop similar speech and text corpora for Hindi, Bengali and Manipuri languages.

Some examples of the speech corpora development of the other centers are as follows: **C-DAC Kolkata** has been developing speech corpora (similar to the ones described in the previous paragraph) in Bengali, Assamese, and Manipuri languages, **C-DAC Trivendrum** in Malayalam, Tamil, and Telugu languages, and **C-DAC Pune** in Urdu, Sindhi, and Kashmiri languages. However, out of all the C-DAC centres, **C-DAC Noida** is the only one working in the ***Punjabi language*** at present.

2. Indian Institutes of Technology (IIT) *at* Chennai, Delhi, Guwahati, Kanpur, Kharagpur, Mumbai

Almost all major Indian Institutes of Technology throughout India have been active in the speech corpora/database development in various Indian languages at one time or the other. Some examples are: Chennai (Hindi, Tamil, Telugu), Delhi (Hindi, Punjabi), Guwahati (Assamese, Manipuri), Kanpur (Hindi, Nepali), Kharagpur (Hindi, Marathi, Urdu) and Mumbai (Marathi, Konkani). IIT Mumbai is involved in designing the concatenation synthesis Text-to-Speech (TTS) system called *Vani*.

3. Indian Institute of Science (IISc), Bangalore

IISc, in addition to other speech corpora/database related activities, has been active in the development of a multichannel isolated word database for Indian English to be used in the telephone systems for speech recognition in Indian English.

4. Central Electronics Engineering Research Institute (CEERI) Pilani *and*

Tata Institute of Fundamental Research (TIFR), Mumbai

These two organizations have been developing the speech corpora/databases to be used in the testing and design of speech recognition and synthesis systems in several languages including Hindi, Marathi, and English. One prime example of their collaborative work is a speech corpus development to be used in the voice-operated Railway Reservation System.

5. Thapar University Patiala

Thapar University led a 7-8 member team of speech researchers between 2000 and 2004. The team worked on an 88.8 lakhs project known as the *Resource Centre for Indian Language Technology Solutions* for the Ministry of Communications and Information Technology (MoCIT) Govt. of India. The team developed **LIKHARI** (a *word processing* software tool for the Punjabi language) that later on led to a similar package **AKHAR** at the Punjabi University Patiala. It is interesting to note that LIKHARI means ***writer*** and AKHAR means ***word*** in the Punjabi language.

6. Punjabi University Patiala

The *Advanced Centre for Technical Development of Punjabi Language, Literature & Culture* at the Punjabi University Patiala has been active in a variety of projects as implied by the name of the centre. The corpus development for the Punjabi language has been an on-going activity with the major objective of Text-to-Speech (TTS) Synthesis.

7. Indian Institute of Information Technology (IIIT) Hyderabad

IIIT Hyderabad mainly concentrating on the speech corpora / databases developmental projects in Hindi and Telugu languages has also been dealing with other Indian languages.

8. Central Forensic Science Lab (CFSL) Chandigarh *and*

Centre for Artificial Intelligence & Robotics (CAIR) Bangalore

CFSL has designed a text independent Speaker Identification database (SPID) for forensic applications for English, Hindi and Punjabi languages. Two more examples of the CFSL corpora development work include: a corpora recording in Hindi, Indian English and Punjabi languages with native speakers of Punjabi, and another corpora in Hindi, Indian English and Kannada languages with native speakers of Kannada. The two organizations (CFSL and CAIR) have joined hands to expand this speech corpora/database development work to 10 Indian languages with 10 different channels, distortion, and several disguises to address the specific needs of the forensic applications.

9. Kamrah International Institute of Technology (KIIT) Gurgaon

This institution has been developing a multilingual corpus consisting of more than 10000 sentences and words in Punjabi, Hindi, Nepali and Indian English languages.

In addition to the above well-known projects and institutions, other organizations known to be developing task-oriented special-purpose databases in India or several other corpora development projects mentioned in the literature include:

1. HP Labs (in collaboration with IIIT Hyderabad) working for the Automatic Speech Recognition (ASR) and Text-to-Speech (TTS) applications in Hindi, Assamese and Indian English

2. Utkal University Bhubneswar (Oriya)

3. Aligarh Muslim University (AMU), Aligarh (Hindi, Urdu, Arabic)

4. Bharati Vidyapeeth, Pune (Speech synthesis word concatenation system database for Marathi)

5. Prologics, Lucknow [51, pp. 94-97]

6. Bhrigus Software (I) Pvt. Ltd. Hyderabad [51, pp. 94-97]

7. Interactive Communications Systems (ICS), Hyderabad [51, pp. 94-97]

The institutions actively involved in the text and speech corpora / databases developmental work for the Punjabi language (present and past) *in India* include Punjabi University Patiala, Thapar University Patiala, C-DAC Noida & CSIO, KIIT, CFSL & CAIR, IIT Delhi, and CIIL Mysore. The representative examples described in this section have been the *continuous* source of inspiration for the development of many new corpora such as the one designed in this work.

At present, the major challenges for the research in speech processing in the Punjabi language include the corpora development, and the efficient coding of these corpora. This thesis addresses these two issues in Chapter II and Chapter IV. The aim of this chapter is to develop a new and representative text and speech corpus in the ***Malwai*** dialect of the Punjabi language.

4.4. OVERVIEW OF THE NEW CORPUS

The new corpus designed in this work is discussed in the following sections. This corpus consists of approximately 300 items (sentences, and single line folk songs known as ***bolis***). The corpus is divided into two parts: *Part A* and *Part B*. **Part A** consists of about 200 items (mainly sentences and about **10 *bolis***), whereas **Part B** consists of slightly more than 100 ***bolis***. This section presents an overview of both parts of the corpus. The first part ***(Part A)*** of the corpus consists of 52 sets of the Punjabi speech sentences: one set for each of the **35** letters in the Gurmukhi script, one set for each of the **6** letters with a dot, known as *bĩdi* (.) placed below a letter symbol, and one set each for three conjunct consonants [h], [r], and [v]. The 45th set includes sentences with short and long forms of some words leading to different meanings due to this variation in the length of the pronunciation. The 46th set includes sentences that describe the tonal nature of the Punjabi language using the phoneme ***h*** (ਹ). The next (47th) set demonstrates the contrast between the five pairs of ten Gurmukhi vowels: ਅ, ਆ; ਇ, ਈ; ਉ, ਊ; ਓ, ਔ; ਐ, ਏ. The last five (48th to 52nd) sets concentrate on the five *tonemes* (ਘ, ਝ, ਢ, ਧ, ਭ) to illustrate the *tonal* nature of the Punjabi language. These five sets illustrate the contrasts between five *tonemes* and the five letters immediately preceding these *tonemes* as follows: ਗ/ਘ; ਜ/ਝ; ਡ/ਢ; ਦ/ਧ; ਬ/ਭ. The second part ***(Part B)*** of the corpus consists of 35 sets of ***bolis*** (each set includes several items). Each item in this corpus concentrates on something special about the Punjabi language, the Gurmukhi script, or the ***Malwai*** dialect.

Since this corpus will be mainly used for the linear prediction analysis and synthesis of the Punjabi speech sentences, so the ***complete sentences*** (rather than *words* only) have been designed in this corpus. All categories and phonetic characteristics of the speech sounds (e.g., voiced, unvoiced, nasals, non-nasals, aspirated, unaspirated) spoken by the male and female speakers from different villages and cities of several districts of the ***Malwa*** region of the Punjab state of India have been tape-recorded. In particular, sentences demonstrating tones, pairs of words with almost similar sounds, conjunct consonants, reduplication, and extended pronunciation have been included. Some lines of the popular folk songs have been used in their *original* form, whereas some lines have been used in the *modified* form (see section **4.7.8**). Similarly, some single line folk songs (***bolis***) have been used unaltered. Some new ***bolis*** have been written since the author [26-30] is a creative writer. The new ***bolis***, written by the author, end with the symbol *double dandi* (॥) to emphasize the originality of these ***bolis***. Some words that are slowly fading out from everyday use as well as some *ṭheṭh pendu shabads* (rustic words) and expressions have been recorded in the corpus.

In addition to ***Malwain*** (a female of the ***Malwa*** region) and ***Punjaaban*** (a female of the ***Punjab*** state), the names of several villages and cities of the ***Malwa*** region prominently appear in the ***bolis*** to highlight the fact that this work concentrates on the

Malwa region of the Punjab state in India. Some cities outside of the ***Malwa*** region and the ***Punjab*** state have also been mentioned in some ***bolis*****.** Many popular names/nick-names for ***Malwai*** males and females, the names of several freedom fighters, trees/crops, birds, insects, and animals, and jewelry items of the ***Malwa*** region have been prominently mentioned throughout the corpus.

The examples included in this chapter are sentences and ***bolis*** in the Punjabi language (written in the Gurmukhi script), followed by coding in International Phonetic Alphabet (IPA). In some cases, the examples have *also* been transcribed by using the newly designed ARPAbet-compatible phonetic coding scheme called ***PUNJARPAbet*** (designed in Chapter II). The complete corpus is given in Appendix A and Appendix B, where *each* sentence is transcribed in three different ways: the Punjabi language (Raavi), IPA, and ***PUNJARPAbet***. Various categories of users (readers knowledgeable in the Punjabi language in Gurmukhi script, linguists knowledgeable in IPA, and the scientists knowledgeable in ***PUNJARPAbet***) can equally understand and benefit from the corpus.

4.5. RECORDING OF THE NEW CORPUS

Speech sentences spoken by *different* Punjabi speakers from *different* villages and cities of *different* districts of the ***Malwa*** region of the Punjab state of India have been recorded using a cassette tape recorder as follows:

CASSETE I:

SIDE A
Speaker 1: Ranjit Singh, Male, 33 years, Longowal (Sangrur), 23 July 2007
Speaker 2: Gian Singh, Male, 48 years, Bahadurpur (Sangrur), 23 July 2007
Speaker 3: Daljit, Male, 58 years, Bathinda, 24 July 2007
Speaker 4: Seereen, Female, 25 years, Bathinda, 24 July 2007
Speaker 5: Surinderpal Kaur, Female, 54 years, Bathinda, 24 July 2007

SIDE B
Speaker 6: Swaranjit Kaur, Female, 26 years, Bhang Jadee (Mukatsar), 24 July 2007
Speaker 7: Gurpreet Kaur, Female, 26 years, Lambee Dhab (Mukatsar), 24 July 2007
Speaker 8: Gurdev Singh, 24 years, Ferozepur, 25 July 2007
Speaker 9: Surinder Kaur Mann, Female, 53 years, Faridkot, 25 July 2007
Speaker 10: Swaranjit Kaur, Female, 58 years, Mansa, 25 July 2007

CASSETE II:

SIDE A
Speaker 11: Talwinder Singh, Male, 39 years, Ferozepur, 25 July 2007
Speaker 12: Tek Singh, Male, 70 years, Mala Kalan (Moga), 25 July 2007

Speaker 13: Davinder Kaur, Female, 48 years, Samana (Patiala), 26 July 2007

SIDE B
Speaker 14: Bhim Raj Bansal, Male, 65 years, Barnala, 9 August 2012
Speaker 15: Surinderpal Singh, Male, 62 years, Ludhiana, 10 August 2012

Age Group:

Males: 24, 33, 39, 48, 58, 62, 65, 70
Females: 25, 26, 26, 48, 53, 54, 58

Fifteen speakers were chosen at random from the various segments of the society (students, workers, professionals, villagers, and city residents) so that the corpus is as representative as practical. These speakers were from ***ten*** different districts of the *Malwa* region of the Punjab state (*in alphabetical order*) as follows: Barnala, Bathinda, Faridkot, Ferozepur, Ludhiana, Mansa, Moga, Mukatsar, Patiala, *and* Sangrur.

4.6. TECHNICAL CONSIDERATIONS

Technical considerations for recording the speech data include *sampling frequency* and *resolution*.

4.6.1. Sampling Frequency

If the highest frequency present in an analog signal is represented by f_n, and the sampling frequency is represented by f_s, then according to Shannon's Sampling Theorem, any digital sequence generated from the analog signal using the sampling frequency f_s that satisfies the inequality ($f_s \geq 2 f_n$) is sufficient to represent the original analog signal. If this inequality is not satisfied, then a phenomenon commonly known as ***aliasing*** occurs resulting in distortion when the analog signal is reconstructed from the corresponding digital (sampled) sequence. Other way of stating this is that *aliasing* is a problem that is caused by ***undersampled systems*** (sampling too slow), where a frequency higher than f_n assumes the identity (or ***alias***) of a lower frequency.

A related term is the ***Nyquist frequency*** (named after Harry Nyquist). It is half the sampling frequency (f_s) and represents the upper bound on the frequencies that should be contained in the digital signal. The *Nyquist frequency* is also known as the ***folding frequency*** of a sampling system. If $f_s = 2 f_n$, i.e. the sampling frequency is exactly equal to twice the highest frequency, then the sampling is said to be at the ***Nyquist rate***.

It is better to choose the sampling rate f_s to be slightly greater than $2 f_n$ to account for the practical hardware limitations. In case $f_s > 2 f_n$, then the analog signal is said to be ***oversampled.***

Four natural sampling frequencies (6.4 *kHz*, 8 *kHz*, 10 *kHz*, 16 *kHz*) have been used in practice [Rabiner and Schafer, 89, pp. 18-19] as summarized in **Table 4.1**.

Table 4.1: Speech Bandwidth

Speech Bandwidth	f_n (kHz)	f_s (kHz)
Telephone:	3.2	6.4
Extended Telephone	4	8
Oversampled Telephone	5	10
Wideband (hi-fi)	8	16

4.6.2. Resolution

In addition to the ***sampling frequency***, the second parameter is the ***resolution*** or ***word size*** used for recording data. Two values (8-bit or 16-bit) are in general use in commercially available systems for the *resolution*. The 8-bit resolution ranges from -2^7 to $+(2^7 - 1)$, whereas the 16-bit ranges from -2^{15} to $+(2^{15} - 1)$. For an efficient VoCoder consideration from the viewpoint of low bit rate transmission (see Section **5.5.3**), it is customary to use 8-bit resolution at the cost of slightly degraded quality of the speech.

These two parameters (***sampling frequency*** and ***resolution***) must be known in order to play the recorded sound (speech or music) data files. In this project, the values of f_s = 8 *kHz,* and 8-bit resolution have been used.

4.7. <u>ORIGINAL FEATURES OF THE NEW CORPUS</u>

This corpus consists of at least ***twenty*** original features. The features of this corpus have been described (exemplified with words in **bold,** wherever appropriate) in this section as follows:

4.7.1. Uniqueness

Each item of the corpus is unique. Each sentence/***boli*** in the corpus has been carefully designed so as to convey something new and special about the Punjabi language [10, 13-14, 21, 95-97, 111, 116, 128], Malwai dialect [140], Gurmukhi script [78, 107, 109-111, 118], Phonetics, vowels, consonants, and vowels signs (aka *matras* or *accessory signs* or *diacritical marks*) by using a wide variety of vocabulary, idioms and expressions. In particular, a special feature called **Anupras Alankar (ਅਨੁਪ੍ਰਾਸ ਅਲੰਕਾਰ)** has been used throughout the development of the corpus (*Anupras* means “alliteration”). According to Wikipedia [155]: “In language, ***alliteration*** is the repetition of a particular sound in the *prominent lifts* (or stressed syllables) of a series of words or phrases.” Consequently, the *Anupras Alankar* means the repeated usage of a word or a letter to enhance the artistic beauty of a piece of literature. In Indian languages and literature, the Anupras Alankar has been used for centuries. The idea behind the usage of the Anupras Alankar in *this work* is that the repeated use of a letter will enable the user to thoroughly analyze and synthesize the corresponding phoneme in a single item. Two examples from the new corpus (predominantly making use of the letters ਸ and ੜ respectively) to illustrate *Anupras Alankar* using the ***PUNJARPAbet*** are given below:

> ਸੁਘੜ ਸੁਡੌਲ ਸੁਨੱਖੀ, ਢੋਲਣਾ ਨਹੀਂ ਲੱਭਣੀ॥
>
> sÚgəṛ sUḍɔl sUnəkkhi, ṭòlṇa nəhĩ ləbbəṇi.
> /S UH hG AH RH - S UH D: AO L - S UH N AH KKH IY, T:l OW N: AA - N AH H IHn - L AH hBB N: IY./
>
> ਪੌੜੀ ਚੜ੍ਹਗੀ ਮੜਕ ਨਾਲ ਲੜ ਕੇ, ਕਾੜ ਕਾੜ ਬੂਹਾ ਭੰਨਗੀ॥
> pɔṛi cə́ṛgi məṛək naḷ ləṛ ke, kaṛ kaṛ buha pə̀nngi.
> /P AO RH IY - CH AH hRH G IY - M AH RH AH K - N AA L –
> L AH RH - K EY, K AA RH - K AA RH - B UW H AA - Pl AHn NN G IY./

4.7.2. Speech Sounds

All categories and phonetic characteristics of the speech sounds (e.g., voiced, unvoiced or voiceless, nasals, non-nasals, aspirated, unaspirated) have been recorded. All places of articulation (bilabials, labiodentals, dentals, alveolars, retroflexes, palatals, velars, uvulars, pharyngeals, and glottals) and manners of articulation (plosives, affricates, nasals, fricatives, laterals. rolled, flapped, and semi-vowels) have been represented throughout the corpus [131].

4.7.3. Selection of the words and sentences

The words and sentences used in the corpus have been selected from books written by the *Sahitya-Academy Award* winner writers [147] of the ***Malwa*** region (The Sahitya-Academy Award is the highest literary award administered by the Government of India).

The words and sentences have been selected from several books where the word ***Malwa*** is included in the title of the book [5, 64, 98, 103-105, 112-114, 140]. In particular, the ***bolis*** have been selected from the books by Sidhu [103], and N. Singh [112-114].

4.7.4. Tones (ਘ, ਝ, ਢ, ਧ, ਭ, ਹ)

Punjabi is a tonal language [14,16-19,48,96,129]. Tonal languages make use of the relative pitch variations to signal lexical differences [129, pp. 596-597]. About a century ago (in 1914), T. Grahame Bailey [14, pp. xv] stated: “Variations in the tone of the voice form a very remarkable feature of Panjabi pronunciation. There are two special tones, apart from the ordinary tone of speaking. They occur in stressed syllables only.” In the later paragraphs on the same page, Bailey [14] calls the ***two*** special tones *mentioned* *above* as (a) low rising tone *or* rising-falling tone (b) high falling tone. The **voiced aspirates** (ਘ, ਝ, ਢ, ਧ, ਭ) in the *initial position* of words and stressed syllables represent the **unaspirated voiceless** (ਕ, ਚ, ਟ, ਤ, ਪ) followed by a low tone. For the *non-initial (middle/medial or final) positions* of the voiced aspirates (ਘ, ਝ, ਢ, ਧ, ਭ), there is a high tone on the vowel before the **voiced unaspirated** (ਗ, ਜ, ਡ, ਦ, ਬ), or a low tone on the vowel following the **voiced unaspirated** (ਗ, ਜ, ਡ, ਦ, ਬ). Five sets (set numbers 48-52) in the corpus have been designed to illustrate these *tonemes*. We present here two example sentences from the corpus whereas more examples will follow later:

1. ਬਘਿਆੜ ਮੇਘੇ ਘੁਮਿਆਰ ਦਾ ਘੋੜਾ ਖਾ ਗਿਆ।

   bəgIàṛ mége kÙmIar da kòṛa kha gIa.
   /B AH Gl IH AA RH - M EY hG EY - Kl UH M IH AA R - D AA -
   Kl OW RH A - KH AA - G IH AA/

2. **ਪਾਂਧੀ** ਦਾ **ਪੰਧ ਪੱਧਰਾ**, **ਧੁੰਦ ਧਰਮਾਂ** ਦੀ **ਵੱਧ**॥

   pā́di da pə̃́d pə́ddəra, tǜdd tə̀rəmã di və́dd.
   /P AAn hD IY - D AA - P AHn hD - P AH hDD AH R AA, Tl UWn DD -
   Tl AH R AH M AAn - D IY - V AH hDD./

The consonantal value of letter ਹ represents the phoneme /h/ when initial. The non-initial ਹ or the conjunct consonant ਹ, in several words, is replaced with the appropriate high or low tone. Two examples from the corpus (set 46) are:

1. ਪਾਣੀ **ਪੀ** ਕੇ ਚੱਕੀ **ਪੀਹ**।

   paṇi pi ke cəkki pí.
   /P AA N: IY - P IY - K EY - CH AH KK IY - P IYh/

2. **ਵਰ ਹਾਣ** ਦਾ ਕੁੜੀ ਨੂੰ ਮਿਲ਼ ਜੇ, ਟਿੱਬੀ ਉਤੇ **ਮੀਂਹ ਵਰ੍ਹ** ਜੇ॥

   vər **haṇ** da kUṛi nũ mIḷ je, ṭIbbi Utte **mĩ́ və́r** je.
   V AH R - H AA N: - D AA - K UH RH IY - N UWn - M IH L̲ - J EY,
   /T IH BB IY - UH TT EY - M IHnh - V AH hR - J EY/

4.7.5. Reduplication (use of *ə́dək*)

In the corpus, several sentences have been designed to demonstrate that the meaning of a word can change with the addition of the sign called (*ə́dək*) as in ਪਤਾ (means *address*) and ਪੱਤਾ (means *leaf*). Gill and Gleason [43] state: "Gemination is written by the sign /əddək/ above and before the consonant to be doubled." According to Bahri [13]: "Long (or double) consonants have an overhead crescent sign, called *adhak*, before them." The following pairs of words are good examples of the effects of the *reduplication*:

ਪਤਾ/ਪੱਤਾ, ਦਸ/ਦੱਸ, ਘਟਾ/ਘੱਟਾ, ਰਸਾ/ਰੱਸਾ, ਕਟੀ/ਕੱਟੀ

4.7.6. Extended Pronunciation (ਲਮਕਵਾਂ ਉਚਾਰਣ)

Examine the pair of words *italicized* and in **bold** in the following sentences from the corpus:

1. ***ਭਰਾ*** ਜੀ! ਫੂਕ ***ਭਰਾਅ*** ਲੀ?

   pə̀ra ji! phuk pə̀raə li?
   /Pl AH R AA - J IY! PH UW K - Pl AH R AA AH - L IY?/

2. ***ਖੜਕਾ***ਦੜਕਾ ਹੋ ਜੂ ਕੁੜੀਏ! ਨਾ ***ਖੜਕਾਅ***ਨੀ ਕੁੰਡਾ ॥

   khəṛka dəṛka ho ju kuṛie! na khəṛkaə ni kŨḍḍa.
   /KH AH RH K AA - D AH RH K AA - H OW - J UW - K UH RH IY EY!
   N AA - KH AH RH K AA AH - N IY - K UHn D:D: AA./

Several sentences in the corpus (set 45) have been designed to demonstrate that in these pairs of words, the meaning of the word changes with the addition of /ਅ/ at the end of the word, and its pronunciation is also extended. That is why the new term ***Extended Pronunciation (ਲਮਕਵਾਂ ਉਚਾਰਣ)*** has been coined by the author for this feature of the Punjabi language.

4.7.7. Popular Folk Songs

Some lines of the popular folk songs have been used in the *original* form. One example is from a Punjabi movie song:

ਘੁੱਟ ਪਾਣੀ ਪਿਆ ਦੇ ਨੀ, ਸੋਹਣੀਏਂ ਘੜਾ ਭਰੇਂਦੀਏ ਨਾਰੇ

kÙṭṭ paṇi pIa de ni, sónie kə̀ṛa pèrẽdie nare
/Kl UH T:T: - P AA N: IY - P IH AA - D EY - NIY, S OWh N: EYn -
Kl AH RH AA- Pl AH EYn D IY EY- N AA R EY/

4.7.8. Modified form of Folk Songs

Some lines of the popular folk songs have been used in the *modified* form. One example from the corpus is:

ਘੁੱਗੂਆ ਟਾਹਲੀ 'ਤੇ, ਘੁੱਗੀ ਕਰੇ ਘੂੰ ਘੂੰ॥
kÙggua ṭàli 'te, kÙggi kəre kù̃ kù̃.
/Kl UH GG UW AA - T: AAh L IY - 'T EY, Kl UH GG IY - K AH R EY - Kl UWn - Kl UWn/

In the above example, the word ਜ਼ਾਲਮਾਂ in the original ***boli*** was changed to ਘੁੱਗੂਆ, because new ***boli*** of the corpus was designed to study the *tonal* letter /ਘ/.

4.7.9. Bolis (Single line Folk Songs)

Some single line folk songs (***bolis***) have been used. Two examples from the corpus (Part B) are given below:

1. ਚੰਨ ਭਾਵੇਂ ਨਿੱਤ ਚੜ੍ਹਦਾ, ਸਾਨੂੰ ਸੱਜਣਾਂ ਦੇ ਬਾਝ ਹਨੇਰਾ
   cə̃nn pàvẽ nItt cə́ṛda, sanũ səjjəṇa de báj hənera

2. ਛੋਟਾ ਦਿਓਰ ਬੜਾ ਟੁੱਟ-ਪੈਣਾ, ਹੱਸਦੀ ਦੇ ਦੰਦ ਗਿਣਦਾ
   choṭa dIor baṛa ṭUṭṭ-pɛṇa, həssədi de də̃d gIṇda

4.7.10. New Bolis

More than 40 new ***bolis*** have been written (The author [26-30] is a creative writer, and has published five books of original Punjabi poetry). The new ***bolis***, written by the author, end with the symbol *double dandi* (॥) to emphasize the originality of these ***bolis***. Five examples are given below. These new ***bolis*** also illustrate the occurrence of each of the five *tonemes* (ਘ, ਝ, ਢ, ਧ, ਭ) in the initial, middle (medial), as well as the final positions (words in **bold** below) in a single ***boli***:

1. **ਘੁੰਡ** ਕੱਢ **ਪੀਂਘ** ਝੂਟਦੀ, ਵਾਲ਼ **ਸੰਘਣੇ** ਕਲੋਲਾਂ ਕਰਦੇ॥
   kÙ̃ḍ kə́ḍḍ pĩ́g cùṭdi, vaḷ sə̃́gṇe kəlolã kərde.
2. **ਬਾਝ** ਨਸੀਬਾਂ ਦੇ, **ਬੁਝਣ ਝਨਾਂ** ਦੇ ਦੀਵੇ॥
   báj nəsibã de, bÚjəṇ cə̀nã de dive.
3. **ਢਿੱਲੋਂ ਕੱਢਦਾ** ਗੇੜੇ, ਪਾਣੀ ਪੀ **ਠੰਢਾ**॥
   ṭÌllõ kə́ḍḍəda geṛe, paṇi pi ṭhə̃́ḍa.
4. **ਧੰਦੇ ਵਧਗੇ ਧਨ** ਕੁਰੇ ਤੇਰੇ, **ਕੰਧਾਂ** ਵਿੱਚ ਕੈਦ ਹੋ ਗਈ॥
   tə̀̃de və́dge tə̀n kUre tere, kə̃́dã vIcc kɛd ho gəi.
5. **ਭਿੱਜਗੀ ਭਾਗਭਰੀ, ਸਾਂਭ** ਲਈਂ **ਭਰਜਾਈਏ**॥
   pÌjjgi pàgpə̀ri, sã́b ləĩ pə̀rjaie.

4.7.11. Rustic Words and Expressions

Some *ṭheṭh pendu shabads* (rustic words) and expressions that are slowly fading out from everyday use have been included in the corpus. Fading letters (e.g., ਙ, ਞ) have also been included. Some examples of the fading words and expressions are:

1. ਚੇਤੂ **ਚੌਰੇ** ਨੇ **ਚਕਚੂੰਧਰ** ਚਲਾਅ ਕੇ ਚਾੜ੍ਹਤਾ ਚੰਦ?
   cetu cɔre ne cəkcũ̀dər cəlaə ke cáṛta cə̃d?
2. ਚੋਰਾ! ਚੈਂ ਚੈਂ ਚੀਂ ਚੀਂ ਛੱਡ, **ਚੂਕਣੇਂ ’ਚ ਚਾਰ ਠੋਕੂੰ**!
   cora! cɛ̃ cɛ̃ cĩ cĩ chəḍḍ, cukṇẽ ’c car ṭhokũ!
3. ਚੰਨੇ ਨੂੰ ਚੰਨਾ ਸਾਹਮਣਾ, ਉੱਤੇ **ਕਾਂਞਣ** ਸਿੱਧੀ ਸਤੀਰ।
   cə̃nne nũ cə̃nna sámṇa, utte kã̄ɲəṇ sÍddi sətir.
4. **ਟੁੱਕ-ਟੇਰ** ਨੇ **ਟਟੀਹਰੀ ਆਂਙੂੰ** ਅਸਮਾਨ ਥੰਮ੍ਹਿਆ।
   ṭUk-ṭek ne ṭəṭíri ãŋũ əsman ṭhə̃́mmIa.

4.7.12. Variety of Speakers (sex and age)

Speech sentences spoken by ***fifteen*** adult male and female speakers (age range: 24 – 70 years) have been recorded for the *speech corpus*.

4.7.13. Variety of Speakers (location and districts)

Speech sentences spoken by ***fifteen*** Punjabi speakers from different villages and cities of ***ten*** districts of the ***Malwa*** region of the Punjab state of India have been recorded for this *speech corpus*. These districts (*in alphabetical order*) include: Barnala, Bathinda, Faridkot, Ferozepur, Ludhiana, Mansa, Moga, Mukatsar, Patiala, Sangrur.

4.7.14. Names of Places

In addition to ***Malwain*** (a female of the ***Malwa*** region) and ***Punjaaban*** (a female of the ***Punjab*** state), the names of ***twenty-four*** villages and cities of the ***Malwa*** region (*in alphabetical order:* Barnala, Dakha, Dangon, Daudhar, Duggri, Faridkot, Jagraon, Jaito, Jangpur, Jarg, Kaunke, Kotkapura, Ludhiana, Maurh, Moga, Mohi, Mukatsar, Nabha, Pandori, Patiala, Raikot, Sanghera, Sarabha, Sunam) prominently appear in some of the ***bolis*** and sentences of the corpus to highlight the fact that this work concentrates on the ***Malwa*** region of the Punjab state in India. Four examples are:

1. ਹਾਰੀਂ ਨਾ **ਮਲਵੈਣੇ**, ਗਿੱਧਾ ਹਾਰ ਗਿਆ
   harĩ na məlvɛṇe, gÍdda har gIa
2. ਧਮਕ ਪਵੇ ਸਰਕਾਰੇ, ਅਣਖ **ਪੰਜਾਬਣ** ਦੀ॥
   tə̀mək pəve sərkare, əṇəkh pə̃jabəṇ di.

3. **ਜੈਤੋ** ਦਾ ਕਿਲਾ ਟਪਾ ਦੂੰ, ਜੇ ਕੱਢੀ ਮਾਂ ਦੀ ਗਾਲ਼ ਵੇ

   jɛto da kIla ṭəpa dũ, je kə́ḍḍi mã di gaḷ ve

4. ਤਿੰਨ ਪਿੰਡ ਕੰਜਰਾਂ ਦੇ: **ਮੋਹੀ**, **ਜਾਂਗਪੁਰ**, **ਦਾਖਾ**

   tĨn pĨd kə̃jrã de: mohi, jãgpUr, dakha

The above examples include references to *four places* in the Punjab state (Jaito, Mohi, Jangpur, Dakha) in addition to the prestigious words ***Malwain*** and ***Punjaaban***.

4.7.15. Slang Names of Places

Some ***bolis*** mention the name of the city of *Ludhiana* as ***Ludhehana***, since the ***Malwai*** people pronounce *Ludhiana* as ***Ludhehana.*** Similarly, places named *Barnala, Faridkot, Jagraon, Moga, Mukatsar* and *Raikot* have also been used in the corpus in their slang form as follows: Barnale = *to/in/from* Barnala, Faridkotia = A person *from* Faridkot, Faridkoto(n) = *from* Faridkot, Jagrava(n) = Jagraon, Mogio(n) = *from* Moga, Muksar = Mukatsar, Raikotee = A person *from* Raikot.

One *boli* mentions the name of *Amritsar* as ***Ambarsar***, since the ***Malwai*** people pronounce it as ***Ambarsar*** (the city of *Amritsar* is in the *Majha* region and not in the ***Malwa*** region of the Punjab state). *Sanghoḷ* (of the *Puadh* region) has also been mentioned in the corpus. Cities outside of the Punjab state (Delhi-India, and London-UK) have also been mentioned in the corpus. *Five* illustrating examples are given below from the corpus:

1. **ਮੁਕਸਰ** ਮੌਜਾਂ ਮਾਨਣ ਨੂੰ ਮੰਤਰ ਪੜ੍ਹਨੇ ਆਂ?

   mUksər mɔjã manəṇ nũ mə̃tər pə́ṛne ã?

2. ਘੰਟਾ ਘਰ **ਸੰਘੋਲ਼** ਵਾਲ਼ਾ ਖੂਹ ਘੱਟ ਡੂੰਘੈ

   kə̃̀ṭa kə̀r sə̃gòḷ vaḷa khú kə̀ṭṭ ḍű̃gɛ

3. ਜੱਟੀ **ਕੋਟਕਪੂਰੇ** ਦੀ, ਤੇ ਬ੍ਾਮਣ **ਅੰਬਰਸਰ** ਦਾ

   jəṭṭi koṭkəpure di, te bámən̩ ə̃bərsər da

4. **ਲੁੱਦੇਹਾਣੇ** ਕੋਲ਼ ਦੁੱਗਰੀ, ਰੀਸ **ਦਿੱਲੀ** ਦੀ ਕਰਦੀ

   lUddehaṇe koḷ dUggəri, ris dIlli di kərdi

5. **ਊਧਮ** ਵੀਰੇ ਦੀ, ਧੁੰਮ **ਲੰਡਨ** ਵਿੱਚ ਪੈ ਗੀ॥

   údəm vire di, tÙmm lə̃ḍən vIcc pɛ gi.

4.7.16. Popular Names and Nick-names

Many popular names and nick-names for the ***Malwai*** males and females are included in various parts of the corpus. Some examples of the male names are as follows: Amar, Ishar, Inder, Shera, Sunder, Seva, Sadhu, Himat, Hukma, Kewal, Kaila, Kharhak Singh, Genda, Jagira, Ginder, Megha, Chetoo, Chhinda, Jotee Jindal, Juala, Jhanda, Tehala, Thakar, Dogar, Dheroo, Kundha, Ganda Singh, Thamman, Dulloo, Dheedo, Pooran, Phakeereea, Phumman, Phaggoo, Bhola, Maghar, Suchcha, Khushia, Jindua, Ghudda, Jeonha Maurh, Bachana, Modan, Munshee. One sentence is given here as an example where the predominant phoneme is [ਫ] = [ph], and the *male* name **ਫਕੀਰੀਆ (**phəkiria) has been used in its slang form as **ਫਕੀਰੀਏ** (phəkirie):

> **ਫਕੀਰੀਏ** ਦਾ ਫੁੱਫੜ ਫਰੀਦਕੋਟੋਂ ਆਇਆ ਸੀ।
>
> phəkirie da phUphəṛ phəridkoṭõ aIa si.

Some examples of the female names included in the corpus are: Bachno, Bhago, Bhindo, Bhag Bharee, Bindo, Billo, Dhan Kur, Gelo, Jamalo, Jeeto, Jindro, Mindo, Nimmo, Ranhi, Ranho, Tarsemo. One example ***boli*** involving the *female* name **ਜੈ ਕੁਰੇ** (jɛ kUre) is given here:

> ਹਾਕਾਂ ਮਾਰਦੇ ਬੱਕਰੀਆਂ ਵਾਲ਼ੇ, ਦੁੱਧ ਪੀ ਕੇ ਜਾਈਂ **ਜੈ ਕੁਰੇ**
>
> hakã marde bəkkəriã vaḷe, dÚdd pi ke jaĩ jɛ kUre

4.7.17. Freedom Fighters (Martyrs)

Young freedom fighters *Shaheed* Kartar Singh Sarabha, *Shaheed* Bhagat Singh, and *Shaheed* Udham Singh Sunam (*Shaheed* means *Martyr*), who sacrificed their lives during the independence struggle before 1947 are very popular amongst the youth of the ***Malwa*** region. They were hanged by the then British Rulers of India in November 1915, March 1931, and July 1940 *respectively*. It is just a coincidence that Kartar Singh Sarabha and Udham Singh Sunam were born in the Ludhiana and the Sangrur Districts of the ***Malwa*** region *respectively*. All three of them have been respectfully mentioned in several sentences and ***bolis*** in this corpus. Two examples are given below:

1. **ਜੰਞ** ਚੜ੍ਹਗੀ **ਸਰਾਭੇ ਕਰਤਾਰ** ਦੀ, ਛੇ ਸਰਬਾਲ੍ਹੇ ਸਜਗੇ॥

   jə̃ɲ cə́ṛgi sərábe kərtar di, che sərbále səjge.
2. **ਊਧਮ, ਭਗਤ, ਸਰਾਭੇ**, ਫਾਂਸੀ ਹੱਸ ਚੜ੍ਹਦੇ॥

   údəm, pə̀gət, sərábe, phãsi həss cə́ṛde.

4.7.18. Trees/weeds/crops

The following trees, weeds, and crops are either grown by seeding or naturally grown as weeds in the ***Malwa*** region: ਨਿੰਮ **(**Margosa Tree), ਬੇਰੀ **(**Jujube Tree), ਤਰ (a kind of oblong fruit, a kind of cucumber). ਤਰਬੂਜ਼ (water melon), ਆਲੂ **(**Potato**)**, ਲੌਂਗ (Clove)**,** ਸਰ੍ਹੋਂ **(**Rapeseed plant or crop, Black mustard), ਸਾਗ **(**a leafy vegetable: often mustard leaves),

ਛੋਲਿਆਂ ਦਾ ਖੇਤ (farm of grams), ਤੁੰਮੇ/ਕੌੜਤੁੰਮੇ **(**Colocynth), ਨਰਮਾ **(**American Cotton)**,** ਕਿੱਕਰ **(**Acacia), ਤੂਤ **(**Mulberry). Two examples of the ***Bolis*** from the corpus including the names of *four* of the trees, weeds, and crops (last four items in the above list) are as follows:

1. **ਤੁੰਮਿਆਂ** ਦੀ ਵੇਲ ਵੱਢ ਕੇ, ਜੱਟ ਬੀਜਦੇ ਖੇਤ ਵਿੱਚ **ਨਰਮਾ**

   tŨmmIã di vel və́ḍḍ ke, jəṭṭ bijde khet vIcc nərma

2. ਮੁੰਡਾ ਰੋਹੀ ਦੀ **ਕਿੱਕਰ** ਦਾ ਜਾਤੂ, ਵਿਆਹ ਕੇ ਲੈ ਗਿਆ **ਤੂਤ** ਦੀ ਛਿਟੀ

   mŨḍa rohi di kIkkər da jatu , vIá ke lɛ gIa tut di chIṭi

4.7.19. Birds, Insects and Animals:

Many birds, insects, and animals found in the ***Malwa*** region are frequently mentioned in everyday conversations and communications of the ***Malwai*** population. Some of these are: ਘੁੱਗੀ (Dove), ਤਿੱਤਰ (Partridge), ਕੋਲ/ਕੋਇਲ Kol (Indian Cuckoo, Nightingale), ਕੱਛੂ (Tortoise, Turtle), **ਛੀਂਬਾ-ਸੱਪ** (A species of snake), **ਢਾਂਡੀ** (Cow/Ox), ਕੁੱਤਾ (Dog), ਖੋਤਾ (Donkey, Ass), ਬਾਂਦਰ (Monkey), ਬੋਤਾ (Camel), ਟੱਟੂ (Pony, Hack), **ਮੌਲੀ (**Old female animal), ਮੈਂਸ/ਮੱਝ (Buffalo), ਝੋਟੀ (Adult young she Buffalo), ਬੂਰਾ ਝੋਟਾ (Adult young he Buffalo, Brown Color), ਵਹਿੜਕਾ (Young Bullock), ਟਟੀਹਰੀ (sandpiper, plover, peewit, pewit), ਘੋੜੀ (Mare), ਇੱਲ੍ਹ (Kite, Bird of Prey), ਭਰਿੰਡ (Wasp, Yellow jacket), ਭੇਡ (Sheep). Three examples of the ***bolis*** from the corpus including the names of the birds, insects and animals (last three in the above list) are as follows:

1. ਅੱਖ ਪਟਵਾਰਨ ਦੀ, ਜਿਉਂ **ਇੱਲ੍ਹ** ਦੇ ਆਲ੍ਹਣੇ ਆਂਡਾ

   əkkh pəṭvarən di, jIõ Íll de áləṇe ãḍa

2. ਛੇੜ ਕੇ **ਭਰਿੰਡਾਂ**-ਰੰਗੀਆਂ, ਕਿੱਥੇ ਜਾਏਂਗਾ ਬੂਬਨਿਆਂ ਸਾਧਾ

   cheṛ ke pə̀rĨḍã-rə̃giã, kItthe jaẽga bubənIã sáda

3. ਤੋਰ ਸ਼ੁਕੀਨਣ ਦੀ, ਤੂੰ ਕੀ ਜਾਣਦੀ **ਭੇਡੇ**

   tor ṣUkinəṇ di, tũ ki jaṇdi pèḍe

4.7.20. Jewelry Items

Males and females of the ***Malwa*** region are fond of wearing jewelry items generally made of silver and gold. Many jewelry items have been prominently mentioned in many sentences and ***bolis*** of the corpus: ਝਾਂਜਰ An ornament for the ankle (females), ਝੁਮਕੇ Dome shaped pendant for the ear, Eardrop (females), ਬਾਂਕਾਂ a silver ornament for the ankle (females), ਲੌਂਗ nose pin or nose stud (worn by females), ਕੰਠਾ Necklace (worn by males), ਕੰਙਣ (Thick Bracelet or Bangle, usually made of Gold or Silver, worn by females), ਵੰਙਾਂ (Bangles of Glass, worn by females), ਨੱਤੀਆਂ (Ear rings for males), ਪਿੱਪਲ਼-ਪੱਤੀਆਂ (an ornament for the ear, worn by females).Three examples of the sentences and ***bolis*** from the corpus including names of the four jewelry items (last four in the above list) are as follows:

1. **ਕੰਙਣ** ਛਣਕਾਉਂਦੀਏ! ਦੁੱਧ 'ਚ ਮੀਂਙਣਾ ਨਾ ਪਾ
   kə̃ŋəṇ chəṇkaŨdie! dÚdd 'c miŋəṇa na pa

2. ਵਣਜਾਰਿਆ, ਬਾਵਿਆਂ ਵਿਹੜੇ **ਵੰਙਾਂ** ਵੇਚਦੈਂ ਕਿ ਵੰਝਲੀਆਂ?
   vəṇjarIa, bavIã vére və̃ŋã vecdɛ̃́ ke və̃jliã?

3. ਆਹ ਲੈ **ਨੱਤੀਆਂ** ਘੜਾਅ ਲੀਂ **ਪਿੱਪਲ਼-ਪੱਤੀਆਂ,** ਕਿਸੇ ਕੋਲ਼ੇ ਗੱਲ ਨਾ ਕਰੀਂ
   á lɛ nəttiã kə̀ṛaə lĩ pIppəḷ-pəttiã, kIse koḷe gəll na kərĩ

4.8. CONCLUSION

In this chapter, a new text and speech corpus for the Punjabi language has been designed. The new corpus is designed with special reference to one of the major dialects of the Punjabi language in India: the ***Malwai*** dialect. At least 20 special features of the new corpus have been described in this chapter. A new term *Extended Pronunciation (ਲਮਕਵਾਂ ਉਚਾਰਣ)* has been coined by the author to describe a feature of the Punjabi language where the meaning of the word changes with the addition of /ਅ/ at the end of the word, and its pronunciation is also extended.

The corpus consists of approximately 300 items. *Only* a small number of examples have been given in this chapter due to space limitations. The complete corpus has been given in Appendix A and Appendix B, where each item is transcribed in three different ways: the Punjabi language (Gurmukhi script), IPA, and ***PUNJARPAbet.*** Various categories of users (readers knowledgeable in the Punjabi language in Gurmukhi script, linguists knowledgeable in IPA, and the scientists knowledgeable in PUNJARPAbet) can equally understand and benefit from the corpus.

The fact that the new corpus is very rich and versatile due to a wide variety of its linguistic and cultural features makes it an ideal corpus for any serious speech processing work in the Punjabi language. ■

CHAPTER V
LINEAR PREDICTION ANALYSIS AND SYNTHESIS OF PUNJABI SPEECH[4]

5.1. INTRODUCTION

In this chapter, all the theoretical concepts required to analyze and synthesize speech are discussed. These concepts have been implemented to synthesize the Punjabi speech sentences towards the end of this chapter. Topics discussed in this chapter include Linear Prediction Analysis and Synthesis of speech; Pitch, Speech synthesis, and tones; Analysis/synthesis considerations; Voice Coders (VoCoder); Data compression; Computational savings; and the list of the Punjabi sentences synthesized in this project.

Linear prediction technique is also known as *Linear Predictive Coding* or *LPC* [Rabiner and Schafer, 89, pp. 473]. The term *linear predictive coding* (LPC) refers to several formulations which are essentially equivalent as far as the modeling of the speech signal is concerned. At least seven different formulations have been mentioned in literature by various authors [76, 87-89, 99]. We will discuss *two of these formulations:* covariance method and autocorrelation method in Section 5.2.1 because they are sufficient to complete this project.

No work has so far been reported in the literature where the Punjabi speech has been analyzed/synthesized using the linear prediction model of speech production. This thesis, therefore, concentrates on the ***speech analysis and synthesis of the Punjabi language*** using the linear prediction model of speech production. The *linear prediction model of speech production,* also known as '*linear prediction model*' utilizes an all-pole digital filter to represent the characteristics of the speech signal $\boldsymbol{s_n}$ for short-segments under consideration. The transfer function H(Z) of the all-pole filter is expressed as

$$\mathrm{H(Z)} = \frac{S(Z)}{U(Z)} = \frac{G}{1+\sum_{j=1}^{p} a_j z^{-j}} \tag{5.1}$$

In statistics, the all-pole model is termed the *autoregressive* (AR) model, because the output is said to *regress* on itself [24, pp. 273]. In Eq. (5.1), *G* is the gain factor; a_j*'s* are

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the *linear prediction (LP) coefficients*, and *p* is the number of *LP coefficients* or the *predictor coefficients* (The *order of the model* or the *number of poles* also mean the same thing). The value of a_0 is normalized to unity.

In *Linear prediction analysis, we* determine the *four* control parameters (as defined in Section 5.2) of the *linear prediction model* (**Fig. 5.1**), due to Atal and Hanauer [11-12, 99] directly from the speech waveform. The objective of *Linear prediction synthesis* is to synthesize the same speech waveform by utilizing these *four* control parameters as an input to the linear prediction synthesis model or *linear prediction synthesizer* (**Fig. 5.2**), due to Atal and Hanauer [11-12, 99].

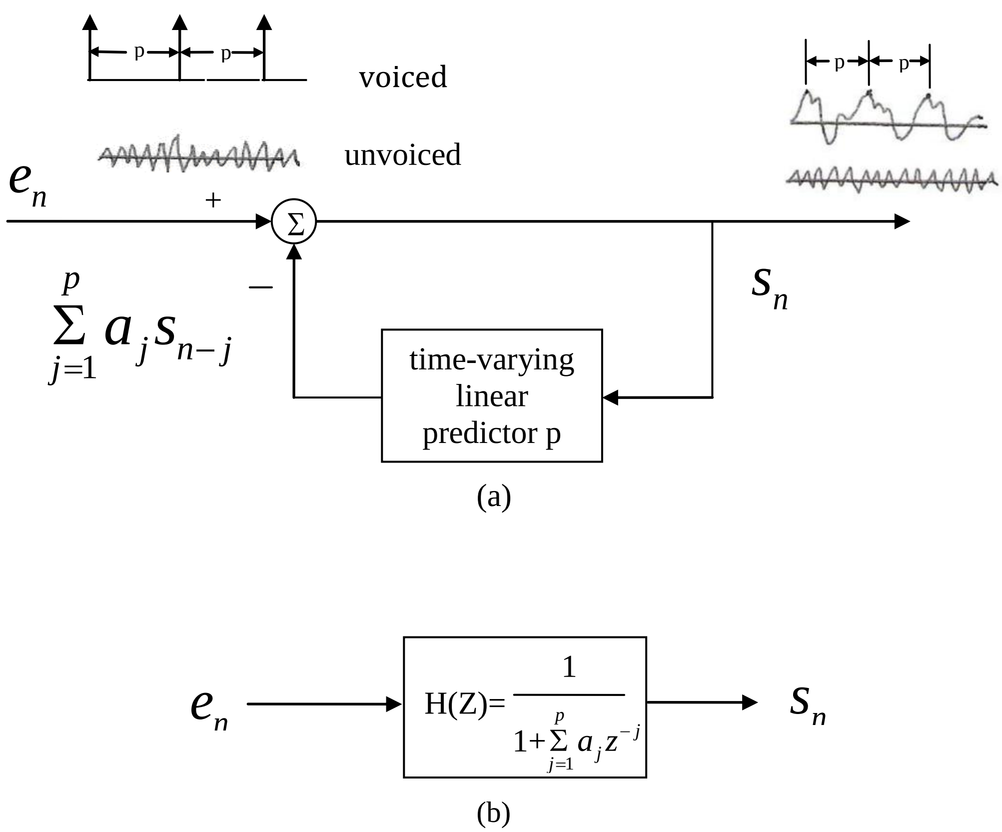

Figure 5.1: Linear prediction model of speech production
(a) Time-domain representation (b) Frequency-domain representation
(due to Atal and Hanauer [12])

With reference to **Fig. 5.1** and **Fig. 5.2**, the *three* variables (e_n, u_n, and v_n) are defined as follows:

(a) e_n is the error between the actual value of speech sample s_n, and its predicted value $\hat{s}_n$. The error $e_n = s_n - \hat{s}_n$ is also called *residual* or *residual error* or *prediction error*.
(b) u_n is the excitation function for the *voiced sounds*. Its value is zero except for one sample at the beginning of every pitch period.
(c) v_n is the excitation function for the *unvoiced sounds*. v_n is stationary white noise, i.e., a sequence of unity variance, zero mean random numbers from the random number generator.

5.2. LINEAR PREDICTION ANALYSIS

The basic idea behind *Linear Prediction analysis* (*LP analysis*) is that a speech sample can be estimated, approximated, or *predicted* as a linear combination of the past *p* speech samples. By minimizing the sum of the squared differences (over a *finite interval of speech segment*) between the actual speech samples (s_n), and the predicted speech samples ($\hat{s}_n$), a unique set of *p* coefficients, known as *LP coefficients or predictor coefficients* can be computed. The *finite interval of speech segment* represents a new vocal tract configuration in the speech production, and the *LP coefficients* are the *weighting coefficients* in the linear combination.

Linear prediction analysis aims to evaluate the following four control parameters of the *linear prediction model* (**Fig. 5.1**) due to Atal and Hanauer [11-12, 99].

i) a_j; $j = 1, 2, 3, .., p$ (LP coefficients)
ii) G (Gain factor)
iii) V/UV (Voiced / Unvoiced decision)
iv) P (Pitch period for voiced speech)

In this project, these parameters have been determined from the speech samples using well-known mathematical techniques discussed in the following subsections.

5.2.1. LINEAR PREDICTION COEFFICIENTS

The all-pole model of Eq. (5.1) can be characterized by a difference equation of the form:

$$s_n = -\sum_{j=1}^{p} a_j s_{n-j} + Gu_n \tag{5.2}$$

The excitation function u_n is zero except for one sample at the beginning of every pitch period for voiced sounds. Thus

$$s_n = -\sum_{j=1}^{p} a_j s_{n-j}; n > 0$$

(5.3)

Eq. (5.3) implies that for $n > 0$, the speech sample s_n is a linear combination of the previous p samples. Stating slightly differently, it means that the *current* speech sample s_n is *linearly predictable* from the previous p samples. This is where the name *Linear Prediction* comes from. If the data to be modeled corresponds exactly to the all-pole model of Eq. (5.1), then Eq. (5.3) will be satisfied exactly. Since the model is not perfect in this sense, the linearly predicted sample will only be a close approximation to s_n. Let us denote the predicted sample as $\hat{s}_n$ so that:

$$\hat{s}_n = -\sum_{j=1}^{p} a_j s_{n-j}; n > 0$$

(5.4)

Let us define an error e_n between the actual value of speech sample s_n, and the value $\hat{s}_n$ predicted by Eq. (5.4) as the difference s_n - $\hat{s}_n$:

$$\begin{aligned} e_n &= s_n - \hat{s}_n \\ &= s_n + \sum_{j=1}^{p} a_j s_{n-j} = \sum_{j=0}^{p} a_j s_{n-j}; n > 0 \end{aligned}$$

(5.5)

The error e_n is also referred to as *residual* or *residual error* or *prediction error*. The *linear prediction coefficients* a_j's are chosen so as to minimize the total squared error (of the frame under consideration) given by

$$E = \sum_n e_n^2$$

(5.6a)

$$= \sum_n \left(s_n + \sum_{j=1}^{p} a_j s_{n-j} \right)^2$$

(5.6b)

In order to solve for a set of the *LP coefficients* a_j's, Eq. (5.6) is differentiated with respect to a_k's. The result of the differentiation is then, set equal to zero as follows:

$$\frac{\partial E}{\partial a_k} = 0; \; 1 \le k \le p$$

(5.7)

This leads us to the following set of linear equations:

$$\sum_{j=1}^{p} a_j \sum_n s_{n-j} s_{n-k} = -\sum_n s_n s_{n-k}; 1 \le k \le p$$

(5.8)

The minimum total squared error E_m is given by equations (5.6) and (5.8) as:

$$E_m = \sum_n s_n{}^2 + \sum_{j=1}^{p} a_j \sum_n s_n s_{n-j}$$

…(5.9)

Eq. (5.8) and Eq. (5.9) have been derived considering only the *voiced sounds* of Eq. (5.3) where the excitation function is an impulse at the beginning of the pitch period. Same results can be achieved for the *unvoiced sounds* where the excitation function v_n is stationary white noise (a sequence of unity variance, zero mean random numbers from the random number generator), as we can see in the following equations (5.10-5.14). The unvoiced sounds are defined as follows:

$$s_n = -\sum_{j=1}^{p} a_j s_{n-j} + v_n$$

(5.10)

Therefore, the predicated sample for the unvoiced sounds can be defined as:

$$\hat{s}_n = -\sum_{j=1}^{p} a_j s_{n-j} + v_n$$

(5.11)

Because the s_n for unvoiced sounds is a sample of a random process, the *residual or residual error* $e_n = s_n - \hat{s}_n$ is also a sample of a random process [74]. We can minimize the expected value (where < > stands for *expectations*) of the square of the error. As a result, we have:

$$E = \left\langle e_n{}^2 \right\rangle = \left\langle \left(s_n + \sum_{j=1}^{p} a_j s_{n-j} - v_n \right)^2 \right\rangle$$

(5.12)

We know that v_n and s_n are uncorrelated, hence $\langle v_n . s_{n-k} \rangle$ is zero. Applying Eq. (5.7) to Eq. (5.12) gives:

$$\sum_{j=1}^{p} a_j \langle s_{n-j} s_{n-k} \rangle = -\langle s_n s_{n-k} \rangle ; 1 \le k \le p$$

(5.13)

The minimum total squared error E_m is expressed as

$$E_m = \langle s_n^{\ 2} \rangle + \sum_{j=1}^{p} a_j \langle s_n s_{n-j} \rangle$$

(5.14)

Speech is a nonstationary process, but can be considered locally stationary due to its slowly time-varying quasi-periodic nature [12, 74, 87-89]. So, taking the expectations of Eq. (5.13) and Eq. (5.14) will give us the same equations as Eq. (5.8) and Eq. (5.9).

Considering that s_n is non-zero for $0 \le n \le N-1$ (where N is the *speech segment length* or *frame length* in terms of number of samples), and on applying the Z-transform to Eq. (5.5), we get

$$E(Z) = \left(1 + \sum_{j=1}^{p} a_j Z^{-j} \right) \cdot S(Z) = A(Z) \cdot S(Z)$$

(5.15)

where

$$A(Z) = 1 + \sum_{j=1}^{p} a_j Z^{-j}$$

(5.16)

is an *all-zero filter* known as *Inverse Filter* or *Prediction Error Filter* [74, 76, 99]. The name *inverse filter* comes from the fact that A(Z) is an *inverse filter* for the system H(Z) of Eq. (5.1) rewritten as follows:

$$H(Z) = \frac{G}{A(Z)}$$

(5.17)

The *residual* or the *prediction error* e_n can therefore be considered as the result of passing s_n through the inverse filter *A(Z)*. This important observation is exploited in some of the pitch detection algorithms (e.g., the *SIFT* algorithm described in Appendix D).

The limits of summation in equations (5.6, 5.8 and 5.9) were purposely left unspecified. There are two basic approaches to this question leading to two different formulations of *linear prediction analysis*. These two formulations are the *first two*, out of the *seven* equivalent formulations of *linear prediction*, mentioned in literature as listed below:

1. the covariance method [Atal and Hanauer (11-12), 99]
2. the autocorrelation method [Makhoul (74); Markel and Gray (76)]
3. the lattice method [Burg (87-89), Makhoul (74)]
4. the inverse filter formulation [Markel and Gray (76)]
5. the spectral estimation formulation [Burg (87-89)]
6. the maximum likelihood formulation [Itakura and Saito (52), 99]
7. the inner product formulation [Markel and Gray (76)]

As pointed out by Rabiner and Schafer [87-89], "the differences mainly are often philosophical or in point of view toward the problem of speech modeling. The differences mainly concern the details of the computations used to obtain the predictor coefficients". The authors discuss only first three formulations (or three *basic methods* of analysis) in their latest book [89, pp. 474] stating that "all the other formulations are essentially equivalent to one of these three. The importance of linear prediction lies in the accuracy with which the basic model applies to speech."

We will discuss only two formulations, which are sufficient for the completion of this project in the following two sub-subsections:

5.2.1.1. AUTOCORRELATION METHOD

In this method the speech segment (frame) is assumed to be identically zero outside the interval $0 \leq n \leq N\text{-}1$. This can be achieved by multiplying s_n by a finite length window (e.g., Hamming window) that is identically zero outside the interval $0 \leq n \leq N\text{-}1$. The corresponding prediction error E is non-zero over the interval $0 \leq n \leq N\text{-}1+p$:

$$\boldsymbol{E} = \sum_{n=0}^{N-1+p} \boldsymbol{e}_n^{\,2} \tag{5.18}$$

Eq. (5.8), then, becomes

$$\sum_{n=0}^{N-1+p} s_{n-j} s_{n-k} = \sum_{n=0}^{N-1-|j-k|} s_n s_{n+|j-k|}$$
$$= R\left(| j-k |\right);\ 1 \leq j,\ k \leq p \tag{5.19}$$

Equations to be solved for this method, therefore, are:

$$\sum_{j=1}^{p} a_j R\left(| j-k |\right) = -R(k); 1 \leq k \leq p$$

..(5.20)

and the minimum mean square prediction error of Eq. (5.9), for this method becomes:

$$E_m = R(0) + \sum_{j=1}^{p} a_j R(j)$$

(5.21)

where the autocorrelation coefficients for equations (5.12-5.13) are specified by:

$$R(m) = \sum_{n=0}^{N-1-m} s_n s_{n+m}; 0 \le m \le p$$

(5.22)

The set of Eq. (5.20), known as 'Normal Equations' in *least squares terminology* [71, 74, 91], can be expressed in the matrix form as follows:

$$\begin{bmatrix} R(0) & R(1) & R(2) & .... & R(p-1) \\ R(1) & R(0) & R(1) & .... & R(p-2) \\ R(2) & R(1) & R(0) & .... & R(p-3) \\ .... & .... & .... & .... & .... \\ .... & .... & .... & .... & .... \\ R(p-1) & R(p-2) & R(p-3) & .... & R(0) \end{bmatrix} \begin{bmatrix} a_1 \\ a_2 \\ a_3 \\ .... \\ .... \\ a_p \end{bmatrix} = - \begin{bmatrix} R(1) \\ R(2) \\ R(3) \\ .... \\ .... \\ R(p) \end{bmatrix}$$

(5.23)

This $p \times p$ matrix of autocorrelation coefficients is a Toeplitz matrix, named after Otto Toeplitz [152], and it is a special matrix in linear algebra. It is a *diagonal-constant matrix*, i.e., all the elements along any diagonal are equal and it can be defined with only the first row and the first column. A linear system involving an $n \times n$ Toeplitz matrix has only *2n-1* degrees of freedom rather than n^2 degrees of freedom, and it is easier to solve. In addition, the Toeplitz matrix involved in Eq. (5.23) is also symmetric and positive definite (Note that a *symmetric* Toeplitz matrix is defined by just one row). These special properties of Eq. (5.23) lead to an *efficient* solution by Levinson-Robinson or Levinson-Durbin recursive algorithm [Levinson (71), Robinson (91), 11, 15, 24, 99]. From the Algorithm Design and Analysis point of view, the computational complexity of the Levinson-Durbin algorithm is on the order of p^2 as compared with the *Gaussian elimination technique*, or the *matrix inversion technique* whose computational complexity is on the order of p^3. Even more-efficient algorithms have been proposed, but they are unacceptable to most speech researchers because they are numerically unstable [15, pp.125]. A brief description of this algorithm has been included in Appendix C for the sake of completeness.

If all the autocorrelation coefficients are scaled by a constant, then the solution to Eq. (5.23) remains unchanged. In particular, if all *R(j)* are normalized by dividing by *R(0)*, the resulting coefficients *r(j)* are called normalized autocorrelation coefficients:

$$r(j) = \frac{R(j)}{R(0)}$$

(5.24)

Since *R(0)* is always ≥ *R(j)*, therefore |*r(j)*| ≤ 1. Normalized error (normalized residual energy) from Eq. (5.21) is:

$$E_n = \frac{E_m}{R(0)} = 1 + \sum_{j=1}^{p} a_j r(j) = \prod_{j=1}^{p}\left(1 - k_j^{\,2}\right)$$

(5.25)

where k_j; 1 ≤ j ≤ p are intermediate quantities in the solution process of Levinson-Robinson (Levinson-Durbin) algorithm (Appendix C). These intermediate quantities are known as Reflection Coefficients (PARCOR Coefficients) with the special property that $k_j \leq |1|$. Therefore the normalized residual energy has the property that

$$0 \leq E_n \leq 1$$

(5.26)

In order to ensure reliable results by using this method, the *speech segment length N* should be of the order of several pitch periods (*N* = 2*P or* 2 pitch periods, has been used in this work).

5.2.1.2. COVARIANCE METHOD

In the covariance method [11-12], we assume that the prediction error E in Eq. (5.6) is minimized over a finite interval *0 ≤ n ≤ N-1* and the signal is assumed to be known for the interval *-p ≤ n ≤ N-1* (total *p + N* samples). No assumptions are to be made about the signal outside this interval and no windowing is necessary (N can be different than the autocorrelation method):

$$E = \sum_{n=0}^{N-1} e_n^{\,2}$$

(5.27)

Eq. (5.8), then, becomes

$$\sum_{j=1}^{p} a_j \phi(j,k) = -\phi(0,k); 1 \leq k \leq p$$

(5.28)

and the minimum mean square prediction error is

$$E_m = \phi(0,0) + \sum_{j=1}^{p} a_j \phi(0,j)$$
(5.29)

where

$$\phi(j,k) = \sum_{n=0}^{N-1} s_{n-j} s_{n-k} = \phi(k,j)$$
(5.30)

In the matrix form $p \times p$ matrix of Eq. (5.28) is symmetric and positive definite but not Toeplitz; and the solution is generally obtained by the Cholesky decomposition method (or square root method).

While choosing a method, computational efficiency and the stability are two major considerations.

The autocorrelation method requires somewhat less computation (*Np* multiplications for correlation matrix [44-45] and about p^2 multiplications for solution to the matrix equations by Levinson-Robinson algorithm) than the covariance method {*Np* multiplications for correlation matrix and $(p^3+9p^2+2p)/6$ multiplications, *p* divisions and *p* square roots (exact figure by Portnoff *et al.* [74, 76, 87-89, 99] for the solution to the matrix equations by the Cholesky decomposition method}.

In the autocorrelation method all the roots of A(Z) lie inside the unit circle in Z-plane which means that stability of H(Z) is guaranteed whereas no such assurances exist in case of the covariance method [11-12, 74, 76, 87-89, 99]. So the practical advantages of the autocorrelations method over the covariance method are obvious. In the present work, like most of the speech analysis research, the autocorrelation method has been used.

5.2.2. GAIN FACTOR (G)

It is reasonable to expect that the Gain factor (*or* Gain) *G* could be determined by matching the energy in the speech signal with the energy of the linearly predicted samples [88, pp. 404]. From Eq. (5.2) and Eq. (5.5), the *residual error* is given by

$$e_n = Gu_n = s_n + \sum_{j=1}^{p} a_j s_{n-j}$$
(5.31)

Since the *error* e_n is proportional to input u_n, therefore it is a reasonable assumption that the energy in the input signal is equal to the energy in the error signal [74, 76, 79], given as E_m in Eq. (5.21). Therefore we have:

$$G^2 \sum_{n=0}^{N-1} u_n{}^2 = \sum_{n=0}^{N-1} e_n{}^2 = E_m \tag{5.32}$$

The gain factor G is therefore given by:

$$G = \sqrt{E_m} = [R(0) + \sum_{j=1}^{p} a_j R(j)]^{1/2} \tag{5.33}$$

This expression for the gain factor G has been used by Makhoul [74], Markel & Gray [76] and Oppenheim [79].

Another method for calculating gain factor was proposed by Atal and Hanauer [11-12] and further improved by Klayman *et al.* [76, 87-89] on the basis of input-output energy matching in the original and the synthesized speech. According to these authors, the transmitted gain is a measure of energy per sample and is, hence, simply equal to the *RMS* value of the input signal:

$$G = \left(\frac{1}{N} \sum_{n=0}^{N-1} s_n{}^2 \right)^{1/2} \tag{5.34}$$

Therefore, the input-output energy for the actual speech signal and the synthesized speech signal is matched by replacing the synthesized sample $\hat{s}_n$ by $B \times \hat{s}_n$ where:

$$B = \frac{G}{\left(\frac{1}{N} \sum_{n=0}^{N-1} \hat{s}_n{}^2 \right)^{1/2}} \tag{5.35}$$

In the present work, the *RMS* formulation for gain has been used for analysis and synthesis (mainly due to its accuracy and simplicity), although both formulations described in Eq. (5.33) and Eq. (5.34) are equally acceptable to most speech researchers [87-89, 99].

5.2.3. <u>V/UV DECISION AND PITCH EXTRACTION</u>

The problem of V/UV decision is to determine whether the vocal cords are vibrating during the generation of a short speech segment under consideration, *or* not. If the vocal cords are vibrating, then the speech segment consists mainly of *voiced sounds*. The problem of pitch extraction, then, is to determine the pitch period P, where P is the reciprocal of fundamental frequency F_0 (the rate of oscillation of vocal cords is called *fundamental frequency* or *pitch frequency* or *pitch*).

The following remarks by some of the well-known researchers in this area can be considered representative as well as interesting:

"A thorough discussion of published techniques for fundamental frequency or pitch period estimation would probably be as long as this book".

- [Markel and Gray,76, pp. 190]

"Of the numerous systems for pitch extraction that have been proposed, none is free from deficiencies either in performance or in excessive complexity".

- [Maksym, 76, pp. 281]

"Nevertheless, no single estimater yet developed offers decisive advantages in either reliability or computational simplicity, a fact which attests to the difficulty of the problem".

- [Tucker and Bates, 28, pp. 597]

"No single pitch detector was uniformly top ranked across all speakers, recording conditions and error measurements".

- [Rabiner *et al.*, 99, pp. 209]

"It is the firm belief of this author that all of the proposed methods have their merits, and in fact, that they yield similar performance in reliability. Preference of one approach over another is primarily determined by the particular application in which such a system is to be used".

- [Knorr, 27, pp. 264]

Taking into account the complexity and the reliability of dozens of the pitch detection algorithms available in literature [12, 15, 75, 76, 82-83, 86-90, 99-102, 122-126, 129], the *SIFT* (Simplified Inverse Filter Tracking) algorithm, due to Markel [75-76, 24, 87-89, 99] has been applied in the earlier works of the author [26, 28-29, 31] for the voiced/unvoiced decision and the pitch extraction. The *SIFT* algorithm (described in Appendix D) is used mainly because it is based upon linear prediction and claimed by Markel to be "efficient and accurate" as compared with some of the other techniques based on the linear prediction principles [76, pp. 206] due to Atal and Hanauer [12], S. Boll [15], and Itakura and Saito [52, 99]. The Gold-Rabiner pitch tracker [82, 86-89] and the Autocorrelation pitch tracker [82, 87-89] have also been used in the earlier work of the author [30].

Since many pitch detection algorithms are available in literature, it was decided to experiment with pitch detection algorithms other than the above *three* algorithms (the *SIFT* algorithm, the *Gold-Rabiner pitch tracker*, and the *Autocorrelation pitch tracker*). It was not an easy task to decide which new algorithm should be tried, since "there is no single theory that comprehensively accounts for the apparently simple task of pitch perception, and this is perhaps reflected in the complexity of designing methods of automatic pitch extraction" [123, pp. 33], and "no algorithm has been found that performs robustly in all cases in accordance with human perception" [82, pp. 152].

In addition to the above *three* pitch detection algorithms, *two* more pitch detection algorithms that have gained wide acceptance due to their stability and computational efficiency are:

(a) ZFF (Zero Frequency Filtering)

(b) RAPT (Robust Algorithm for Pitch Tracking).

These *two* algorithms have also been used in this project. A brief description of these *two* algorithms is given below.

1. The Zero Frequency Filtering (ZFF) algorithm as described by its originators [122] is summarized here in point form:

(i) Zero Frequency Filtering (ZFF) is a technique used in the characterization and analysis of glottal activity from speech signals.

(ii) The filter design originally proposed has an infinite impulse response (IIR) filter followed by two successive finite impulse response (FIR) filters.

(iii) A simplified FIR implementation is employed in the latest version. The advantage of the FIR filter implementation is realized in the reduction of the computational requirements for zero frequency filtering which include two important characteristics: (a) use of single-precision floating point, and (b) stability of the filter.

2. The Robust Algorithm for Pitch Tracking (RAPT) is based on normalized cross-correlation function (NCCF) of Atal [12] and SIFT algorithm of Markel [75-76]. RAPT has gained popularity because it "has been used with satisfactory results on speech recordings varying in quality from noisy telephone to quiet laboratory conditions… The algorithm has been embedded in a commercially available speech-processing package and is in widespread use in speech research laboratories" [124, page 515].

Summarizing the discussion regarding the V/UV decision and pitch extraction, we have tried various algorithms for pitch detection (SIFT, Gold-Rabiner pitch tracker, Autocorrelation pitch tracker, ZFF, RAPT) for this work. No significant improvement has been noticed in the overall performance of the speech synthesizer when the different *pitch detection algorithms* were used. The well-known result that *no single pitch detection algorithm is uniformly top-ranked across all environments* [90, 99] has been confirmed.

5.3. LINEAR PREDICTION SYNTHESIS OF SPEECH

Speech can be synthesized [22, 41, 49, 59, 100, 125, 126] by utilizing the four control parameters of the linear prediction analysis as *input* to a system having the same parametric representation as the analysis model. **Figure 5.2** shows the linear prediction synthesizer due to Atal and Hanauer [12].

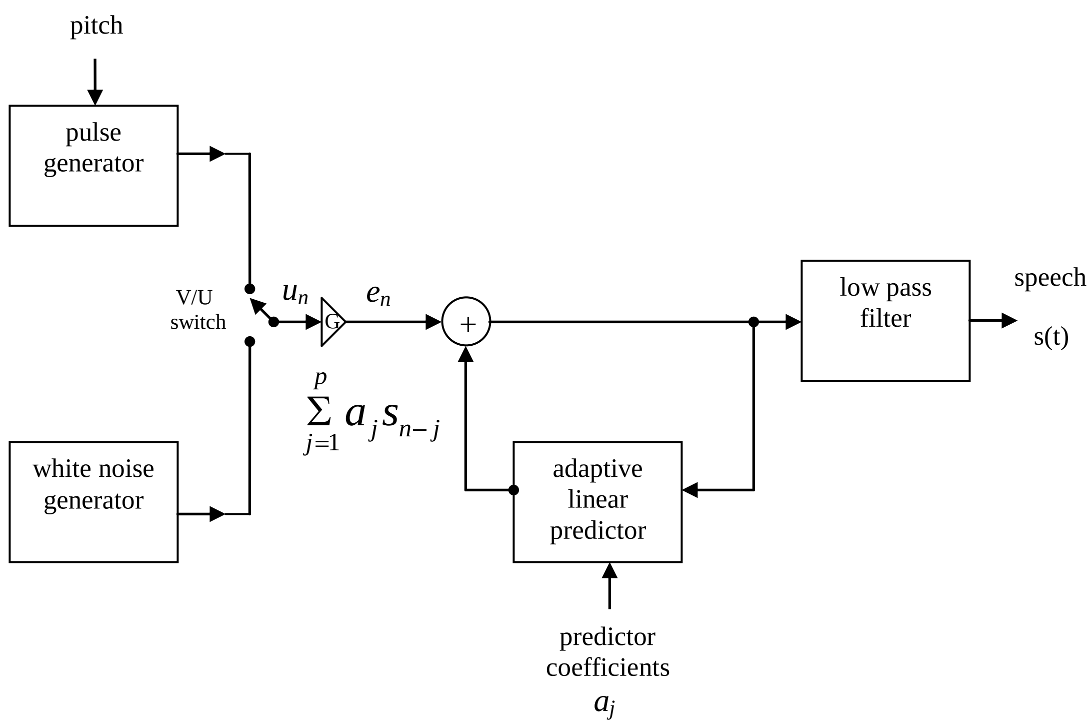

Figure 5.2: Linear prediction synthesizer (due to Atal and Hanauer [12])

If the control parameters are updated at the beginning of a pitch period using a variable frame length every time, then the synthesis is called *pitch synchronous synthesis* whereas if the control parameters are updated once every time for a fixed-length frame, then the process is called *pitch asynchronous synthesis* [12, 76, 87-89, 99]. Pitch asynchronous synthesis requires interpolation of the control parameters which is not very simple [12] and the interpolation of the a_j's can even lead to an unstable filter. Therefore, the *pitch synchronous synthesis* is generally preferred [87-89].

The *pitch synchronous synthesis* in the present work has been performed by using variable frame length of 2*P* samples for voiced frame and a fixed frame length of 200 samples for unvoiced frame (*P* is the pitch period). Using impulse generator and white noise generator (producing zero mean, unity standard deviation, uncorrelated random sample sequence v_n) as the excitation sources for voiced and unvoiced sounds respectively, the synthesis can be represented by these equations:

(i) voiced sounds ($0 \le n \le N - 1$, $N = 2P$):

$$\hat{s}_n = -\sum_{j=1}^{p} a_j \hat{s}_{n-j} + G u_n;$$
$$u_n = 1 \text{ for } n = 0,\ n = p,$$
$$u_n = 0 \text{ for } n \neq 0,\ n \neq p$$

(5.36a)

(ii) unvoiced sounds ($0 \le n \le N - 1$, N = 160):

$$\hat{s}_n = -\sum_{j=1}^{p} a_j \hat{s}_{n-j} + v_n$$

(5.36b)

Linear prediction synthesizer (**Fig. 5.2)** implements Eq. (5.36) and requires *p* multiplications and *p* additions to synthesize a *single* output sample $\hat{s}_n$.

5.4. PITCH, SPEECH SYNTHESIS AND TONES

This section is mainly based on the description of the *Pitch Variation* given by Bhaskararao [129, pp. 596-597]. It has been **reproduced** (Several words have been reproduced as *italicized* and/or reproduced in **bold** to emphasize the connection amongst the Concepts of Pitch, Speech synthesis, and Tones. These points should be appropriately addressed in any speech synthesis project), as under:

1. "*Pitch* is the perceptual correlate of fundamental frequency. All natural languages use relative variations in pitch to bring out intonational differences. Intonational differences can signal syntactic differences (such as differences between interrogative and declarative sentences) or to bring out paralinguistic features such as emotional and attitudinal differences on the part of the speaker."

2. “Although it may be too early to model paralinguistic features of intonation at the current state of *speech synthesis*, intonational patterns have to be modelled for quality *speech synthesis*.”

3. “In addition to the use of relative pitch variation for syntactic purpose, some languages use relative pitch variations to signal lexical differences. Such languages are called *tone languages*. Several of the languages of the *Tibeto-Burman family* within India are *tone languages*. The number of contrastive tones that these languages use may vary from a minimum of **two** tones to a maximum of **five** tones. For instance, *Manipuri* has a two-way contrast of tones whereas *Mizo* has a three-way contrast.”

4. “While synthesizing tones for a *tonal language*, it should be remembered that it is the relative variation of pitch that defines the tonal distinction but not any absolute values of fundamental frequency.”

5. “As tones in a *tonal language* carry lexical load, the built-in lexicon of the language should carry tone markings and the synthesizer should be able to generate the appropriate tonal pattern for the given word.”

6. “Another unique case of contrastive pitch variation occurs in *Panjabi*. An underlying rewrite process of script letter sequences into phoneme sequences occurs here. In Panjabi the written sequences {b^hV, d^hV, ḍ^{h}V, j^hV, g^hV, hV} are realized phonemically as: /pV́, tV́, ṭV́, cV́, kV́, V́/. Here V́ stands for a vowel with a high tone. Hence, *speech synthesis for Panjabi* will have to handle the transfer of each of the five members {b^hV, d^hV, ḍ^{h}V, j^hV, g^hV}of voiced aspirated plosive set to the corresponding member from the voiceless unaspirated plosive set. In addition, the corresponding vowel has to be assigned the appropriate fundamental frequency. Notice that the letter sequence {hV} is transformed in to the phoneme /V́/. *Dogri* also has a similar set of rules but its writing has evolved using a separate ‘accent mark’ (*svara chihna*) to take care of this change.”

Bhaskararao [129, pp. 596-97] gives us a broader perspective by mentioning *Manipuri*, *Mizo*, and *Dogri* languages in addition to the *Punjabi* language. His point number 6 above has been clearly stated in **section 4.7.4** of this thesis. The ***two*** special tones in Punjabi are:

(a) low rising tone (or rising-falling tone)

(b) high falling tone (simply called *low tone*, and *high tone*).

The **voiced aspirates** (ਘ, ਝ, ਢ, ਧ, ਭ) in the *initial position* of words and stressed syllables (mentioned in point 6 above as {b^hV, d^hV, ḍ^{h}V, j^hV, g^hV}) represent the **unaspirated voiceless** (ਕ, ਚ, ਟ, ਤ, ਪ) followed by a low tone (mentioned in point 6 above as /pV́, tV́, ṭV́, cV́, kV́/ in different order). The consonantal value of letter ਹ represents the phoneme /h/ when initial, but non-initial ਹ in several words, is replaced with tone (mentioned in point 6 above as /hV/ and /V́/ respectively).

5.5. SPEECH PROCESSING CONSIDERATIONS

Before we examine the *specific* considerations for speech analysis and synthesis, we need to look at some *general* speech processing considerations including *Analog and digital speech signals, speech compression, speech coders,* and *voice coders (vocoders).*

5.5.1. Analog and digital speech signals

The inventor of telephone A. G. Bell wrote to a friend named Watson the following message [40, pp.3]: "Watson, if I can get a mechanism which will make a current of electricity vary its intensity as the air varies in density when sound is passing through it, I can telegraph any sound, even the sound of speech".

A. G. Bell based his invention (telephone) on the basic principle that the speech signal, like many other analog signals "is represented by measuring and reproducing the amplitude fluctuations of the acoustic waveform of the speech signal" [40 (pp. 3), 89 (pp. 663)]. The *digital speech signal* corresponding to the *analog speech signal* is often represented by *speech samples* or *a sequence of numbers* equivalent to amplitude variations.

In general, the *digital speech signals* are generally sampled at f_s = 8 kHz or 8000 samples/sec, and each sample is represented by b = 8 bits. This corresponds to an *uncompressed information rate* (I_w) of 64 kbps or kilobits/sec [154]. All sentences in this project have been recorded at this rate.

5.5.2. Speech Compression

The website called *Speech Compression* [154], based on the works of the famous speech researchers Atal [11-12], Rabiner and Schafer [87-89], Deller, Proakis, and Hansen [24], Furui [41], Schroeder [100], Goldberg and Rick [47], Childers [22] and others, *states* that "The compression of speech signals has many practical applications. One example is in digital cellular technology where many users share the same frequency bandwidth. Compression allows more users to share the system than otherwise possible. Another example is in digital voice storage (e.g. answering machines). For a given memory size, compression allows longer messages to be stored than otherwise… With current compression techniques (all of which are lossy), it is possible to reduce the rate to 8 kbps with almost no perceptible loss in quality. Further compression is possible at a cost of lower quality. All of the current low-rate ***speech coders*** are based on the principle of *linear predictive coding (LPC).*" This fact further enhances the significance of the present work, because LPC is our main focus.

5.5.3. Speech Coders

The art of reducing the bit rate required to represent a speech signal is called *speech coding*. The algorithms used to reduce the required bit rate are called speech-coding algorithms, or *speech coders* [Kleijn, 15, pp. 283-84]. Two broad classes of the digital speech coding systems, commonly known as ***speech coders*** (A-to-D converter and D-to-A converters) have been mentioned in literature. These have been presented in the following subsections:

5.5.3.1. Waveform Coding Systems or waveform Coders

In all *waveform coders*, sampling and quantization are fundamental features. In order to digitally represent the speech waveform sampled at $f_s = 1/T$ (assuming that *the* number of bits for representing one sample is equal to b), the information rate I_w in these systems can be written as:

$$I_w = b \times f_s$$

This process for representing the speech waveform is known as *Pulse Code Modulation* (PCM). The PCM technique was developed by Shannon and others in a classic paper (The Philosophy of PCM) published in November 1948.

5.5.3.2. Vocoder Systems

These systems are also known as *hybrid coders*, or *model-based systems*, or *analysis/synthesis systems*. The goal of this class of digital speech coding system (or model-based coders) is to preserve the perceived speech quality and speech intelligibility at an information rate ($\boldsymbol{I_m}$) lower than the information rate ($\boldsymbol{I_w}$) for the waveform coders. Assuming the analysis frame rate ($\boldsymbol{F_r}$) and ($\boldsymbol{b_f}$) bits required to represent one frame, an expression for I_m can be written as:

$$I_m = b_f \times F_r$$

The basic goal of these *vocoder systems* is to achieve $I_m < I_w$ with the speech quality of the synthesized speech comparable with the original input speech signal.

5.5.3. Voice Coders (Vocoders)

Vocoders or *voice coders* [Dudley (33, 99)], also known as *analysis/synthesis methods*, can operate at rates between 1 and 3 kb/sec [37 (ch.5), 82 (ch. 4 and 5)]. Three vocoders generally associated with the Linear Predictive Coding (LPC) are: *Multipulse-excited LPC* (MLPC), *Residual-Excited Linear Prediction (*RELP) vocoder, and *Line Spectrum Pairs* (LSP). Whereas *MLPC* and the *RELP* vocoders are typically used for bit rates around 9600 bits/sec, the *LSPs* have been used to achieve bit rates around 2400 bit/sec

[82], comparable with the low bit rate reported by Atal and Hanauer [12, 99], Benesty *et al.* [15], Goldberg and Riek [47], Rabiner and Schafer [87-89], Kondoz [65], and others.

In addition to the above vocoders, several other representative vocoders frequently mentioned in literature [154, 23, 47, 65, 77] include the following:

- Adaptive Differential Pulse Coded Modulation (ADPCM) scheme
- Low-Delay Code Excited Linear Prediction (LD-CELP) scheme
- Conjugate-Structured Algebraic Code Excited Linear Prediction (CS-ACELP) scheme.
- Code Excited Linear Prediction (CELP) scheme. The bit rate is 0.6 bits/sample (compression ratio of 13.3:1).
- Linear Predictive Coding (LPC10) scheme.

We have practically implemented LPC*p* scheme in this chapter, where *p* = No. of poles. We have used *p* = 2, 4, 6, 8, 10, and 12. The relative speech compression performance of the *ADPCM*, *LD-CELP*, *CS-ACELP*, *CELP*, and *LPC10* vocoder schemes as compared with the original signal is given in **Table 5.1**, whereas the bit rates in bits per second (*bps*) for LPC*p* (with *p* = 2, 4, 6, 8, 10, and 12) is tabulated in **Table 5.2**.

Table 5.1: Vocoders and Speech Compression

No.	Item/ Vocoder	bit rate (kbps)	Quantization (bits/sample)	Compression Ratio
1	Original	64	8	1:1
2	ADPCM	32	4	2:1
3	LD-CELP	16	2	4:1
4	CS-ACELP	8	1	8:1
5	CELP	4.8	0.6	13.3:1
6	LPC10	2.4	0.3	26.6:1

5.6. ANALYSIS/SYNTHESIS CONSIDERATIONS

Quality of the synthesized output speech from analysis control parameters involves some considerations such as choice of methods, windowing, pre-emphasis, sampling rates *(f_s)*, order of the model *(p)*, length of the analysis frame *(N)*, and tones in a tonal language such as the Punjabi language. Although some of these have been discussed in the appropriate sections, yet all of these will be summarized here for completeness.

Considering accuracy, storage and computation, the sampling frequency $f_s = 8\ kHz$ is generally taken as a representative sampling rate [12, 75-76, 79, 85-89, 99-102], where speech signal is bandlimited to less than 4 kHz (cut-off frequency $f_c = 3.9\ kHz$)

bandwidth to avoid aliasing. A Nyquist frequency of 4 kHz (or lower) is commonly assumed for “telephone speech” [89, pp.667]. Sampling frequency $f_s = 8\ kHz$ has been used in the present work.

Order of the model (i.e., no. of the a_j’s) depends mainly on the sampling rate. One complex pole per kHz is required to represent the vocal tract and 3-4 poles are required to represent source excitation and lip radiation. For $f_s = 8\ kHz$, value of p equal to 11 or 12 is needed. Atal & Hanauer [11-12] showed in a graph that the prediction error decreases only by a small amount when p is increased beyond 12. A value of p less than or equal to 12 is used in this work.

The process of passing the signal through a single-zero filter $1 - \mu Z^{-1}$ $(0.9 \leq \mu \leq 1.0)$ before the analysis is known as *pre-emphasis*. *Pre-emphasis* before analysis is a procedure used to estimate the spectral characteristics of the *vocal tract* alone without the effects of the *glottal* and *lip radiation* characteristics. *Pre-emphasis* has been, therefore, used in the SIFT algorithm to sharpen the autocorrelation peaks in pitch detection but not for the estimation of a_j’s because it leads to additional complexities and undesirable effects in the synthesis spectral properties such as low frequency boost [75-76].

Although a rectangular window is implicit in the autocorrelation method, an explicit window such as Hamming window which tapers down s_n to zero is recommended to check the spectral distortion effects of discontinuities at s_0 and s_{N-1}. A Hamming window has been used both in the estimation of a_j’s and pitch.

Variable frame length, equal to 2P for voiced frames and equal to 20 ms for unvoiced frames has been used. The combination of the Pitch synchronous analysis and synthesis is less complex than the pitch asynchronous analysis and synthesis combination. Therefore, the Pitch synchronous analysis and synthesis has been used in this work.

As far as choice of methods in the control parameter estimation is concerned, the autocorrelation method for the a_j’s has been chosen due to its stability and computational efficiency. The *RMS* formulation for gain factor G is chosen for its accuracy and simplicity. The *ZFF* and *RAPT* methods have been used in the two MATLAB [36, 121] programs written by the author for this project to compute the V/UV decision and the pitch extraction for their efficiency. The *SIFT* algorithm has been discussed in Appendix D for its efficiency and close relationship with linear prediction.

Tones in the Punjabi language, and the Punjabi speech synthesis are also a special consideration. These have been discussed in Chapter I, Chapter IV (4.7.4), Section 5.4, and Chapter VI under the appropriate titles of *Tones*, *Tonemes (Tonal Phonemes)*, or *Tonal Systems*.

With reference to the *all-pole model*, two points have been emphasized by many authors [40, 74, 79, 87-89, 99]:

(1) The speech waveform is sufficiently complex so that we cannot expect it to match exactly even a *pole-zero model*, let alone the *simplified all-pole model* as that of Eq. (5.1).
(2) It is only a good compromise that the simplicity of the *all-pole model* can preserve many of the important characteristics of the speech signal at the cost of some accuracy.

5.7. ANALYSIS AND SYNTHESIS (COMBINED)

Internet website titled "LPC Analysis and Synthesis of Speech" presents a compact description of the "speech compression technique known as Linear Prediction Coding (LPC) using DSP System Toolbox™ functionality" [153] available at the MATLAB command line [36, 121]. The website explains this technique using the block diagram (**Fig. 5.3**) by combing the two steps (analysis and synthesis) as outlined below. Let us call these two steps as ***step A*** and ***step B.***

Step A:
The analysis section divides the original speech signal into frames of size 3200 samples (0.4 seconds) with an overlap equivalent to 0.2 seconds (that translates to1600 samples). After passing each frame through the Hamming window, the *autocorrelation coefficients* a_j*'s* for number of poles $p = 12$ are found. Using the Levinson-Durbin algorithm (Appendix C), the *reflection coefficients* are calculated from these *autocorrelation coefficients*. Once the *reflection coefficients* are extracted from the original speech signal, the original speech signal is passed through an all-zero analysis filter (with coefficients as *the reflection coefficients*) to compute the residual signal.

Step B:
The synthesis section reconstructs the original signal using the residual signal and reflection coefficients as input to a synthesis filter (which is the inverse of the analysis filter).

This simulation plots the Signal and LPC spectrum (**Fig. 5.4**) using the two helper functions from the MATLAB [153]. These two helper functions are called: (1) hfigslpc.m (2) plotlpcdata.m.

This results in significant computational savings (as described in the next section) since the residual signal and reflection coefficients require less number of bits to code than the original speech signal.

5.8. COMPUTATIONAL SAVINGS

Atal and Hanauer [12, 37, 99] concluded that the overall bit rate for transmission [65] and storage of speech required for good quality synthesized speech is $(5p + 12) \times F_r$ bits/sec where p is the number of poles and F_r is the number of frames per second. For high quality speech (f_s = *8 kHz*), the average frame rate used in this work is 50. Using Atal and Hanauer formula, the bit rates in *bits per second* (*bps*) achievable for various number of poles *p* used in this work (*p* = 2, 4, 6, 8, 10, and 12) can be computed. The bit rates for LPCp (with *p* = 2, 4, 6, 8, 10, and 12) thus computed are tabulated in **Table 5.2**.

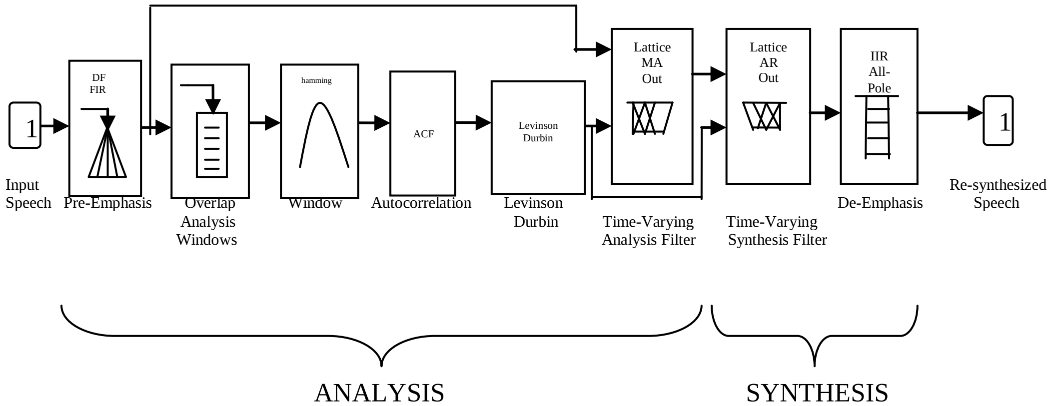

Figure 5.3: LPC Analysis and Synthesis of Speech

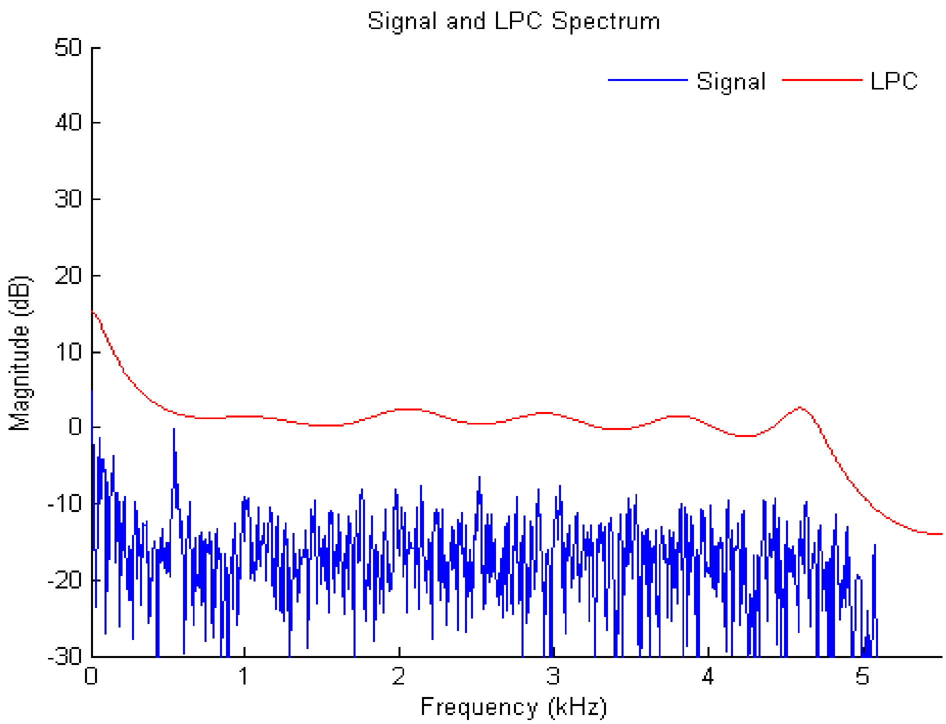

Figure 5.4: Signal and LPC Spectrum

Table 5.2: Poles and Bit Rate

No.	poles (*p*)	Vocoder	bit rate (bps)
1	2	LPC2	1100
2	4	LPC4	1600
3	6	LPC6	2100
4	8	LPC8	2600
5	10	LPC10	3100
6	12	LPC12	3600

5.9. SYNTHESIS OF PUNJABI SENTENCES

Twenty five Punjabi sentences were selected from the newly-designed corpus (in Chapter IV) for the purpose of this project so that a representative analysis and synthesis can be conducted. These sentences have been listed in Appendix E. In the following description, '#' stands for the 'sentence number *x*' in Appendix E. While choosing these sentences, the themes taken into consideration included the *vowels and consonants, tonemes, nasals, semi-vowels, extended pronunciation* [139, pp. (ਨ)] and some *special Punjabi speech sounds* as follows:

ੳ ਅ ੲ; ਘ ਝ ਢ ਧ ਭ; ਙ ਞ ਣ ਨ ਮ; ਯ ਵ, ਛ ਠ ਤ ਫ ਲ਼ ੜ, ਘੜਾ/ਘੜਾਅ, ਹਰਾ/ ਹਰਾਅ, ਹ ਹ੍

1. VOWELS (5 sentences):
   Three *Matra Vahaks (vowel forms),* two long and short vowels (i & I; u & U)
   ੳ ਅ ੲ, ਚਿਰ / ਚੀਰ, ਸੁਰ / ਸੂਰ (# 1, 2, 3, 24, 25)
2. TONEMES (6 sentences):
   ਘ (2) ਝ ਢ ਧ ਭ (# 6, 22, 33, 9, 36, 38)
3. NASALS (5 sentences):
   ਙ ਞ ਣ ਨ ਮ (# 30, 34, 35, 11, 12)
4. SEMI-VOWELS (2 sentences):
   ਯ ਵ (39, 19)
5. SPECIAL PUNJABI SOUNDS (6 sentences):
   ਛ, ਠ, ਤ, ਫ, ਲ਼, ੜ (# 7, 8, 10, 83, 18, 41)
6. EXTENDED PRONUNCIATION (2 sentence):
   ਹਰਾ/ ਹਰਾਅ (Green / defeat) (# 4)
   ਘੜਾ/ ਘੜਾਅ (Water Pot made of clay / make jewelry) (# 22)
7. TONE (2 Sentences)
   ਹ ਹ੍ (# 4, 19)

The total of the above sentences (5+6+5+2+6+2+2=28) is higher than 25 because three of these 25 sentences belong to more than one category. The details of these 25 sentences are given below:

1. VOWELS (5 sentences): ੳ ਅ ੲ, ਚਿਰ / ਚੀਰ, ਸੁਰ / ਸੂਰ (# 1, 2, 3, 24, 25)

ੳ 1. ਓਏ ਉੱਲੂ! ਊਂਘਦਾ ਕਿਓਂ ਐਂ? ਉਂਗਲੀ ਫੜ!

ਅ 2. ਅਮਰ! ਐਂ ਕਰ, ਔਹ ਐਨਕ ਅੰਦਰ ਲੈ ਆ।

ੲ 3. ਈਸ਼ਰ ਅਤੇ ਇੰਦਰ, ਇਕਵੰਜਾ ਇੱਟਾਂ ਏਥੇ ਲਿਆਓ।

24. **ਚਿਰ** ਨਾ ਲਾ, ਸਾਗ **ਚੀਰ**।

25. ਓਏ **ਸੂਰ**, **ਸੁਰ** 'ਚ ਗਾ!

2. NASALS (5 sentences): ਙ ਞ ਣ ਨ ਮ (# 30, 34, 35, 11, 12)

ਨ 11. ਨਿੰਮੋ ਦੀ ਨੂੰਹ ਦੇ ਨੱਕ 'ਤੇ ਨੈਂ ਟੰਕੇ ਲੱਗੇ।

ਮ 12. ਮੱਘਰ ਦੀ ਮਾਂ, ਮਾਮਾ ਮਾਮੀ, ਮਾਸੀ ਮਾਸੜ, ਮੇਲੇ ਗਏ।

ਙ 30. ਕੰਙਣ ਛਣਕਾਉਂਦੀਏ ਨੀ! ਕਾਹਤੋਂ ਦੁੱਧ 'ਚ ਮੀਂਙਣਾ ਪਾਉਂਦੀ॥

ਞ 34. ਜੰਞ ਚੜ੍ਹਗੀ ਸਰਾਭੇ ਕਰਤਾਰ ਦੀ, ਛੇ ਸਰਬਾਲ੍ਹੇ ਸਜਗੇ॥

ਣ 35. ਸੁਹਣੀ ਨਣਦ ਕਹੇ ਭਰਜਾਈਏ, ਜਾਣੀ-ਜਾਣ ਜਾਣ ਗਿਆ॥

3. TONEMES (6 sentences): ਘ×2 ਝ ਢ ਧ ਭ (# 6, 9, 22, 33, 36, 38)

ਘ 6. ਬਘਿਆੜ ਮੇਘੇ ਘੁਮਿਆਰ ਦਾ ਘੋੜਾ ਖਾ ਗਿਆ।

ਢ 9. ਢੱਗੇ ਦੇ ਢੂੰਢੀਆਂ ਨਾ ਵੱਢ ਕੁੰਢਿਆ, ਢਿੰਬਰੀ ਟੈਟ ਕਰਦੂੰ!

22. ਘੜਾ ਮਾਘ ਭਰ ਭਰੂੰ ਤੇਰਾ ਮੱਘਰਾ, ਝਾਂਜਰਾਂ ਘੜਾਅ ਦੇ ਮਿੱਤਰਾ॥

ਝ 33. ਬਾਝ ਨਸੀਬਾਂ ਦੇ, ਬੁਝਣ ਝਨਾਂ ਦੇ ਦੀਵੇ॥

ਧ 36. ਧੰਦੇ ਵਧਗੇ ਧਨ ਕੁਰੇ ਤੇਰੇ, ਕੰਧਾਂ ਵਿੱਚ ਕੈਦ ਹੋ ਗਈ॥

ਭ 38. ਭਾਰਤ-ਭੂਮੀ ਨੂੰ, ਲੱਭਿਆ ਭਗਤ, ਸਰਾਭਾ॥

4. SPECIAL SENTENCES (9 sentences): (# 4, 7, 8, 10, 18, 19, 39, 41, 83)

ਹ 4. ਹਾਕਮ ਨੇ ਹੰਸ ਨੂੰ ਹਰਾਅ ਕੇ ਹਰਾ ਹੀਰਾ ਜਿੱਤਿਆ।

ਛ 7. ਛਿੰਦੇ ਨੇ ਛੱਪੜ 'ਚੋਂ ਛੇਤੀ ਛੇਤੀ ਛੇ ਕੱਛੂ ਫੜੇ।

ਠ 8. ਠੂਹ-ਠਾਹ ਛੱਡ, ਠੀਕ ਹੋ ਕੇ ਠੁੱਕ ਨਾਲ਼ ਰਹਿ।

ਤ 10. ਤਰਸੇਮੋ, ਤੂੰ ਤੋਤਕੜੇ ਬੰਦ ਕਰਕੇ ਤੱਕਲ਼ਾ ਸਿੱਧਾ ਕਰ।

ਲ਼ 18. ਮਲ਼ ਮਲ਼ ਨ੍ਹਾਉਂਦੀ, ਮਲ ਮਲ ਪਾਉਂਦੀ।

19. ਵਰ ਹਾਣ ਦਾ ਕੁੜੀ ਨੂੰ ਮਿਲ਼ ਜੇ, ਟਿੱਬੀ ਉਤੇ ਮੀਂਹ ਵਰ੍ਹ ਜੇ॥

ਯ 39. ਯਾਰ ਜਾਣਗੇ ਯੱਕੇ ’ਤੇ ਚੜ੍ਹਕੇ, ਯੱਭਲ਼ਾਂ ਨੂੰ ਪਊ ਤੁਰਨਾ॥

ੜ 41. ਪੌੜੀ ਚੜ੍ਹਗੀ ਮੜਕ ਨਾਲ ਲੜਕੇ, ਕਾੜ ਕਾੜ ਬੂਹਾ ਭੰਨਗੀ॥

ਫ 83. ਫੁੰਮਣ ਫੁਕਰਾ ਫੇਰ ਕੀ ਫੰਨੂ ਖੋਹ ਦੂ!

5.10. <u>CONCLUSION</u>

Twenty five representative sentences (listed above) sampled at the sampling frequency f_s=*8 kHz*, were processed for linear prediction analysis and synthesis of the Punjabi speech sentences utilizing the methods discussed in the previous sections. The duration of these sentences spoken by different male and female adult speakers is between 2.0 to 4.0 seconds. The sentences are representative for speech processing in the sense that these are made of all typical speech sounds (Chapter II), i.e., voiced, unvoiced, plosive, nasal and non-nasal sounds, vowels, consonants, and tonemes.

After *analysis*, the Punjabi speech sentences were *synthesized* with different numbers of poles (*p*). Results of the *informal perceptual listening tests* can be summed up as follows:

(i) The quality of the synthesized speech for p = 12 was found to be almost as good as the original speech. Increasing p beyond 12 *did not* show any significant change/improvement in the quality of the synthesized speech thereby leading to the conclusion that p = 12 is sufficient to provide an adequate representation of the speech signals.

(ii) Slight degradation in the quality of synthesized speech was noticeable when p was decreased to 8 especially in nasal and plosive sounds (**Table 5.2**).

(iii) Although poor in quality, the synthesized speech for p even as low as two was intelligible (**Table 5.2**).

(iv) The quality of the synthesized speech was better when the Hamming window was used in autocorrelation method than the speech obtained otherwise using an implicit rectangular window.

(v) The quality of the nasal, plosive and voiced fricative sounds in the synthesized speech was not as good as the quality of the voiced, non-nasal or unvoiced sounds. This was so expected due to the limitations of the simplified all pole model.

(vi) The analysis/synthesis of the Punjabi speech sentences was investigated by varying the algorithms used for pitch detection (*SIFT*, Gold-Rabiner pitch tracker, Autocorrelation pitch tracker, *ZFF*, *RAPT*). No significant improvement has been noticed in the overall performance of the speech synthesizer when different *pitch detection algorithms* were used. Therefore, the well-known result that *no single pitch detection algorithm is uniformly top-ranked across all environments* [90, 99] has been confirmed.

These results are basically similar to the results reported by the leading speech researchers such as Atal and Hanauer [11-12, 15, 85-89, 99], Markel and Gray [75-76, 87-89, 99], Rabiner and Schafer [86-90, 99], Oppenheim [79, 86-89, 99-100], Makhoul [79, 99-100], Parsons [83], Benesty *et al.* [15], Yegnanarayana [129], and supported by recent books [20, 22, 23, 41, 49, 59, 100, 125, 126].

Original waveforms, synthesized speech waveforms ($p = 2$ and $p = 12$), Fast Fourier Transform (FFT) spectrograms [72-73], as well as the pitch, intensity and formants plots generated by *MATLAB* and *Praat* for several representative sentences analyzed and synthesized in this project are presented in the next chapter.

This chapter confirms that the nature of this project is highly interdisciplinary. This work not only requires the knowledge of the Punjabi Language, Gurmukhi script, Malwai dialect, Linguistics and Phonetics (Chapters I-IV), it will also require the knowledge of Computing Science, Information Technology, Engineering, Mathematics, and Statistics to implement the speech analysis and synthesis in this chapter. ■

CHAPTER VI
GRAPHICAL ANALYSIS[5]

6.1. INTRODUCTION

This chapter includes the graphical analysis of the results obtained in Chapter II and Chapter V. The graphical analysis consists of the following items:

(a) Spectrographic analysis, *formant frequencies* as well as *the pitch* and *intensity variations* of speech waveforms analyzed and synthesized in Chapter V.

(b) Graphical evaluation of the new phonetic coding scheme ***PUNJARPAbet*** designed in Chapter II by using corpus, and the typing rates of different coding schemes.

Before we give the spectrographic analysis, all necessary concepts based on the internet websites [154-160] are presented to provide necessary background (in addition to that presented in Chapters I to V) to enable the reader to thoroughly understand this analysis. These concepts include: Vocal Tract and Linear Prediction Model, Spectrograms, Components of Sound, Praat and MATLAB, Spectral Characteristics, and Sentences used for analysis/synthesis.

For an adult male vocal tract (length = 17 cm.), the first three unconstricted resonant frequencies generally fall at about f_1 = 500 Hz, f_2 = 1.5 kHz, f_3 = 2.5 kHz. Although the higher formants (resonances of the vocal tract) do contribute to produce speech sounds of acceptable quality, perceptually only the first three formants mentioned here are important in determining the sound that is heard. The speech spectrum typically rolls off at –12 to –18 *decibels/octave* from about 1 kHz on. Consistent with these observations, the spectral characteristics periodograms (log magnitude vs frequency) has been plotted by using FFT [72-73] to gain additional insight into the perceptual listening tests of the synthesized speech in Chapter V. The graphs for *formant frequencies* [38-40, 99] as well as the *pitch* and *intensity* variations have also been presented in this chapter.

Some of the features of the corpus designed in Chapter IV and transcribed using ***PUNJARPAbet*** designed in Chapter II, have also been graphically evaluated in this chapter. The graphical analysis summarized in figures and tables in this chapter clearly demonstrates that ***PUNJARPAbet*** is a faster, versatile, efficient and convenient phonetic coding scheme. It is free from the laborious, irritating, and time-consuming necessities for dealing with the special symbols for vowels, nasalization, tones, and inserting diacritical marks (especially where two diacritical marks over the ten vowel signs are needed for the Punjabi language in Gurmukhi script). ***PUNJARPAbet*** is an efficient

[5] The results obtained in this chapter have been published in **Journal of Circuits, Systems, and Computers (JCSC), Volume 23, No. 5, June 2014 (SCI)** and **PARKH, Volume II, July-Dec 2013.** The partial results of this chapter have also been presented in the international conference **INSODE-2014** (Rome, Italy).

coding scheme not only for the Punjabi language, but also for any language which has sounds similar to the ones found in the Punjabi speech.

6.2. VOCAL TRACT AND LINEAR PREDICTION MODEL

The relationship between the physical (vocal tract) model and the mathematical (Linear prediction or LPC) model will be helpful to understand the quantities (pitch, intensity, and formant frequencies) being graphed in this chapter. This relationship can be stated as follows [154]:

- Vocal Tract *is equivalent to* LPC filter with transfer function ***H(Z)***
- Vocal Cord vibration *is equivalent to* ***V*** (*Voiced speech*)
- Fricatives and Plosives *are equivalent to* ***UV*** (*Unvoiced speech*)
- Vocal Cord Vibration period *is equivalent to* ***P*** (*Pitch period*)
- Air *is equivalent to* Excitation function u_n
- Air Volume (loudness) *is equivalent to Gain (**G**)*

LPC model leads to significant savings as mentioned below:
Assume we are dealing with the speech coder **LPC10** (the model with LP coefficients p = 10). For the sampling frequency f_s = 8 kHz, *average* frame rate F_r = 50, and frame size N = 20 ms = 160 samples, the vector A generated by the LPC10 consists of the following 13 values:

$$A = (a_1, a_2, a_3, a_4, a_5, a_6, a_7, a_8, a_9, a_{10}, \text{V/UV}, \text{P}, \text{G}).$$

However, this vector has completely and compactly represented the following 160 values of the original speech signal described by the vector S:

$$S = (s_0, s_1, s_2, s_3, \ldots, s_{159}).$$

This is how the computational savings are achieved by the linear prediction model of speech production. This phenomenon is described in this chapter (from a slightly different angle than that expressed in Chapter V) for the sake of completeness.

6.3. SPECTROGRAMS

A spectrogram is a visual representation of the spectrum of frequencies in a sound or other signal as they vary with an independent variable such as time [156-157]. Various authors have called *spectrograms* by other names such as *sonagrams*, *voicegrams, voiceprints*, or *spectral waterfalls.* In general, independent variable (time) is displayed on the horizontal axis, whereas the frequencies and amplitudes (on a linear or logarithmic scale) are displayed on the vertical axis.

Spectrograms are usually created either by using the analog processing (bandpass filters method), or digital processing (FFT method). Analog processing was the only methodology available before the digital computer revolution.

The instrument that generates a spectrogram is called a *spectrograph* or *sonagraph.* In spectrograms, the amplitude of the frequency components “is expressed by means of the degree of blackness (more energy, more blackness). As formants are frequency regions with a high energy (due to the filter resonances), in the spectrogram they are displayed as dark bands” [157]. In the *spectrographs*, the frequency range from 0 to 4 kHz has been displayed because we have used f_s = 8 kHz.

Spectrograms can be used to identify the spoken words phonetically, and to analyze the various calls of animals. In addition to processing of the speech signals, they have also been used extensively in the understanding and development of the fields of music, sonar, radar, and seismology signals [156]. Spectrograms have many applications. The applications closely related to our project are studying the animal sounds, medical assistance in dealing with the speech defects and speech training, the study of phonetics, and speech synthesis.

6.4. THE COMPONENTS OF SOUND

Different sounds (e.g., thunderstorms, vehicle sounds, animal sounds, and human sounds) sound different to us, due to the *three* properties of sound: **intensity**, **pitch,** and **tone** [159]. Due to the variations in these properties, aeroplanes, and fire alarms are *loud*, whispers are *soft*, and every one of our family members, relatives, and friends has a *different* voice.

Intensity

Like any other wave, the sound waves have height, or amplitude. *Amplitude* is a measure of energy. The more energy a wave has, the higher is its amplitude. As amplitude increases, intensity also increases. **Intensity** is the amount of energy a sound has over an area. The same sound is more intense if you hear it in a smaller area. In general, we call sounds with a higher intensity louder. The sounds can be loud (e.g., yelling), or soft (e.g., breathing). Loudness cannot be assigned a specific number, but intensity can. Intensity is measured in *decibels* or *db*. Decibels and intensity can be measured with instruments. A whisper is about 10-30 *db*, normal conversation is 60 *db*, and the lawn mower sound is 100 *db*. Listening to loud sounds (sounds with intensities above 85 *db*) can damage human ears because the human ear is very sensitive to high sounds. Sounds over 120 decibels (the threshold of pain) are painful to listen to [159].

Pitch

Pitch helps us to distinguish between low and high sounds. If a singer sings the same note twice (*say*, one an octave above the other), we can hear a difference between these two sounds. That is because their pitch is different. Adult males have low pitch voices, whereas women and young children have high pitch voices. Pitch depends on the frequency of a sound wave. **Frequency** is the number of wavelengths that fit into one unit of time. Frequencies are measured in Hz (hertz). One Hz is equal to one cycle of compression and rarefaction per second. High sounds have high frequencies and low sounds have low frequencies. Thunder sounds have frequency range near 50 Hz, whereas a whistle can have a frequency of 1 kHz. The human ear is able to hear frequencies from 20 Hz to 20 kHz. We cannot hear sounds with higher frequencies (e.g. dog whistle), while animals can. Sounds that are too high for us to hear are called ultrasonic [159].

Tone (or sound quality)

Some sounds are pleasant while others are unpleasant, because they have a different tone, or sound quality. Several sounds (e.g. music, sound of rain) are pleasant, while others (e.g., hammer, construction work, an inexperienced learner playing a musical instrument) are unpleasant to listen to. Both music and noise are sounds, but music is much more enjoyable than the noise. To help classify sounds, there are three properties which a sound must have to be musical. A *sound* must have an identifiable *pitch*, a good or pleasing quality of *tone*, and repeating pattern or rhythm to be *music*. *Noise* on the other hand has no identifiable pitch, no pleasing tone, and may have no steady rhythm [159].

When a source vibrates, it actually vibrates with many frequencies at the same time. Each of those frequencies produces a wave. Sound quality depends on the combination of different frequencies of sound waves. This pitch is defined as the *fundamental frequency*. The whole number multiples of the fundamental are called *harmonics*. In most cases, more harmonics mean the better (*or* fuller) quality of a sound. All the different overtones (frequencies higher than the fundamental) of a sound help give it a unique pattern. This is especially true for a person’s voice. Everybody in the world has a different voice print, or pattern of overtones. A criminal can be tracked, if the criminal’s voice print is known, just like the fingerprints (see Section **1.7** and **3.5**). Voice identification equipment is used in advanced security systems to recognize and let in only one authorized person. Voice prints are also used in modern technology, for example, voice activated telephones [159].

6.5. <u>PRAAT and MATLAB</u>

Praat (a Dutch word that stands for "talk") is an open-source program for the analysis of speech [157]. It is a free scientific computer software package for the analysis of speech in phonetics. It was originally designed, and continues to be developed by Paul Boersma and David Weenink of the University of Amsterdam [157-158].

MATLAB (acronym for ***mat****rix* ***lab****oratory*), a multi-paradigm numerical computing environment and fourth-generation programming language, is developed by MathWorks. MATLAB package allows matrix manipulations, plotting of functions and data, implementation of algorithms, creation of user interfaces, and interfacing with programs written in other languages, e.g., C, C++, Java, and FORTRAN [160]. MATLAB, intended primarily for numerical computing, has gained a lot of popularity in signal processing, including *digital speech processing* [36, 121, 160].

Both **Praat** and **MATLAB** have been extensively used in the graphical analysis presented in the next sections.

6.6. SPECTRAL CHARACTERISTICS

The spectral characteristics of the speech sentences analyzed and synthesized using the linear prediction model as discussed in Chapter V are graphically presented in this chapter as Spectrograms (time-varying representations forming images). The frequency-axis can be either linear or logarithmic [156]. The spectrograms of a speech signal are computed by using the Short-time Fourier Transform as outlined here.

The DFT (Discrete Fourier Transform) of a finite sequence $s_n\,(0 \le k \le N-1)$ and its Inverse DFT is defined as:

$$S(k) = \sum_{n=0}^{N-1} s(n)\, e^{-j(2\pi/N)\,nk}, \quad 0 \le k \le N-1 \tag{6.1}$$

$$S(n) = \frac{1}{N}\sum_{k=0}^{N-1} S(k)\, e^{j(2\pi/N)\,nk}, \quad 0 \le n \le N-1 \tag{6.2}$$

The log magnitude spectrum of the input data LM (S) and that of the output of the models LM (G/A) are taken as:

$$\text{LM (S)} = 10\log_{10}\,|S(k)|^2 \tag{6.3}$$

and

$$\text{LM(G/A)} = 10\,\log_{10}\,\frac{G^2}{|A(k)|^2} \tag{6.4}$$

where $0 \le k \le \frac{N}{2}$.

6.7. SENTENCES USED FOR ANALYSIS/SYNTHESIS

Many different approaches can be taken for the purpose of spectrographic analysis of a speech signal. A considerable number of graphs are involved for the spectrographic analysis of a single speech sentence. To keep the volume under control, 25 sentences (listed in Appendix E) have been selected for the purpose of this project so that a representative analysis/synthesis can be conducted ('#' stands for the 'sentence number *x*' as listed in Appendix E). While choosing these sentences, the themes taken into consideration included the *vowels and consonants, tonemes, nasals, semi-vowels, extended pronunciation* [139, pp. (ਨ)] and some *special Punjabi speech sounds* as follows:

ੳ ਅ ੲ; ਘ ਝ ਢ ਧ ਭ; ਙ ਞ ਣ ਨ ਮ; ਯ ਵ, ਛ ਠ ਤ ਫ ਲ਼ ੜ, ਘੜਾ/ਘੜਾਅ, ਹਰਾ/ ਹਰਾਅ, ਹ ਹ੍

8. VOWELS (5 sentences):
   Three *Matra Vahaks*, two long and short vowels (i & I; u & U)
   ੳ ਅ ੲ, ਚਿਰ / ਚੀਰ, ਸੁਰ / ਸੂਰ (# 1, 2, 3, 24, 25)
9. TONEMES (6 sentences):
   ਘ (2) ਝ ਢ ਧ ਭ (# 6, 22, 33, 9, 36, 38)
10. NASALS (5 sentences):
    ਙ ਞ ਣ ਨ ਮ (# 30, 34, 35, 11, 12)
11. SEMI-VOWELS (2 sentences):
    ਯ ਵ (39, 19)
12. SPECIAL PUNJABI SOUNDS (6 sentences):
    ਛ, ਠ, ਤ, ਫ, ਲ਼, ੜ (# 7, 8, 10, 83, 18, 41)
13. EXTENDED PRONUNCIATION (2 sentence):
    ਹਰਾ/ ਹਰਾਅ (Green / defeat) (# 4)

    ਘੜਾ/ ਘੜਾਅ (Water Pot made of clay / make jewelry) (# 22)
14. TONE (2 Sentences)
    ਹ ਹ੍ (# 4, 19)

The total of the above sentences (5+6+5+2+6+2+2=28) is higher than 25 because three of these 25 sentences belong to more than one category. The details of these 25 sentences are given below:

1. VOWELS: ੳ ਅ ੲ, ਚਿਰ / ਚੀਰ, ਸੁਰ / ਸੂਰ (5 sentences: # 1, 2, 3, 24, 25)

ੳ 1.	ਓਏ ਉੱਲੂ! ਊਂਘਦਾ ਕਿਓਂ ਐਂ? ਉਂਗਲੀ ਫੜ!

ਅ 2.	ਅਮਰ! ਐਂ ਕਰ, ਔਹ ਐਨਕ ਅੰਦਰ ਲੈ ਆ।

ੲ 3.	ਈਸ਼ਰ ਅਤੇ ਇੰਦਰ, ਇਕਵੰਜਾ ਇੱਟਾਂ ਏਥੇ ਲਿਆਓ।

24.	**ਚਿਰ** ਨਾ ਲਾ, ਸਾਗ **ਚੀਰ**।

25.	ਓਏ **ਸੂਰ**, **ਸੁਰ** ’ਚ ਗਾ!

2. NASALS (5 sentences): ਙ ਞ ਣ ਨ ਮ (# 30, 34, 35, 11, 12)

ਨ 11.	ਨਿੰਮੋ ਦੀ ਨੂੰਹ ਦੇ ਨੱਕ ’ਤੇ ਨੌਂ ਟੰਕੇ ਲੱਗੇ।

ਮ 12.	ਮੱਘਰ ਦੀ ਮਾਂ, ਮਾਮਾ ਮਾਮੀ, ਮਾਸੀ ਮਾਸੜ, ਮੇਲੇ ਗਏ।

ਙ 30.	ਕੰਙਣ ਛਣਕਾਉਂਦੀਏ ਨੀ! ਕਾਹਤੋਂ ਦੁੱਧ ’ਚ ਮੀਂਙਣਾ ਪਾਉਂਦੀ॥

ਞ 34.	ਜੰਞ ਚੜ੍ਹਗੀ ਸਰਾਭੇ ਕਰਤਾਰ ਦੀ, ਛੇ ਸਰਬਾਲ੍ਹੇ ਸਜਗੇ॥

ਣ 35.	ਸੁਹਣੀ ਨਣਦ ਕਹੇ ਭਰਜਾਈਏ, ਜਾਣੀ-ਜਾਣ ਜਾਣ ਗਿਆ॥

3. TONEMES (6 sentences): ਘ×2 ਝ ਢ ਧ ਭ (# 6, 9, 22, 33, 36, 38)

ਘ 6.	ਬਘਿਆੜ ਮੇਘੇ ਘੁਮਿਆਰ ਦਾ ਘੋੜਾ ਖਾ ਗਿਆ।

ਢ 9.	ਢੱਗੇ ਦੇ ਚੂੰਢੀਆਂ ਨਾ ਵੱਢ ਕੁੰਢਿਆ, ਢਿੰਬਰੀ ਟੈਟ ਕਰਦੂੰ!

22.	ਘੜਾ ਮਾਘ ਭਰ ਭਰੂੰ ਤੇਰਾ ਮੱਘਰਾ, ਝਾਂਜਰਾਂ ਘੜਾਅ ਦੇ ਮਿੱਤਰਾ॥

ਝ 33.	ਬਾਝ ਨਸੀਬਾਂ ਦੇ, ਬੁਝਣ ਝਨਾਂ ਦੇ ਦੀਵੇ॥

ਧ 36.	ਧੰਦੇ ਵਧਗੇ ਧਨ ਕੁਰੇ ਤੇਰੇ, ਕੰਧਾਂ ਵਿੱਚ ਕੈਦ ਹੋ ਗਈ॥

ਭ 38.	ਭਾਰਤ-ਭੂਮੀ ਨੂੰ, ਲੱਭਿਆ ਭਗਤ, ਸਰਾਭਾ॥

4. SPECIAL SENTENCES (9 sentences): (# 4, 7, 8, 10, 18, 19, 39, 41, 83)

ਹ 4.	ਹਾਕਮ ਨੇ ਹੰਸ ਨੂੰ ਹਰਾਅ ਕੇ ਹਰਾ ਹੀਰਾ ਜਿੱਤਿਆ।

ਛ 7.	ਛਿੰਦੇ ਨੇ ਛੱਪੜ ’ਚੋਂ ਛੇਤੀ ਛੇਤੀ ਛੇ ਕੱਛੂ ਫੜੇ।

ਠ 8.	ਠੂਹ-ਠਾਹ ਛੱਡ, ਠੀਕ ਹੋ ਕੇ ਠੁੱਕ ਨਾਲ਼ ਰਹਿ।

ਤ 10. ਤਰਸੇਮੇ, ਤੂੰ ਤੋਤਕੜੇ ਬੰਦ ਕਰਕੇ ਤੱਕਲ਼ਾ ਸਿੱਧਾ ਕਰ।

ਲ਼ 18. ਮਲ਼ ਮਲ਼ ਨ੍ਹਾਉਂਦੀ, ਮਲ ਮਲ ਪਾਉਂਦੀ।

19. ਵਰ ਹਾਣ ਦਾ ਕੁੜੀ ਨੂੰ ਮਿਲ਼ ਜੇ, ਟਿੱਬੀ ਉਤੇ ਮੀਂਹ ਵਰ੍ਹ ਜੇ॥

ਯ 39. ਯਾਰ ਜਾਣਗੇ ਯੱਕੇ ’ਤੇ ਚੜ੍ਹਕੇ, ਯੱਭਲ਼ਾਂ ਨੂੰ ਪਊ ਤੁਰਨਾ॥

ੜ 41. ਪੌੜੀ ਚੜ੍ਹਗੀ ਮੜਕ ਨਾਲ ਲੜਕੇ, ਕਾੜ ਕਾੜ ਬੂਹਾ ਭੰਨਗੀ॥

ਫ 83. ਫੁੰਮਣ ਫੁਕਰਾ ਫੇਰ ਕੀ ਫੰਨੂ ਖੋਹ ਦੂ!

6.8. SPECTROGRAPHIC ANALYSIS (FORMANTS, PITCH, INTENSITY)

The graphical analysis of the 25 sentences synthesized in this project has been summarized in **Table 6.1**. It gives an overview of the four values (pitch, intensity, and the first two formants) for the following five signals: original sentence, residual signal (p = 2), synthesized signal (p = 2), residual signal (p = 12) and the synthesized signal (p = 12), where p stands for the number of poles.

Formant frequencies [38-40, 99] play an important role to distinguish various speech sounds. We have compared original speech spectrum for various sentences and ***bolis*** with synthesized and residual sound spectrum having 2 poles and 12 poles (LPC) respectively for the different groups of the sentences as shown in **Tables 6.2, 6.4, 6.6, and 6.8**. The Pitch and intensity variations for the same groups are shown in **Tables 6.3, 6.5, 6.7, and 6.9**.

Table 6.1: Summary of the Graphical Analysis of the 25 Synthesized Sentences

April 2014													
	Original					Residual				Synthesized			
Sentence No.	Pitch	Intensity	Formant I	Formant II	No. of poles	Pitch	Intensity	Formant I	Formant II	Pitch	Intensity	Formant I	Formant II
1	166.5	71.28	543.12	1423.9	2	157.9	73.55	813.35	1867.02	166.5	74.28	543.15	1423.99
					12	157.1	69.64	932.04	1885.8	166.5	74.28	543.15	1423.99
2	145.2	70.96	630.37	1491.01	2	141.7	71.01	915.34	1773.86	145.2	75.86	630.39	1491.04
					12	138.1	68.68	966.24	1880.12	145.2	75.86	630.39	1491.04
3	155	69.16	529.88	1624.99	2	146.4	69.5	812.62	1839.09	155	73.54	529.85	1624.97
					12	146.9	68.27	958.37	1895.58	155	73.54	529.85	1624.97
4	133.4	69.84	622.18	1482.8	2	135.2	71.03	887.84	1824.15	133.4	73.28	622.17	1482.81
					12	134.6	69.34	956.8	1886.91	133.4	73.28	622.17	1482.81
6	140.3	73.79	558.27	1438.82	2	140.7	71.87	862.04	1769.25	140.3	75.98	558.26	1438.84
					12	137.5	69.91	946.2	1867.03	140.3	75.98	558.26	1438.84
7	158.8	66.47	530.95	1785.74	2	161.3	70.9	748.45	1928.29	158.8	74.35	530.94	1785.71
					12	161.7	66.26	958.22	1912.12	158.8	74.35	530.94	1785.71
8	158.7	70.33	566.71	1484.24	2	161	71.3	848.51	1829.93	158.7	73.77	566.68	1484.24
					12	160.4	70.05	938.81	1896.69	158.7	73.77	566.68	1484.24
9	161.3	74.14	537.18	1588.24	2	168.6	72.93	834.06	1866.62	161.3	75.59	537.31	1588.11
					12	171.5	69.58	966.5	1898.47	161.3	75.59	537.31	1588.11
10	162.5	73.32	561.35	1419.51	2	163.1	72.25	869.22	1786.6	162.5	74.42	561.4	1419.77
					12	157.2	69.39	938.62	1864.63	162.5	74.42	561.4	1419.77
11	157.1	72.62	475.43	1554.53	2	158.1	71.99	795.26	1892.32	157.1	76.06	475.41	1554.51
					12	159.2	70.37	942.24	1887.42	157.1	76.06	475.41	1554.51
12	149.5	74.73	512.55	1533.26	2	148.6	71.27	800.06	1830.18	149.5	76.92	512.55	1533.24
					12	147.3	69.24	948.91	1879.22	149.5	76.92	512.55	1533.24
18	147.8	74.01	490.24	1545.77	2	148.2	70.28	835.08	1883.84	147.8	74.45	490.29	1545.61
					12	150.9	67.96	942.47	1881.45	147.8	74.45	490.29	1545.61
19	155.8	73.52	490.23	1628.65	2	158.8	71.48	762.39	1904.47	155.8	74.97	490.38	1628.65
					12	159.6	69.05	958.56	1901.31	155.8	74.97	490.38	1628.65
22	156.9	75.99	594.35	1381.16	2	158.9	71.1	926.21	1706.66	156.9	75.82	594.28	1381.03
					12	160.8	69.45	948.46	1859.55	156.9	75.82	594.28	1381.03
24	152.3	69.85	636.17	1570.86	2	152.8	73.06	868.75	1808.57	152.3	77.01	636.17	1570.8
					12	152.9	70.44	958.34	1889.63	152.3	77.01	636.17	1570.8
25	162.7	70.73	604.33	1427.35	2	158.5	69.4	891.76	1818.15	162.7	75.13	604.34	1427.38
					12	158.4	67.65	961.8	1899.15	162.7	75.13	604.34	1427.38
30	167.4	68.1	510.9	1594.72	2	168.5	72.68	792.14	1924.11	167.4	76.37	510.86	1594.7
					12	170.4	69.34	948.37	1910.28	167.4	76.37	510.86	1594.7
33	174.4	71.55	488.7	1666.96	2	171.3	69.82	745.22	1920.43	174.4	75.45	488.63	1666.94
					12	173.2	68.22	955.41	1923.52	174.4	75.45	488.63	1666.94
34	180.5	70.55	565.94	1693.76	2	177.9	73.44	823.11	1872.57	180.5	76.15	566.01	1693.81
					12	179.5	70.16	967.44	1902.78	180.5	76.15	566.01	1693.81
35	158.9	69.35	527.21	1691.35	2	161.9	72.02	796.71	1918.5	158.9	75.86	527.19	1691.35
					12	162.1	69.73	962.87	1902.35	158.9	75.86	527.19	1691.35
36	164	69.78	503.08	1657.27	2	164.6	71.64	791.25	1877.79	164	76.29	503.06	1657.26
					12	166.7	69.02	955.9	1895.07	164	76.29	503.06	1657.26
38	161.6	70.4	563.71	1386.34	2	164.6	71.55	876.93	1810.85	161.6	75.99	563.75	1386.35
					12	171.2	68.96	937.22	1874.5	161.6	75.99	563.75	1386.35
39	178.9	71.7	521.41	1576.03	2	184.9	72.71	773.82	1848.37	178.9	75.15	521.41	1576.07
					12	182.4	70.25	954.68	1893.68	178.9	75.15	521.41	1576.07
41	164.9	70.98	523.14	1539.22	2	165.1	72.7	805.05	1855.05	164.9	76.29	523.13	1539.26
					12	167.9	70.89	947.34	1880.75	164.9	76.29	523.13	1539.26
83	200.8	68.36	465.11	1335.09	2	202.5	73.61	779.57	1660.06	200.8	75.87	465.11	1335.08
					12	202.9	71	861.21	1668.58	200.8	75.87	465.11	1335.08

6.8.1. SPECTROGRAPHIC ANALYSIS: VOWEL ANALYSIS

This subsection concentrates on the analysis of the *five* sentences involving *three vowel forms* (ੳ, ਅ, ੲ), as well as the contrast between the *matras* ਿ and ੀ (*I* and *i*), and ੁ and ੂ (*U* and *u*). It has been found that the formant frequencies of synthesized speech sentences are approximately same as those of the original sentences. However, the formant frequencies have been increased by a large magnitude for the residual signals. In case of $p = 12$ (LPC), the formant frequencies for the residual signal are greater than the formant frequencies for the residual signal for $p = 2$, as expected. Resulting table is shown below (**Table 6.2**). Pitch and intensity variations are also shown in **Table 6.3**.

Table 6.2: Vowel Analysis (First two formants: 5 sentences)

Sr. No.	Sentence	No. of poles	Formant I	Formant II
1/1	ਓਏ ਉੱਲੂ! ਊਂਘਦਾ ਕਿਓਂ ਐਂ? ਉਂਗਲੀ ਫੜ!	Original	543.12	1423.9
	Synthesized Signal	2	543.15	1423.99
		12	543.15	1423.99
	Residual Signal	2	813.35	1867.02
		12	932.04	1885.8
2/2	ਅਮਰ! ਐਂ ਕਰ, ਔਹ ਐਨਕ ਅੰਦਰ ਲੈ ਆ।	Original	630.37	1491.01
	Synthesized Signal	2	630.39	1491.04
		12	630.39	1491.04
	Residual Signal	2	915.34	1773.86
		12	966.24	1880.12
3/3	ਈਸ਼ਰ ਅਤੇ ਇੰਦਰ, ਇਕਵੰਜਾ ਇੱਟਾਂ ਏਥੇ ਲਿਆਓ।	Original	529.88	1624.99
	Synthesized Signal	2	529.85	1624.97
		12	529.85	1624.97
	Residual Signal	2	812.62	1839.09
		12	958.37	1895.58
4/24	ਚਿਰ ਨਾ ਲਾ, ਸਾਗ ਚੀਰ।	Original	636.17	1570.86
	Synthesized Signal	2	636.17	1570.8
		12	636.17	1570.8
	Residual Signal	2	868.75	1808.57
		12	958.34	1889.63
5/25	ਓਏ ਸੂਰ, ਸੁਰ ’ਚ ਗਾ!	Original	604.33	1427.35
	Synthesized Signal	2	604.34	1427.38
		12	604.34	1427.38
	Residual Signal	2	891.76	1818.15
		12	961.8	1899.15

Table 6.3: Vowel Analysis (Pitch and Intensity: 5 sentences)

Sr.	Sentence	No. of poles	Pitch	Intensity
1/1	ਓਏ ਉੱਲੂ! ਊਂਘਦਾ ਕਿਓਂ ਐਂ? ਉਂਗਲੀ ਫੜ!	Original	166.54	71.28
	Synthesized Signal	2	166.53	74.28
		12	166.53	74.28
	Residual Signal	2	157.94	73.55
		12	157.06	69.64
2/2	ਅਮਰ! ਐਂ ਕਰ, ਔਹ ਐਨਕ ਅੰਦਰ ਲੈ ਆ।	Original	145.19	70.96
	Synthesized Signal	2	145.18	75.86
		12	145.18	75.86
	Residual Signal	2	141.69	71.01
		12	138.13	68.68
3/3	ਈਸ਼ਰ ਅਤੇ ਇੰਦਰ, ਇਕਵੰਜਾ ਇੱਟਾਂ ਏਥੇ ਲਿਆਓ।	Original	154.96	69.16
	Synthesized Signal	2	154.95	73.54
		12	154.95	73.54
	Residual Signal	2	146.4	69.5
		12	146.87	68.27
4/24	ਚਿਰ ਨਾ ਲਾ, ਸਾਗ ਚੀਰ।	Original	152.26	69.85
	Synthesized Signal	2	152.26	77.01
		12	152.26	77.01
	Residual Signal	2	152.8	73.06
		12	152.91	70.44
5/25	ਓਏ ਸੂਰ, ਸੁਰ ’ਚ ਗਾ!	Original	162.65	70.73
	Synthesized Signal	2	162.65	75.13
		12	162.65	75.13
	Residual Signal	2	158.5	69.4
		12	158.36	67.65

It has been found that

a) Pitch of the synthesized speech signal is approximately same as that of the original speech signal both in case of 2 poles and 12 poles.
b) Pitch of the residual speech signal is *slightly* decreased as compared to the original speech signal.
c) Also for the residual signal, pitch is *slightly* more with 2 poles than that of 12 poles.
d) Intensity of the residual speech signal with 2 poles is *slightly* increased, and with 12 poles is decreased as compared to the original speech signal (except # 24).

6.8.2. SPECTROGRAPHIC ANALYSIS: NASAL ANALYSIS

This subsection concentrates on the analysis of the *five* sentences involving *five nasals* (ਙ, ਞ, ਣ, ਨ, ਮ). It has been found that the formant frequencies of synthesized speech sentences are approximately same as those of the original sentences. However, the formant frequencies have been increased by a large magnitude for the residual signals. In case of p = 12 (LPC), the formant frequencies for the residual signal are greater than the formant frequencies for the residual signal for p = 2, as expected. Resulting table is shown below (**Table 6.4**). Pitch and intensity variations are also shown in **Table 6.5**.

Table 6.4: Nasal analysis (First two formants: 5 sentences)

No.	Sentence	No. of poles	Formant I	Formant II
1/11	ਨਿੰਮੋ ਦੀ ਨੂੰਹ ਦੇ ਨੱਕ 'ਤੇ ਨੌਂ ਟੰਕੇ ਲੱਗੇ।	Original	475.43	1554.53
	Synthesized Signal	2	475.41	1554.51
		12	475.41	1554.51
	Residual Signal	2	795.26	1892.32
		12	942.24	1887.42
2/12	ਮੱਘਰ ਦੀ ਮਾਂ, ਮਾਮਾ ਮਾਮੀ, ਮਾਸੀ ਮਾਸੜ, ਮੇਲੇ ਗਏ।	Original	512.55	1533.26
	Synthesized Signal	2	512.55	1533.24
		12	512.55	1533.24
	Residual Signal	2	800.06	1830.18
		12	948.91	1879.22
3/30	ਕੰਙਣ ਛਣਕਾਉਂਦੀਏ ਨੀ! ਕਾਹਤੋਂ ਦੁੱਧ 'ਚ ਮੀਂਙਣਾ ਪਾਉਂਦੀ॥	Original	510.9	1594.72
	Synthesized Signal	2	510.86	1594.7
		12	510.86	1594.7
	Residual Signal	2	792.14	1924.11
		12	948.37	1910.28
4/34	ਜੰਞ ਚੜ੍ਹਗੀ ਸਰਾਭੇ ਕਰਤਾਰ ਦੀ, ਛੇ ਸਰਬਾਲ੍ਹੇ ਸਜਗੇ॥	Original	565.94	1693.76
	Synthesized Signal	2	566.01	1693.81
		12	566.01	1693.81
	Residual Signal	2	823.11	1872.57
		12	967.44	1902.78
5/35	ਸੁਹਣੀ ਨਣਦ ਕਹੇ ਭਰਜਾਈਏ, ਜਾਣੀ-ਜਾਣ ਜਾਣ ਗਿਆ॥	Original	527.21	1691.35
	Synthesized Signal	2	527.19	1691.35
		12	527.19	1691.35
	Residual Signal	2	796.71	1918.5
		12	962.87	1902.35

Table 6.5: Nasal analysis (Pitch and Intensity: 5 sentences)

No.	Sentence	No. of poles	Pitch	Intensity
1/11	ਨਿੰਮੋ ਦੀ ਨੂੰਹ ਦੇ ਨੱਕ ’ਤੇ ਨੌਂ ਟੰਕੇ ਲੱਗੇ।	Original	157.06	72.62
	Synthesized Signal	2	157.06	76.06
		12	157.06	76.06
	Residual Signal	2	158.12	71.99
		12	159.2	70.37
2/12	ਮੱਘਰ ਦੀ ਮਾਂ, ਮਾਮਾ ਮਾਮੀ, ਮਾਸੀ ਮਾਸੜ, ਮੇਲੇ ਗਏ।	Original	149.51	74.73
	Synthesized Signal	2	149.51	76.92
		12	149.51	76.92
	Residual Signal	2	148.6	71.27
		12	147.33	69.24
3/30	ਕੰਙਣ ਛਣਕਾਉਂਦੀਏ ਨੀ! ਕਾਹਤੋਂ ਦੁੱਧ ’ਚ ਮੀਂਙਣਾ ਪਾਉਂਦੀ॥	Original	167.38	68.1
	Synthesized Signal	2	167.38	76.37
		12	167.38	76.37
	Residual Signal	2	168.45	72.68
		12	170.39	69.34
4/34	ਜੰਞ ਚੜ੍ਹਗੀ ਸਰਾਭੇ ਕਰਤਾਰ ਦੀ, ਛੇ ਸਰਬਾਲ੍ਹੇ ਸਜਗੇ॥	Original	180.5	70.55
	Synthesized Signal	2	180.5	76.15
		12	180.5	76.15
	Residual Signal	2	177.85	73.44
		12	179.51	70.16
5/35	ਸੁਹਣੀ ਨਣਦ ਕਹੇ ਭਰਜਾਈਏ, ਜਾਣੀ-ਜਾਣ ਜਾਣ ਗਿਆ॥	Original	158.87	69.35
	Synthesized Signal	2	158.87	75.86
		12	158.87	75.86
	Residual Signal	2	161.85	72.02
		12	162.1	69.73

It has been found that

a) Pitch of the synthesized speech signal is approximately same as that of the signal both in case of 2 poles and 12 poles.
b) In *two* cases, pitch of the residual sound signal is decreased (ਮ, ਞ) as compared to original sound signal and in other *three* cases (ਨ, ਙ, ਣ), it increases.
c) Intensity of synthesized sound signal is increased as compared to original sound signal both in case of 2 poles and 12 poles.
d) Intensity of the residual sound signals for *two* nasals (ਨ, ਮ) decreases, and for other *three* nasals (ਙ, ਞ, ਣ) it increases as compared to the original sound signal.

6.8.3. SPECTROGRAPHIC ANALYSIS: TONEME ANALYSIS

This subsection concentrates on the analysis of the *six* sentences involving *five tonemes* (ਘ, ਝ, ਢ, ਧ, ਭ). It has been found that the formant frequencies of synthesized speech sentences are approximately same as those of the original sentences. However, the formant frequencies have been increased by a large magnitude for the residual signals. In case of p = 12 (LPC), the formant frequencies for the residual signal are greater than the formant frequencies for the residual signal for p = 2, as expected. Resulting table is shown below (**Table 6.6**). Pitch and intensity variations are also shown in **Table 6.7**.

Table 6.6: Toneme Analysis (First two formants: 6 sentences)

Sr. No.	Sentence	No. of poles	Formant I	Formant II
1/6	ਬਘਿਆੜ ਮੇਘੇ ਘੁਮਿਆਰ ਦਾ ਘੋੜਾ ਖਾ ਗਿਆ।	Original	558.27	1438.82
	Synthesized Signal	2	558.26	1438.84
		12	558.26	1438.84
	Residual Signal	2	862.04	1769.25
		12	946.20	1867.03
2/9	ਢੱਗੇ ਦੇ ਚੂੰਢੀਆਂ ਨਾ ਵੱਢ ਕੁੰਢਿਆ, ਢਿੰਬਰੀ ਟੈਟ ਕਰਦੂੰ!	Original	537.18	1588.24
	Synthesized Signal	2	537.31	1588.11
		12	537.31	1588.11
	Residual Signal	2	834.06	1866.62
		12	966.5	1898.47
3/22	ਘੜਾ ਮਾਘ ਭਰ ਭਰੂੰ ਤੇਰਾ ਮੱਘਰਾ, ਝਾਂਜਰਾਂ ਘੜਾਅ ਦੇ ਮਿੱਤਰਾ॥	Original	594.35	1381.16
	Synthesized Signal	2	594.28	1381.03
		12	594.28	1381.03
	Residual Signal	2	926.21	1706.66
		12	948.46	1859.55
4/33	ਬਾਝ ਨਸੀਬਾਂ ਦੇ, ਬੁਝਣ ਝਨਾਂ ਦੇ ਦੀਵੇ॥	Original	488.7	1666.96
	Synthesized Signal	2	488.63	1666.94
		12	488.63	1666.94
	Residual Signal	2	745.22	1920.43
		12	955.41	1923.52
5/36	ਧੰਦੇ ਵਧਗੇ ਧਨ ਕੁਰੇ ਤੇਰੇ, ਕੰਧਾਂ ਵਿੱਚ ਕੈਦ ਹੋ ਗਈ॥	Original	503.08	1657.27
	Synthesized Signal	2	503.06	1657.26
		12	503.06	1657.26
	Residual Signal	2	791.25	1877.79
		12	955.9	1895.07
6/38	ਭਾਰਤ-ਭੂਮੀ ਨੂੰ, ਲੱਭਿਆ ਭਗਤ, ਸਰਾਭਾ॥	Original	563.71	1386.34
	Synthesized Signal	2	563.75	1386.35
		12	563.75	1386.35
	Residual Signal	2	876.93	1810.85
		12	937.22	1874.5

Table 6.7: Toneme Analysis (Pitch and Intensity: 6 sentences)

No.	Sentence	No. of poles	Pitch	Intensity
1/6	ਬਘਿਆੜ ਮੇਘੇ ਘੁਮਿਆਰ ਦਾ ਘੋੜਾ ਖਾ ਗਿਆ।	Original	140.25	73.79
	Synthesized Signal	2	140.25	75.98
		12	140.25	75.98
	Residual Signal	2	140.66	71.87
		12	137.48	69.91
2/9	ਢੱਗੇ ਦੇ ਢੂੰਢੀਆਂ ਨਾ ਵੱਢ ਕੁੰਢਿਆ, ਢਿੰਬਰੀ ਟੈਟ ਕਰਦੂੰ!	Original	161.34	74.14
	Synthesized Signal	2	161.34	75.59
		12	161.34	75.59
	Residual Signal	2	168.56	72.93
		12	171.45	69.58
3/22	ਘੜਾ ਮਾਘ ਭਰ ਭਰੂੰ ਤੇਰਾ ਮੱਘਰਾ, ਝਾਂਜਰਾਂ ਘੜਾਅ ਦੇ ਮਿੱਤਰਾ॥	Original	156.86	75.99
	Synthesized Signal	2	156.86	75.82
		12	156.86	75.82
	Residual Signal	2	158.86	71.1
		12	160.79	69.45
4/33	ਬਾਝ ਨਸੀਬਾਂ ਦੇ, ਬੁਝਣ ਝਨਾਂ ਦੇ ਦੀਵੇ॥	Original	174.43	71.55
	Synthesized Signal	2	174.43	75.45
		12	174.43	75.45
	Residual Signal	2	171.31	69.82
		12	173.2	68.22
5/36	ਧੰਦੇ ਵਧਗੇ ਧਨ ਕੁਰੇ ਤੇਰੇ, ਕੰਧਾਂ ਵਿੱਚ ਕੈਦ ਹੋ ਗਈ॥	Original	164.03	69.78
	Synthesized Signal	2	164.03	76.29
		12	164.03	76.29
	Residual Signal	2	164.56	71.64
		12	166.74	69.02
5/38	ਭਾਰਤ-ਭੂਮੀ ਨੂੰ, ਲੱਭਿਆ ਭਗਤ, ਸਰਾਭਾ॥	Original	161.56	70.4
	Synthesized Signal	2	161.56	75.99
		12	161.56	75.99
	Residual Signal	2	164.59	71.55
		12	171.2	68.96

It has been found that

a) Pitch of the synthesized speech signal is approximately same as that of the original speech signal both in case of 2 poles and 12 poles.
b) Pitch of residual speech signal is increased as compared to original speech signal.
c) Intensity of the synthesized speech signal is increased as compared to the original speech signal both in case of 2 poles and 12 poles.
d) Intensity of the residual speech signal is decreased both in 2 poles and 12 poles as compared to the original speech signal. Also, Intensity for p = 12 is lower than that for p = 2.

6.8.4. SPECTROGRAPHIC ANALYSIS: SPECIAL SENTENCES

This subsection concentrates on the analysis of the *ten* special sentences involving *the special phonemes* (ਛ, ਠ, ਤ, ਫ, ਲ਼, ੜ, ਧ, ਵ, ਹ, ਹ੍), as well as the examples of the extended pronunciation. It has been found that the formant frequencies of synthesized speech sentences are approximately same as those of the original sentences. However, the formant frequencies have been increased by a large magnitude for the residual signals. In case of p = 12 (LPC), the formant frequencies for the residual signal are greater than the formant frequencies for the residual signal for p = 2, as expected. Resulting table is shown below (**Table 6.8**). Pitch and intensity variations are also shown in **Table 6.9**.

Table 6.8: Special Sentences Analysis (First two formants: 10 sentences)

Sr. No.	Sentence	No. of poles	Formant I	Formant II
1/4	ਹਾਕਮ ਨੇ ਹੰਸ ਨੂੰ ਹਰਾਅ ਕੇ ਹਰਾ ਹੀਰਾ ਜਿੱਤਿਆ।	Original	622.18	1482.8
	Synthesized Signal	2	622.17	1482.81
		12	622.17	1482.81
	Residual Signal	2	887.84	1824.15
		12	956.8	1886.91
2/7	ਛਿੰਦੇ ਨੇ ਛੱਪੜ ’ਚੋਂ ਛੇਤੀ ਛੇਤੀ ਛੇ ਕੱਛੂ ਫੜੇ।	Original	530.95	1785.74
	Synthesized Signal	2	530.94	1785.71
		12	530.94	1785.71
	Residual Signal	2	748.45	1928.29
		12	958.22	1912.12
3/8	ਠੂਹ-ਠਾਹ ਛੱਡ, ਠੀਕ ਹੋ ਕੇ ਠੁੱਕ ਨਾਲ਼ ਰਹਿ।	Original	566.71	1484.24
	Synthesized Signal	2	566.68	1484.24
		12	566.68	1484.24
	Residual Signal	2	848.51	1829.93
		12	938.81	1896.69
4/10	ਤਰਸੇਮੋ, ਤੂੰ ਤੋਤਕੜੇ ਬੰਦ ਕਰਕੇ ਤੱਕਲ਼ਾ ਸਿੱਧਾ ਕਰ।	Original	561.35	1419.51
	Synthesized Signal	2	561.4	1419.77
		12	561.4	1419.77
	Residual Signal	2	869.22	1786.6
		12	938.62	1864.63
5/18	ਮਲ਼ ਮਲ਼ ਨ੍ਹਾਉਂਦੀ, ਮਲ ਮਲ ਪਾਉਂਦੀ।	Original	490.24	1545.77
	Synthesized Signal	2	490.29	1545.61
		12	490.29	1545.61
	Residual Signal	2	835.08	1883.84
		12	942.47	1881.45
6/19	ਵਰ ਹਾਣ ਦਾ ਕੁੜੀ ਨੂੰ ਮਿਲ਼ ਜੇ, ਟਿੱਬੀ ਉਤੇ ਮੀਂਹ ਵਰ੍ਹ ਜੇ॥	Original	490.23	1628.65
	Synthesized Signal	2	490.38	1628.65
		12	490.38	1628.65
	Residual Signal	2	762.39	1904.47

		12	958.56	1901.31
7/22	ਘੜਾ ਮਾਘ ਭਰ ਭਰੂੰ ਤੇਰਾ ਮੱਘਰਾ, ਝਾਂਜਰਾਂ ਘੜਾਅ ਦੇ ਮਿੱਤਰਾ॥	Original	594.35	1381.16
	Synthesized Signal	2	594.28	1381.03
		12	594.28	1381.03
	Residual Signal	2	926.21	1706.66
		12	948.46	1859.55
8/39	ਯਾਰ ਜਾਣਗੇ ਯੱਕੇ ’ਤੇ ਚੜ੍ਹਕੇ, ਯੱਭਲ਼ਾਂ ਨੂੰ ਪਊ ਤੁਰਨਾ॥	Original	521.41	1576.03
	Synthesized Signal	2	521.41	1576.07
		12	521.41	1576.07
	Residual Signal	2	773.82	1848.37
		12	954.68	1893.68
9/41	ਪੌੜੀ ਚੜ੍ਹਗੀ ਮੜਕ ਨਾਲ ਲੜਕੇ, ਕਾੜ ਕਾੜ ਬੂਹਾ ਭੰਨਗੀ॥	Original	523.14	1539.22
	Synthesized Signal	2	523.13	1539.26
		12	523.13	1539.26
	Residual Signal	2	805.05	1855.05
		12	947.34	1880.75
10/83	ਫੁੰਮਣ ਫੁਕਰਾ ਫੇਰ ਕੀ ਫੰਨੂ ਖੋਹ ਦੂ!	Original	496.08	1414.82
	Synthesized Signal	2	496.08	1414.82
		12	496.08	1414.82
	Residual Signal	2	863.04	1834.9
		12	941.66	1903.78

Table 6.9: Special Sentences Analysis (Pitch and Intensity: 10 sentences)

Sr.	Sentence	No. of poles	Pitch	Intensity
1/4	ਹਾਕਮ ਨੇ ਹੰਸ ਨੂੰ ਹਰਾਅ ਕੇ ਹਰਾ ਹੀਰਾ ਜਿੱਤਿਆ।	Original	133.4	69.84
	Synthesized Signal	2	133.4	73.28
		12	133.4	73.28
	Residual Signal	2	135.19	71.03
		12	134.62	69.34
2/7	ਛਿੰਦੇ ਨੇ ਛੱਪੜ ’ਚੋਂ ਛੇਤੀ ਛੇਤੀ ਛੇ ਕੱਛੂ ਫੜੇ।	Original	158.76	66.47
	Synthesized Signal	2	158.76	74.35
		12	158.76	74.35
	Residual Signal	2	161.32	70.9
		12	161.73	66.26
3/8	ਠੂਹ-ਠਾਹ ਛੱਡ, ਠੀਕ ਹੋ ਕੇ ਠੁੱਕ ਨਾਲ਼ ਰਹਿ।	Original	158.74	70.33
	Synthesized Signal	2	158.74	73.77
		12	158.74	73.77
	Residual Signal	2	161	71.3
		12	160.39	70.05

4/10	ਤਰਸੇਮੋ, ਤੂੰ ਤੋਤਕੜੇ ਬੰਦ ਕਰਕੇ ਤੱਕਲ਼ਾ ਸਿੱਧਾ ਕਰ।	Original	162.48	73.32
	Synthesized Signal	2	162.48	74.42
		12	162.48	74.42
	Residual Signal	2	163.09	72.25
		12	157.15	69.39
5/18	ਮਲ਼ ਮਲ਼ ਨ੍ਹਾਉਂਦੀ, ਮਲ ਮਲ ਪਾਉਂਦੀ।	Original	147.75	74.01
	Synthesized Signal	2	147.75	74.45
		12	147.75	74.45
	Residual Signal	2	148.15	70.28
		12	150.92	67.96
6/19	ਵਰ ਹਾਣ ਦਾ ਕੁੜੀ ਨੂੰ ਮਿਲ਼ ਜੇ, ਟਿੱਬੀ ਉਤੇ ਮੀਂਹ ਵਰ੍ਹ ਜੇ॥	Original	155.8	73.52
	Synthesized Signal	2	155.8	74.97
		12	155.8	74.97
	Residual Signal	2	158.79	71.48
		12	159.63	69.05
7/22	ਘੜਾ ਮਾਘ ਭਰ ਭਰੂੰ ਤੇਰਾ ਮੱਘਰਾ, ਝਾਂਜਰਾਂ ਘੜਾਅ ਦੇ ਮਿੱਤਰਾ॥	Original	156.86	75.99
	Synthesized Signal	2	156.86	75.82
		12	156.86	75.82
	Residual Signal	2	158.86	71.1
		12	160.79	69.45
8/39	ਯਾਰ ਜਾਣਗੇ ਯੱਕੇ 'ਤੇ ਚੜ੍ਹਕੇ, ਯੱਭਲ਼ਾਂ ਨੂੰ ਪਊ ਤੁਰਨਾ॥	Original	178.87	71.7
	Synthesized Signal	2	178.87	75.15
		12	178.87	75.15
	Residual Signal	2	184.94	72.71
		12	182.43	70.25
9/41	ਪੌੜੀ ਚੜ੍ਹਗੀ ਮੜਕ ਨਾਲ ਲੜਕੇ, ਕਾੜ ਕਾੜ ਬੂਹਾ ਭੰਨਗੀ॥	Original	164.94	70.98
	Synthesized Signal	2	164.94	76.29
		12	164.94	76.29
	Residual Signal	2	165.13	72.7
		12	167.9	70.89
10/83	ਛੁੰਮਣ ਫੁਕਰਾ ਫੇਰ ਕੀ ਫੰਨੂ ਖੋਹ ਦੂ !	Original	200.8	68.35
	Synthesized Signal	2	200.8	75.87
		12	200.8	75.87
	Residual Signal	2	202.5	73.61
		12	202.93	71

It has been found that

a) Pitch of synthesized sound signal is approximately same as that of original sound signal both in case of 2 poles and 12 poles.
b) Pitch of residual sound signal is increased as compared to original sound signal.
c) Also for residual sound signal, pitch is less with 2 poles than 12 poles in most of cases.
d) Intensity of synthesized sound signal is increased as compared to original sound signal both in case of 2 poles and 12 poles.

e) Intensity of residual sound signal with 2 poles is increased and with 12 poles is decreased as compared to original sound signal.

6.9. SPECTROGRAPHIC ANALYSIS (PRAAT)

The next 10 snapshots have been generated by using ***Praat***. In all the **4-colored snapshots** given below:
Blue color represents *Pitch* (Range: 75 – 500 Hz),
Black color represents *Spectrograms* (Range: 50 – 400 db),
Yellow color represents *Intensity* (Range: 0 – 4000 Hz), and
Red color represents *Formant I to Formant IV* (Range: 0 – 4000 Hz).
These snapshots are presented in the following 10 Figures **(Fig. 6.1-Fig. 6.10)**. In the FFT figures with LPC smoothing, FFT is represented in **Black color**, and LPC smoothing is colored (**Green color** or **Red color**)
a) **Fig.6.1-6.2:** Original sentence (4 colored items described above); FFT with LPC smoothing
b) **Fig. 6.3-6.4:** Residual p = 2 (4 colored items); FFT with LPC smoothing
c) **Fig. 6.5-6.6:** Residual p = 12 (4 colored items); FFT with LPC smoothing
d) **Fig. 6.7-6.8**: Synthesized, p=2 (4 colored items); FFT with LPC smoothing
e) **Fig. 6.9-6.10**: Synthesized p = 12 (4 colored items); FFT with LPC smoothing

These snapshots analyze the sentence (# 11) representing the nasal phoneme [n] = [ਨ] transcribed below in the Punjabi language (Gurmukhi script), IPA, and ***PUNJARPAbet***:

ਨਿੰਮੋ ਦੀ ਨੂੰਹ ਦੇ ਨੱਕ ’ਤੇ ਨੌਂ ਟੰਕੇ ਲੱਗੇ।

nĨmmo di nṹ de nəkk ’te nɔ̃ ṭə̃ke ləgge.

/N IHh MM OW - D IY - N UWnh - D EY - N AH KK - ’T EY - N AOn - T AHn K EY - L AH GG EY/

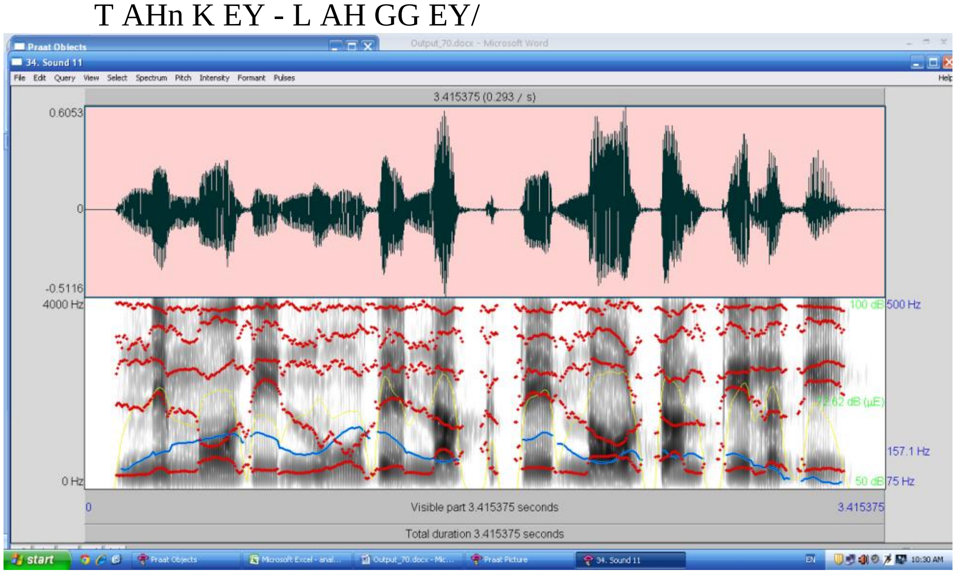

Figure 6.1: Sentence # 11 (Original waveform, Pitch, Spectrogram, Intensity, Formants)

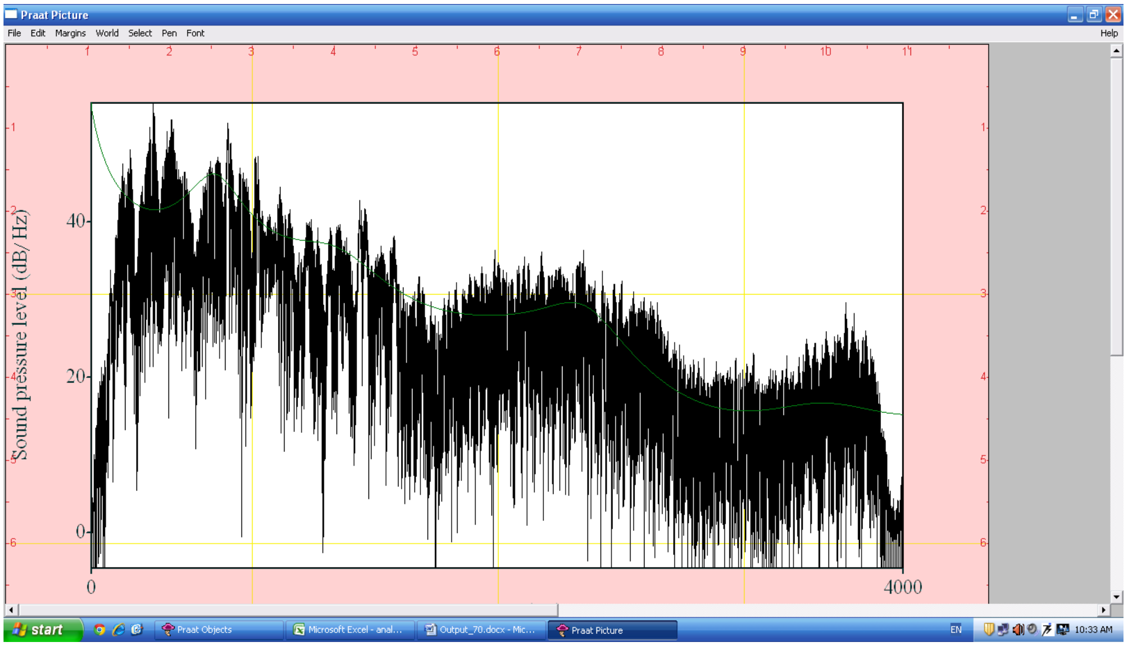

Figure 6.2: Original Sentence 11 (FFT and LPC Smoothing)

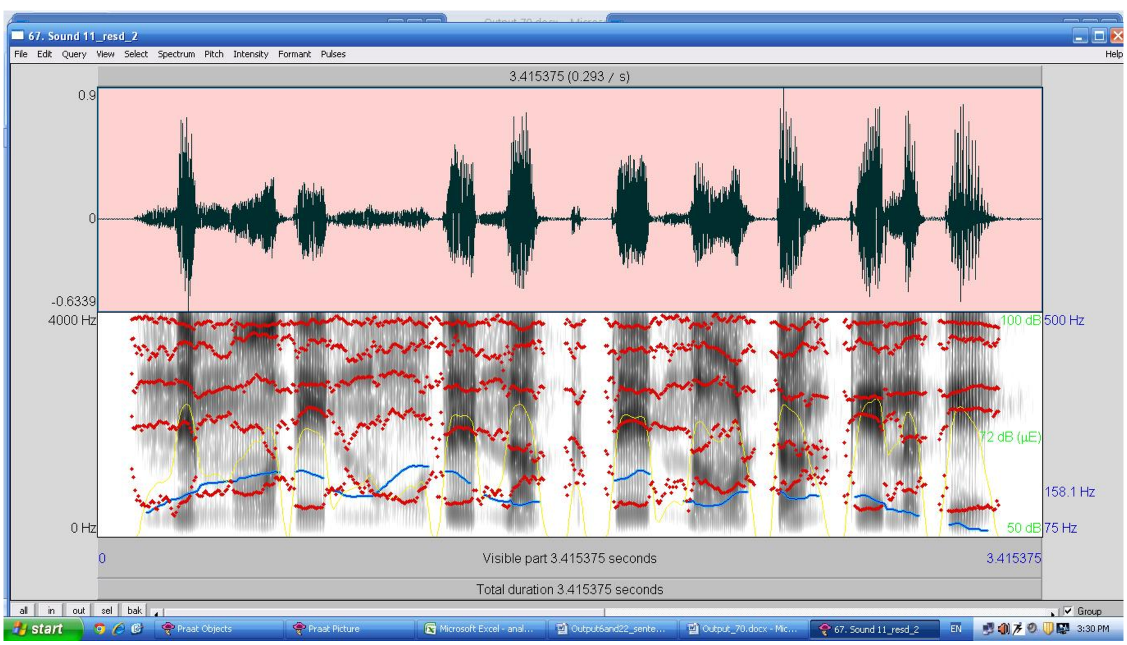

Figure 6.3: Sentence 11 (Residual Signal 2 poles, Pitch, Spectrogram, Intensity, Formants)

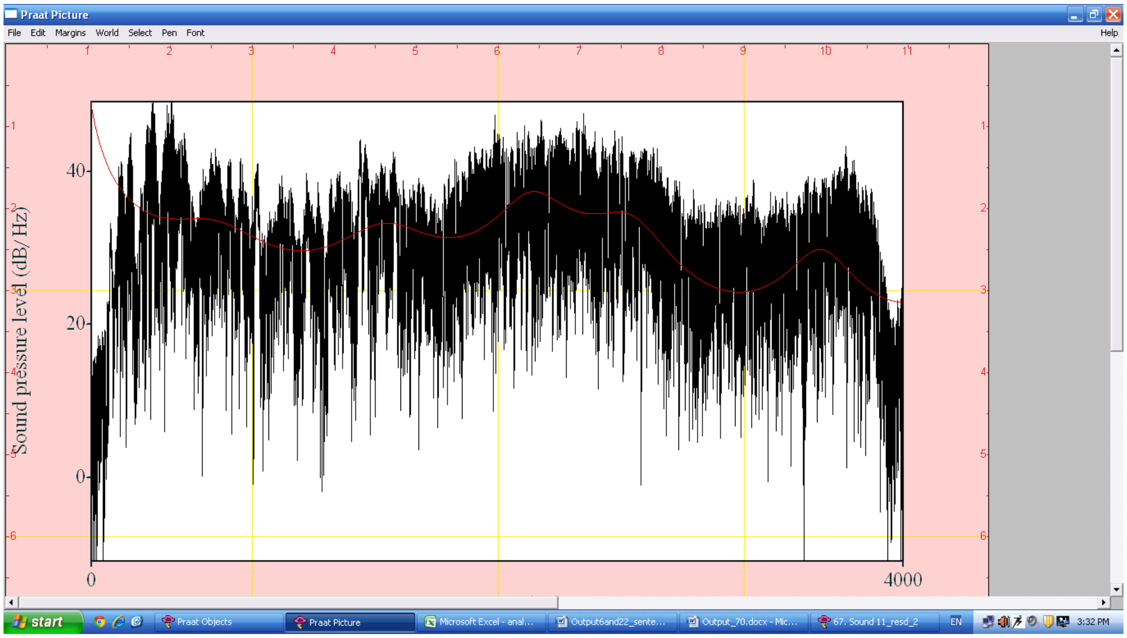

Figure 6.4: Residual Signal 2 poles (FFT and LPC Smoothing)

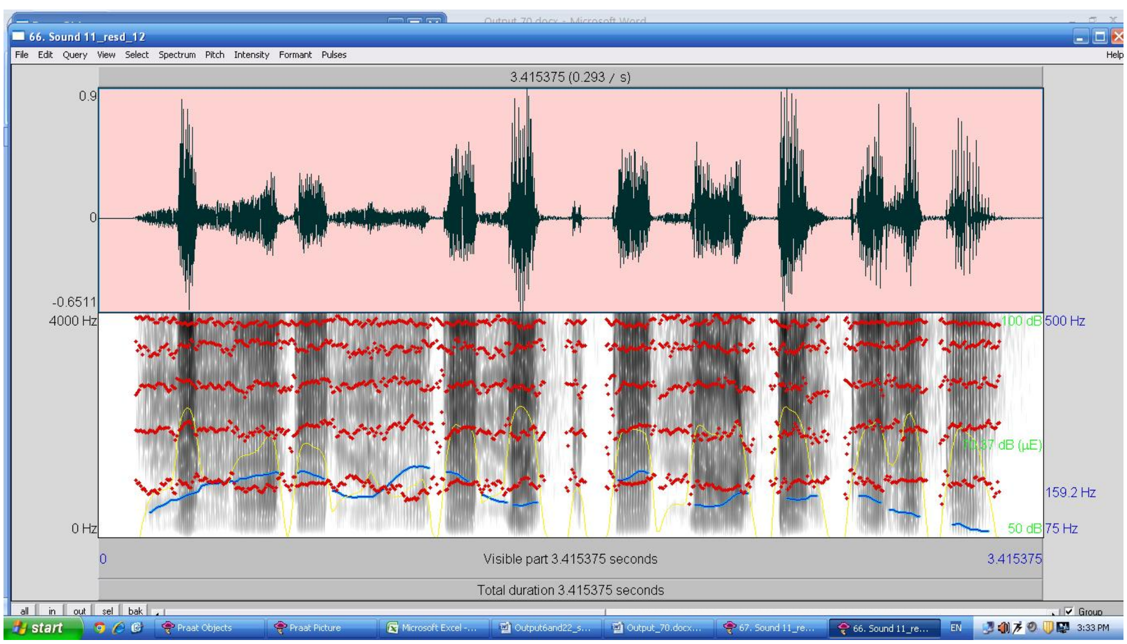

Figure 6.5: Sentence 11 (Residual Signal 12 poles, Pitch, Spectrogram, Intensity, Formants)

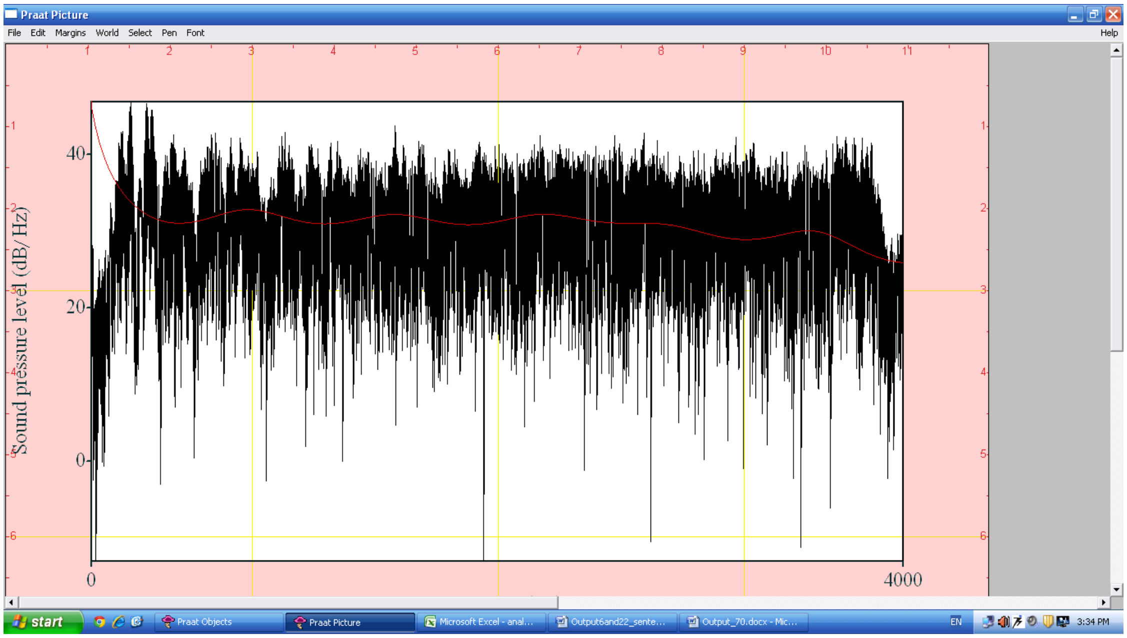

Figure 6.6: Residual Signal 12 poles (FFT and LPC Smoothing)

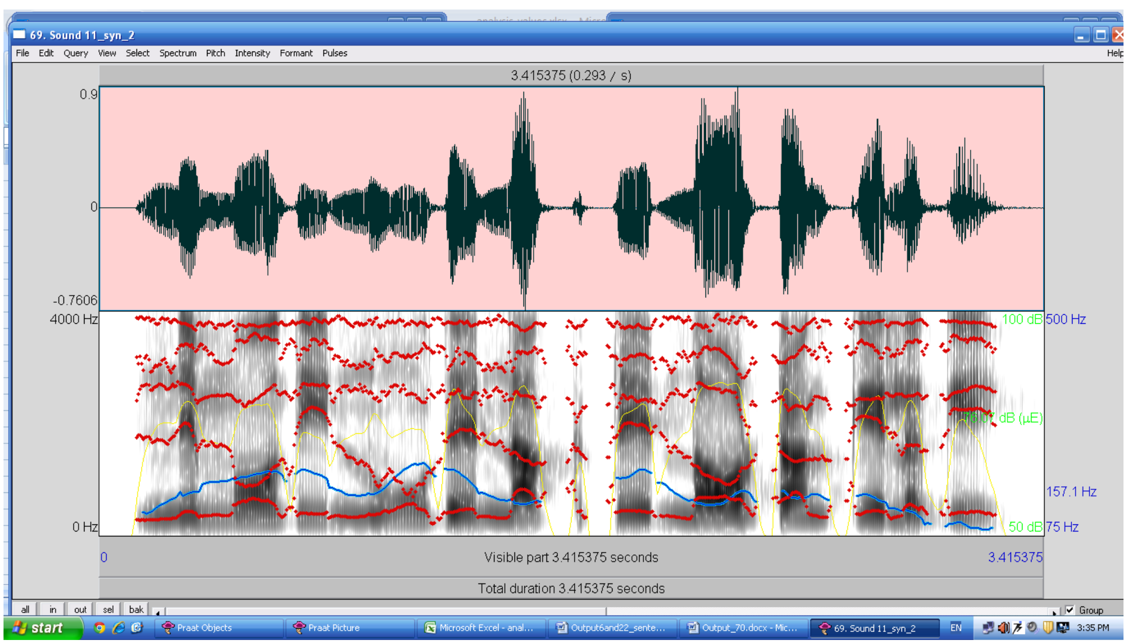

Figure 6.7: Sentence 11 (Synthesized Signal 2 poles, Pitch, Spectrogram, Intensity, Formants)

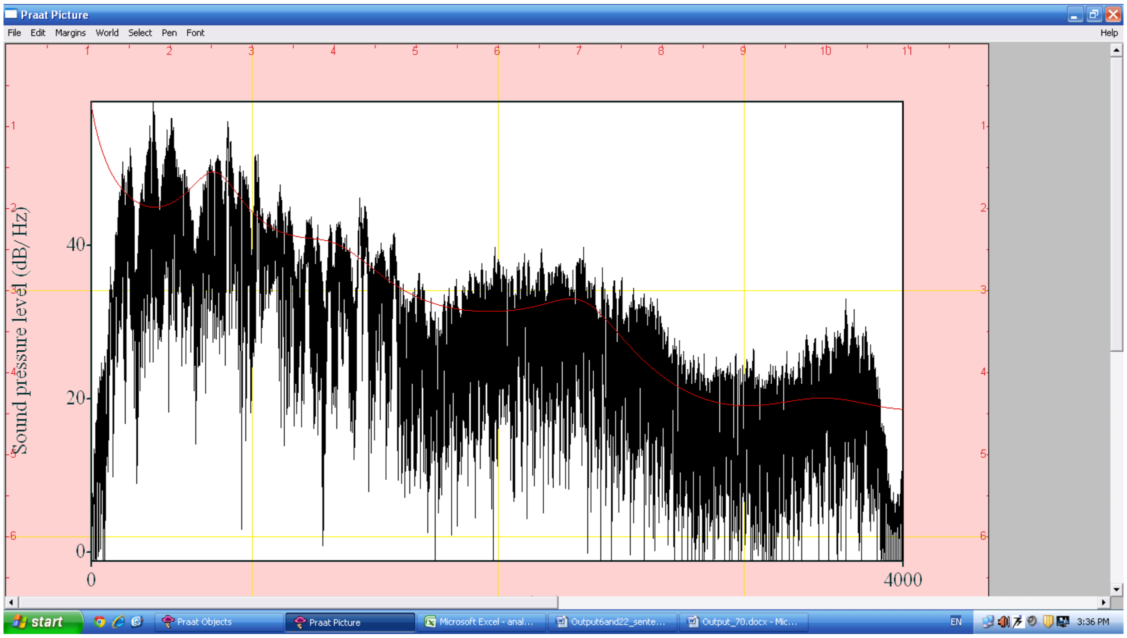

Figure 6.8: Synthesized Signal 2 poles (FFT and LPC Smoothing)

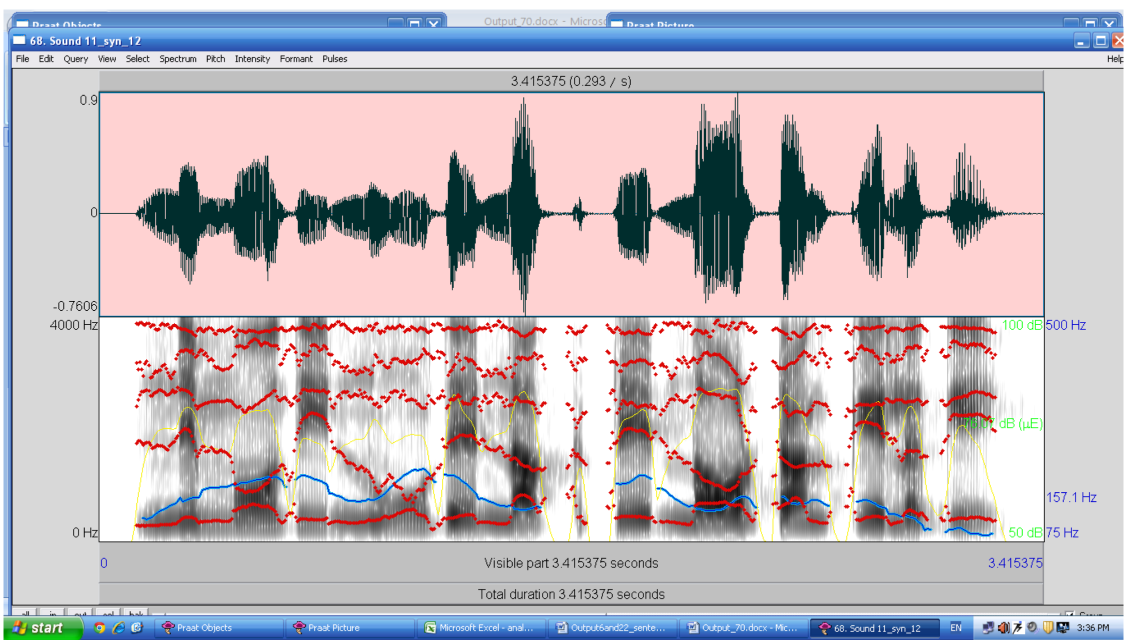

Figure 6.9: Sentence 11 (Synthesized Signal 12 poles, Pitch, Spectrogram, Intensity, Formants)

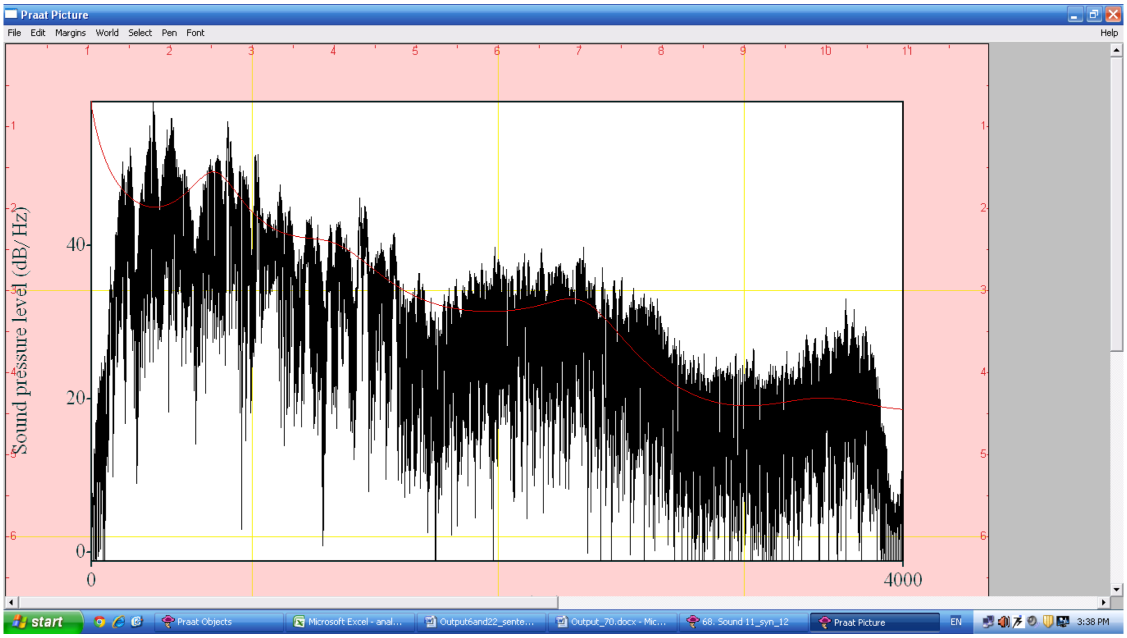

Figure 6.10: Sentence 11 (Synthesized Signal 12 poles: FFT and LPC Smoothing)

6.10. <u>SPECTROGRAPHIC ANALYSIS (MATLAB)</u>

The set of next five figures **(Fig. 6.11-Fig.6.15)**, consisting of the *speech waveforms*, *Pitch contours*, *V/UV decision*, and *FFT*, is generated by the first MATLAB program. These figures concentrate on sentence # 1. This sentence is representing the *vowel form* [ਉ] transcribed below in Gurmukhi script, IPA, and ***PUNJARPAbet***:

ਓਏ ਉੱਲੂ! ਉਂਘਦਾ ਕਿਓਂ ਐਂ? ਉਂਗਲੀ ਫੜ!
oe Ullu! ṹgda kIõ ɛ̃? Ũggli phəṛ!
/OW EY - UH LL UW! UWn hG D AA - K IH OWn - AEn?
UHn GG L IY - PH AH RH!/

In **Fig. 6.11**, we can see that the intensity line is absent in the *pitch contour* for the *unvoiced regions*, whereas the intensity line is present (proportional to the loudness) for the *voiced regions* (represented by rectangles in one of the sub-plots in **Fig. 6.11)** as expected.

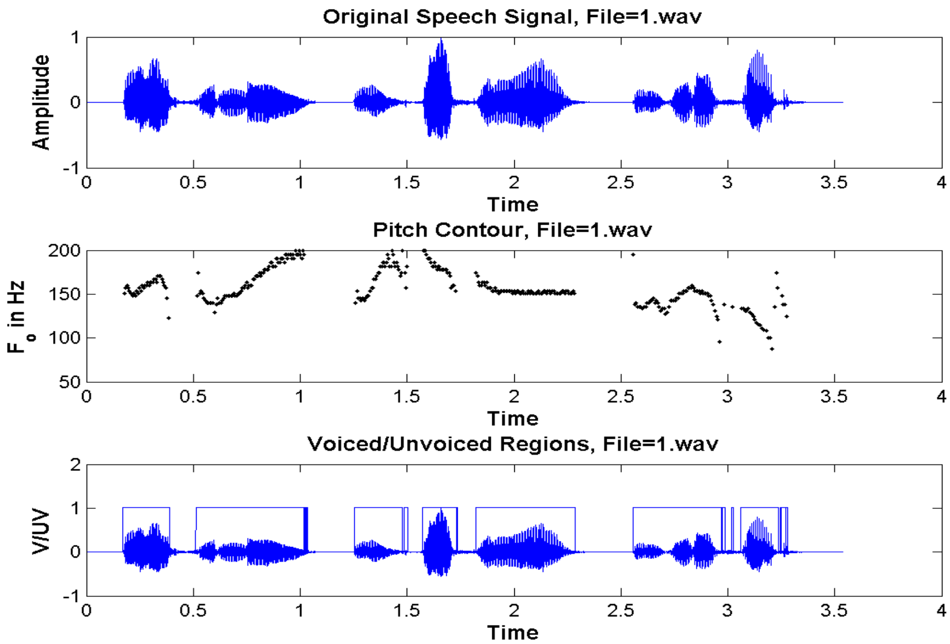

Figure 6.11: Pitch analysis sentence # 1 (original waveform, pitch contour, V/UV regions)

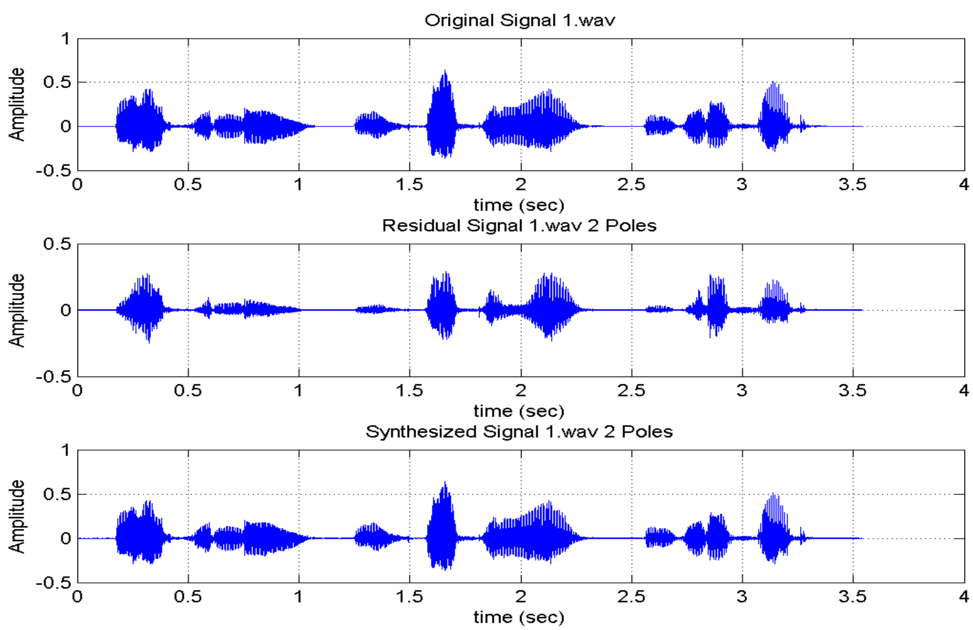

Figure 6.12: Sentence # 1 Waveforms (Original, Residual: 2 poles, Synthesized: 2 poles)

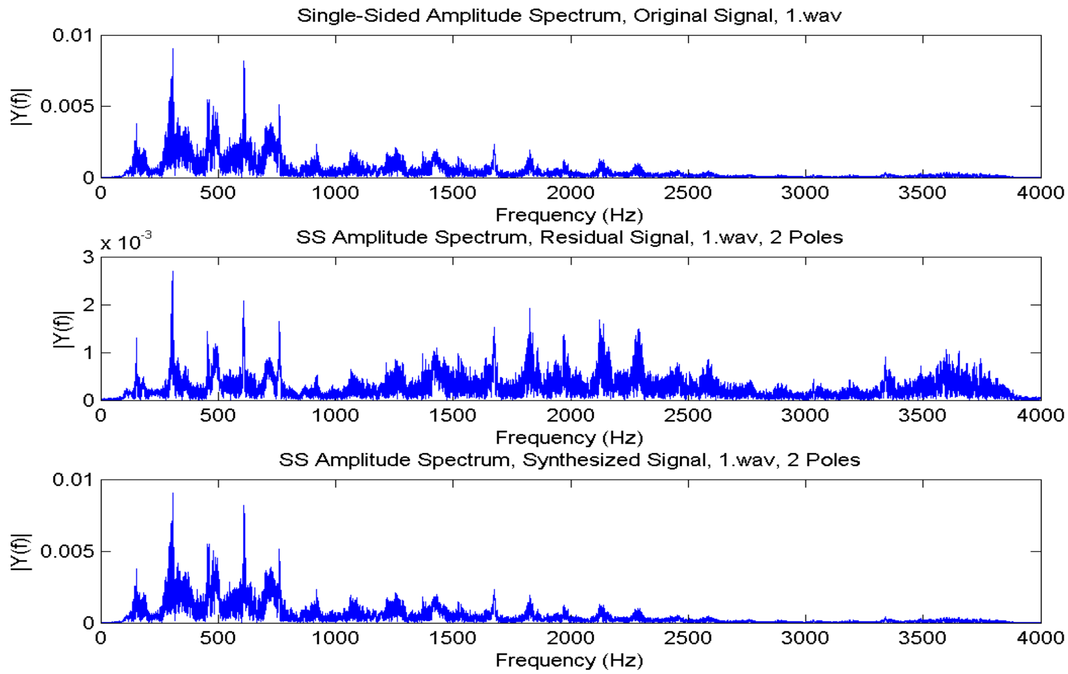

Figure 6.13: Sentence # 1 Amplitude Spectrum (Original, Residual: 2 poles, Synthesized: 2 poles)

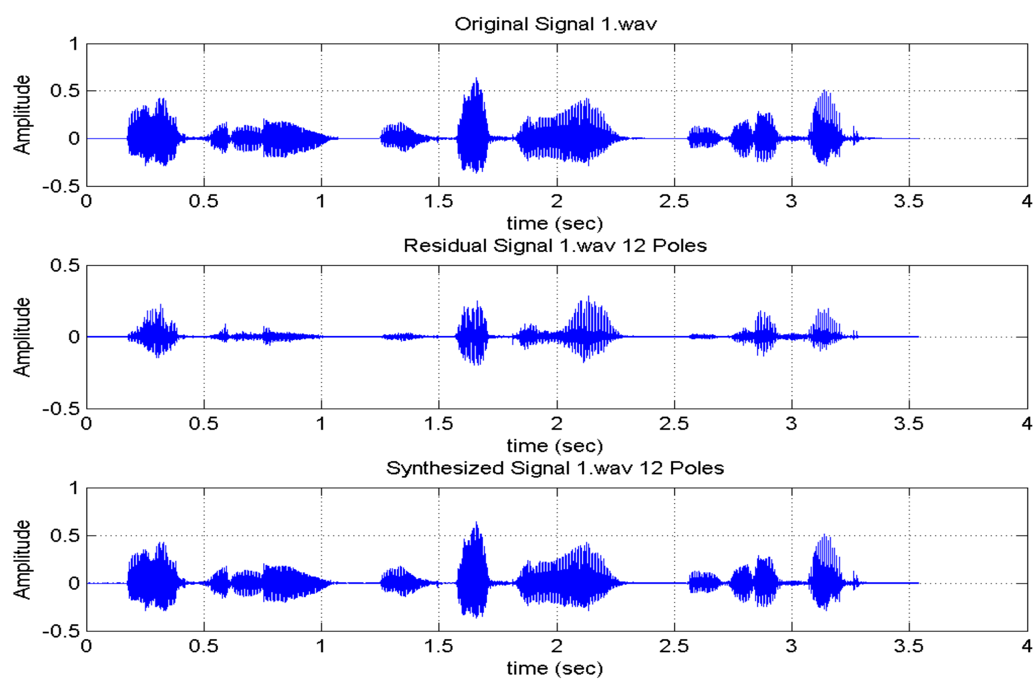

Figure 6.14: Sentence # 1 Waveforms (Original, Residual: 12 poles, Synthesized: 12 poles)

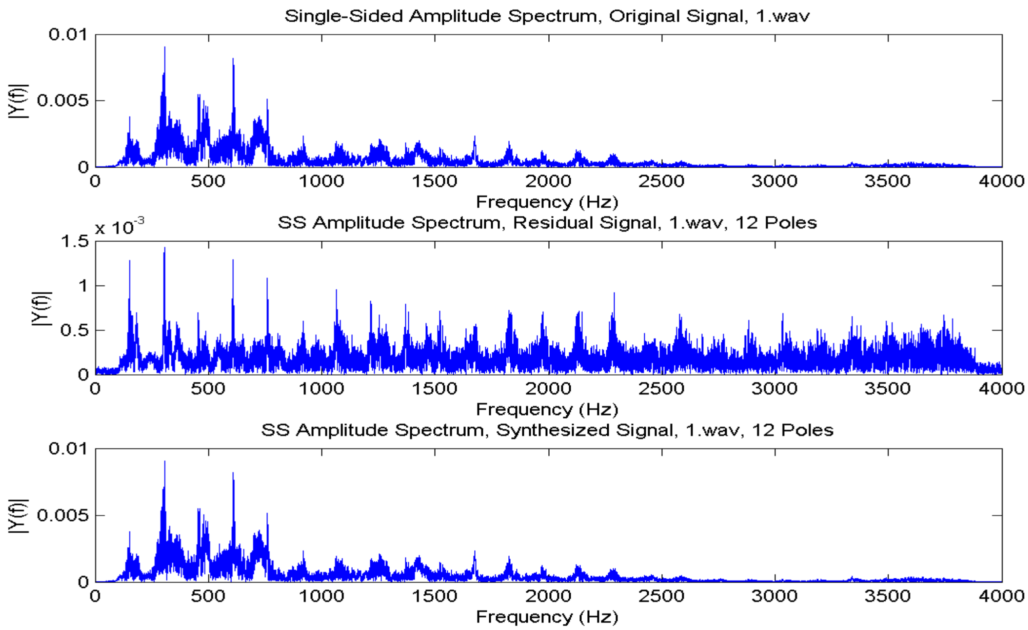

Figure 6.15: Sentence # 1 Amplitude Spectrum (Original, Residual: 12 poles, Synthesized: 12 poles)

The next set of two figures **(Fig. 6.16 and Fig. 6.17)** is generated by the second MATLAB program. These figures concentrate on the *first 1024 samples* (to get a better insight of the *FFT*) of sentence # 3. This sentence is representing the *vowel form* [ੲ] transcribed below in Gurmukhi script, IPA, and ***PUNJARPAbet***:

ਈਸ਼ਰ ਅਤੇ ਇੰਦਰ, ਇਕਵੰਜਾ ਇੱਟਾਂ ਏਥੇ ਲਿਆਓ।
iṣər əte Ĩdər, Ikvə̃ja Iṭṭã ethe lIao.
/IY SH AH R - AH T EY - IHn D AH R, IH K V AHn J AA - IH T:T: AAn - EY TH EY - L IH AA OW/

When we closely examine and compare the figures in this section (e.g., **Fig. 6.16** and **Fig. 6.17)**, we can see that the synthesized speech waveform FFT (for p = 12) is closer to the original speech waveform FFT than the synthesized speech waveform FFT (for p = 2). This is expected because the intelligibility of the synthesized speech for p = 12 is much closer to the original waveform (and much superior to that of the p = 2) than the intelligibility of the synthesized speech for p = 2.

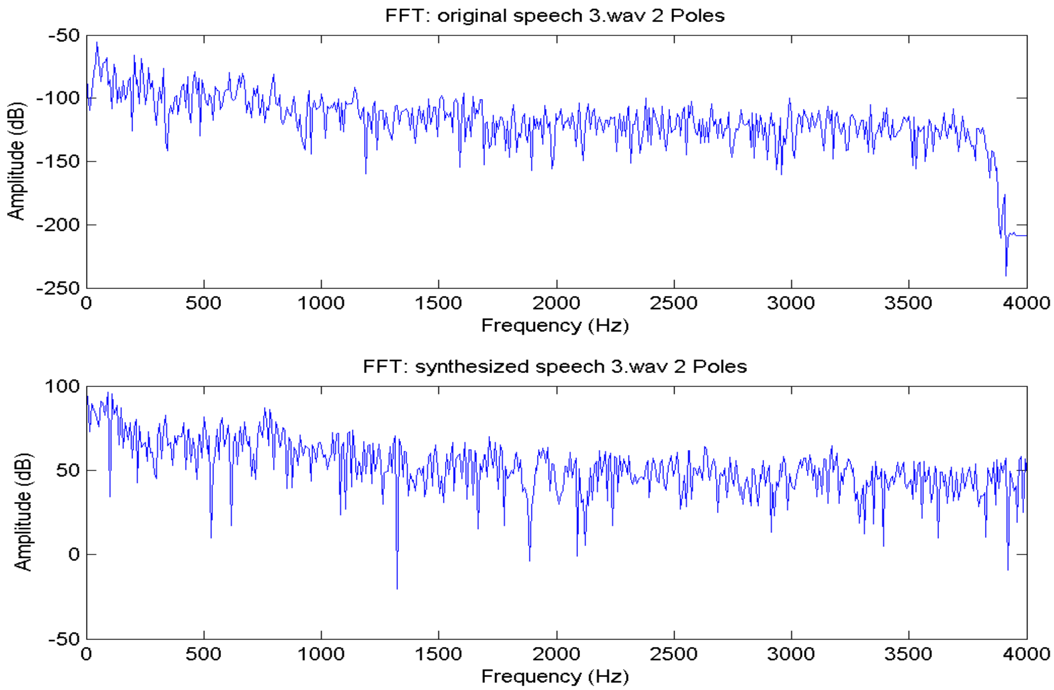

Figure 6.16: FFT (Original Sentence # 3 and Synthesized Speech 2 poles)

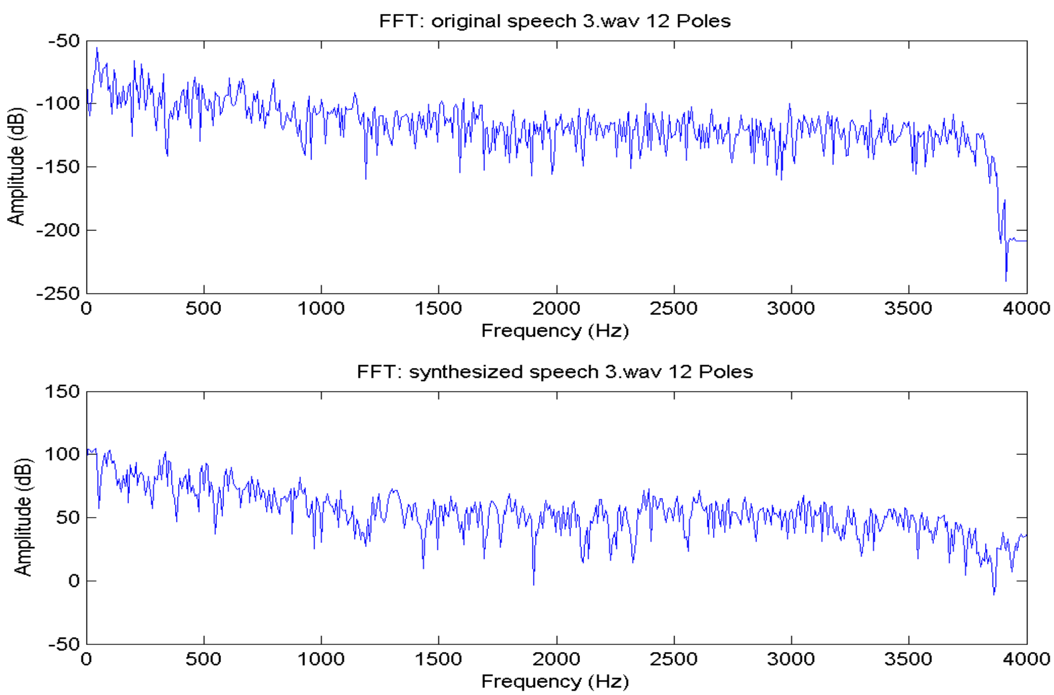

Figure 6.17: FFT (Original Sentence # 3 and Synthesized Speech 12 poles)

6.11. EVALUATION OF PUNJARPAbet BY USING CORPUS

While designing the new phonetic alphabet ***PUNJARPAbet*** in Chapter II, new symbols have been designed for the following 16 Punjabi speech sounds:

ਖ, ਖ਼, ਗ਼, ਘ, ਛ. ਝ, ਞ, ਠ, ਢ, ਣ, ਤ, ਧ, ਫ, ਭ, ਲ਼, ੜ
kh, x, g̣, k/g, ch, c/j, ɲ / ň, ṭh, ṭ / ḍ, ṇ, t, t / d, ph, p / b, ḷ, ṛ

The differentiation between ਖ/ਖ਼, ਗ/ਗ਼ is quite blurry even in the Punjabi language. The reason is that the five (ਸ਼, ਖ਼, ਗ਼, ਜ਼, ਫ਼) out of the six 'dot (bindi) in the foot letters' in the *antim ṭoli* were introduced in the Gurmukhi script in the previous century to represent the foreign sounds belonging to the English, Persian and the Arabic language. Therefore, the analysis concentrates only on the remaining thirteen letters: ਘ, ਛ. ਝ, ਞ, ਠ, ਢ, ਣ, ਤ, ਧ, ਫ, ਭ, ਲ਼, ੜ. These 13 letters can be classified into three distinct categories for the purpose of this evaluation:

1. Tonemes: ਘ, ਝ, ਢ, ਧ, ਭ
2. Nasals: ਞ, ਣ
3. Special Sounds: ਛ, ਠ, ਤ, ਫ, ਲ਼, ੜ

The new phonetic coding scheme ***PUNJARPAbet*** developed in Chapter II has been primarily designed to encode the text and speech corpora developed in Chapter IV. This corpus has at least ***twenty*** special features. ***PUNJARPAbet*** is capable of coding examples related to all special features of the new corpus. ***PUNJARPAbet*** is an *all upper-case* coding scheme and is consistent with the *all upper-case* version of the famous coding scheme **ARPAbet** developed by the Advanced Research Projects Agency (ARPA). The new scheme is very easy to follow, and is the most suitable scheme for typing on an ordinary computer keyboard as well as an ordinary typewriter. Unlike many other schemes such as the famous *International Phonetic Alphabet* (**IPA),** the ***PUNJARPAbet*** is free from the laborious, irritating, and time-consuming necessities for dealing with the special symbols. It has been clearly demonstrated in the following sections that ***PUNJARPAbet*** is a versatile, efficient and convenient coding scheme for not only the Punjabi language, but also any language which has sounds similar to the ones found in the Punjabi speech.

Even though the corpus consists of at least ***twenty*** original features, only ***three*** of these features are described and exemplified in this section using ***PUNJARPAbet*** so as to demonstrate that the newly designed ***PUNJARPAbet*** is versatile enough to handle a wide variety of issues related to the representation of the text and speech corpus in the Punjabi language and Gurmukhi script.

6.11.1. Examples of uniqueness

Each item in the corpus is unique. Each sentence/***boli*** in the corpus has been carefully designed so as to convey something new and special about the Punjabi language, Gurmukhi script, Malwai dialect, phonetics, matras, vowels, and consonants by using a wide variety of vocabulary, idioms and expressions. In particular, a special feature called **Anupras Alankar (ਅਨੁਪ੍ਰਾਸ ਅਲੰਕਾਰ)** has been used throughout the development of the corpus. *Anupras* means "alliteration". According to Wikipedia: "In language, ***alliteration*** is the repetition of a particular sound in the *prominent lifts* (or stressed syllables) of a series of words or phrases." Consequently, the *Anupras Alankar* means the repetitious usage of a word or a letter to enhance the beauty of a piece of literature. In Indian languages and literature, the Anupras Alankar has been used for centuries. The idea behind the usage of the Anupras Alankar in *this work* is that the repetitious use of a letter will enable the user to thoroughly analyze and synthesize any particular phoneme in a single item. Two examples from the new corpus (predominantly making use of the letters ਜ and ਦ respectively) to illustrate *Anupras Alankar* using the ***PUNJARPAbet*** are given below:

ਜਗਦੀ ਮਘਦੀ ਜਾਗੋ, ਜਿੱਤ ਲੀ ਜੀਤੋ ਨੇ॥

jəgdi mə́gdi jago, jItt li jito ne.
/J AH G D IY - M AH hG D IY - J AA G OW, J IH TT - L IY - J IY T OW - N EY./

ਦਰਸ਼ਨ ਦੇਹ ਦੀਪੋ, ਦੇ ਦੇ ਸ਼ੌਂਕ ਦੇ ਗੇੜੇ॥

dərshən dé dipo, de de ṣɔ̃k de geṛe.
/D AH R SH AH N - D EYh - D IY P OW - D EY - D EY - SH AOn K - D EY - G WY RH EY./

6.11.2. Examples of tones

The following examples illustrate the occurrence of each of the five *tonemes* (ਘ, ਝ, ਢ, ਧ, ਭ) in the initial, middle (medial), as well as the final positions (words in **bold** below) in a single item:

ਘੁੱਦੇ ਨੇ **ਖੰਘੂਰੇ** ਮਾਰ ਮਾਰ **ਸੰਘ** ਦਾ **ਕੰਘਾ** ਕਰਾ ਲਿਆ।

kÙdde ne khə̃́gure mar mar sə̃́g da kə̃́ga kəra lIa.
/Kl UH DD EY - N EY - KH AHn hG UW R EY - M AA R - M AA R - S AHn hG - D AA - K AHn hG AA - K AH R AA - L IH AA/

ਮਝੈਲੋ! **ਮੱਝ**, **ਝੋਟੀ** ਦਾ **ਝਗੜਾ ਝੱਟ** ਪੱਟ ਨਬੇੜੋ।

májɛlo! májj còṭṭi da càgṛa càṭ pəṭ nəbeṛo.
/M AH hJ AE L OW! M AH hJJ, CHl OW T:T: IY - D AA –
CHl AH G RH AA - CHl AH T:T: - P AH T:T: - N AH B EY RH OW/

ਢੱਗੇ ਦੇ **ਚੂੰਢੀਆਂ** ਨਾ **ਵੱਢ ਕੁੰਢਿਆ**, **ਢਿੰਬਰੀ** ਟੈਟ ਕਰ ਦੂੰ!
ṭə̀gge de cṹḍiã na vә́ḍḍ kṸḍḍIa, ṭĨ̀bəri ṭɛṭ kər dũ!
/T:l AH GG EY - D EY - CH UWn hD: IY AAn - N AA - V AH hD:D: -
K UHn hD: IH AA, T:l IHn B AH R IY - T: AE T: - K AH R - D: UWn!/

ਭਾਰਤ-ਭੂਮੀ ਨੂੰ, **ਲੱਭਿਆ ਭਗਤ, ਸਰਾਭਾ**॥
pàrət-pùmi nũ, lə́bIa pə̀get, sərába.
/Pl AA R AH T -- Pl UW M IY - N UWn, L AH hB IY AA - Pl AH G AH T,
S AH R AA hB AA./

ਕਿਵੇਂ **ਚਾਂਭਲ਼ੀਆਂ ਭੂਆ** ਤੇ **ਭਤੀਜੀਆਂ**, ਕਿਵੇਂ **ਮਿਲ਼ਗੋਭਾ** ਬਣੀਆਂ॥
kIvẽ cã́bəḷiã pùa te pə̀tijiã, kIvẽ mIḷgóba bəṇiã.
/K IH V EYn - CH AAn hB AH L̲ IY AAn - Pl UW AA - T EY -
Pl AA T IY J IY AAn, K IH V EYn - M IH L̲ G OW hB AA - B AH N: IY AAn./

These items have been especially designed in the corpus to illustrate the five **tonemes** (*voiced aspirates*: ਘ, ਝ, ਢ, ਧ, ਭ) occurring at the various positions in the words. If the tonemes occur in the initial position of words and stressed syllables, then the tonemes represent the *unaspirated voiceless* (ਕ, ਚ, ਟ, ਤ, ਪ) followed by a low tone. For the non-initial (middle/medial or final) positions of these tonemes, there is a high tone on the vowel before the *voiced unaspirated* (ਗ, ਜ, ਡ, ਦ, ਬ), or a low tone on the vowel following the *voiced unaspirated* (ਗ, ਜ, ਡ, ਦ, ਬ). Twenty-nine words from the six items used in this chapter exemplifying the use of tonemes as explained here are tabulated in **Table 6.10** along with their IPA representation.

6.11.3. Examples of extended pronunciation (*ਲਮਕਵਾਂ ਉਚਾਰਣ*)

Examine the pair of words *italicized* and in **bold** in the following items (sentences and ***bolis***) from the corpus:

ਹਾਕਮ ਨੇ ਹੰਸ ਨੂੰ ***ਹਰਾਅ***ਕੇ ***ਹਰਾ***ਹੀਰਾ ਜਿੱਤਿਆ।

hakəm ne hə̃s nũ həraə ke həra hira jIttIa.
/H AA K AH M - N EY - H AHn S - N UWn - H AH R AA AH - K EY -
H AH R AA - H IY R AA - J IH TT IH AA/

Table 6.10: Illustration of tonemes (Punjabi and IPA)

Toneme	Initial	Medial	Final
ਘ	ਘੁੱਦਾ kÙdda	ਖੰਘੂਰਾ khə̃́gura	ਸੰਘ, ਕੰਘਾ sə̃́g da kə̃́ga
ਝ	ਝੋਟੀ, ਝਗੜਾ, ਝੱਟ còṭṭi, cəgṛa, cəṭ	ਮਝੈਲ mə́jɛl	ਮੱਝ mə́jj
ਢ	ਢੱਗਾ, ਢਿੰਬਰੀ ṭə̀gga, ṭĨ̀bəri	ਚੂੰਢੀਆਂ, ਕੁੰਢਿਆ cṹḍiã, kṸḍḍIa	ਵੱਢ və́ḍḍ
ਧ	ਧੁੰਦ, ਧਰਮਾਂ tuĩ̀dd, tərəmã	ਪੱਧਰਾ pə́ddəra	ਪਾਂਧੀ, ਪੰਧ, ਵੱਧ pā́di, pə̃́d, və́dd
ਭ	ਭਾਰਤ, ਭੂਮੀ, ਭਗਤ pàrət, pùmi, pə̀get	ਲੱਭਿਆ lə́bIa	ਸਰਾਭਾ sərába
ਭ	ਭੂਆ, ਭਤੀਜੀਆਂ pùa, pətijiã	ਚਾਂਭਲ਼ੀਆਂ cã́bəḷiã	ਮਿਲ਼ਗੋਭਾ mIḷgóba

ਘੜਾਮਾਘ ਭਰ ਭਰੂੰ ਤੇਰਾ ਮੱਘਰਾ, ਝਾਂਜਰਾਂ ***ਘੜਾਅ***ਦੇ ਮਿੱਤਰਾ॥
kə̀ṛa mág pə̀r pə̀rũ tera mə́ggəra, cə̃̀jrã kə̀ṛaə de mIttəra.
/Kl AH RH AA - M AA hG - Pl AH R - Pl AH R UWn - T EY R AA -
M AH hGG AH R AA, CHl AAn J R AAn - Kl AH RH AA AH - D EY -
M IH TT AH R AA/

ਭਰਾਜੀ! ਫੂਕ ***ਭਰਾਅ***ਲੀ?
pə̀ra ji! phuk pə̀raə li?
/Pl AH R AA - J IY! PH UW K - Pl AH R AA AH - L IY?/

ਮਿੰਦੋ ਮੁਟਿਆਰ ਨੇ ਮੂੰਹ ***ਮਟਕਾਅ***ਕੇ ***ਮਟਕਾ***ਭੰਨਿਆਂ।
mĨdo mUṭIar ne mṹ məṭkaə ke məṭka pə̀nnIa.
/M IHn D OW - M UH T: IH AA R - N EY - M UWnh - M AH T: K AA AH -
K EY- M AH T: K AA - Pl AH NN IH AAn/

ਸ਼ਰਮਾਂ ਵਾਲ਼ਾ ***ਸ਼ਰਮਾ ਸ਼ਰਮਾਅ***ਗਿਆ।
ṣərmã vaḷa ṣərma ṣəṛmaə gIa.
/SH AH R M AAn - V AA L AA - SH AH R M AA - SH AH R M AA AH -
G IH AA/

Several items in the corpus have been designed to demonstrate that in these pairs of words, the meaning of the word changes with the addition of /ਅ/ at the end of the word, and its pronunciation is also extended. The six pairs of words (from the examples used in this chapter) with the changed meanings are tabulated in **Table 6.11** along with their meanings and the IPA representation.

Table 6.11: Illustration of Extended Pronunciation

No.	Word	IPA	Meaning	Word	IPA	Meaning
1	ਹਰਾ	həra	green	ਹਰਾਅ	həraə	to defeat
2	ਘੜਾ	kə̀ṛa	pitcher	ਘੜਾਅ	kə̀ṛaə	to chisel into some design
3	ਭਰਾ	pə̀ra	brother	ਭਰਾਅ	pə̀raə	to fill (air)
4	ਮਟਕਾ	məṭka	pitcher	ਮਟਕਾਅ	məṭkaə	to gesture with eyes
5	ਸ਼ਰਮਾ	ṣərma	Sharma (a last name)	ਸ਼ਰਮਾਅ	ṣərmaə	to feel shy
6	ਖੜਕਾ	khəṛka	noise	ਖੜਕਾਅ	khəṛkaə	to knock

6.12. GRAPHICAL EVALUATION OF *PUNJARPAbet*

One of the main objectives of this research was the development of a new phonetic alphabet consistent with the ARPAbet for the phonetic transcription of the Punjabi language (objective 1). It can be an equally useful tool for natural language processing as well as digital speech processing in the Punjabi language. One of the critical issues we addressed in this research is to come up with balancing the requirements of speech processing and that of linguistics characteristics. In case of speech processing, researchers consider that the quality of data plays dominant role in comparison with the quantity of data. In this section, in order to evaluate the performance of the new coding scheme ***PUNJARPAbet***, we have used a number of different evaluation criteria. In this work, we captured the speech signal using head-worn microphone. Prior to the experimental evaluations, we ensured that all speech material was clearly understood by the participants. We used a variety of categories of people having different levels of schooling. We used five people in each category of different level of schooling. We provided sufficient time to each participant to become familiar with the experimental equipment. The evaluation results in four evaluation areas have been described below.

6.12.1. Speaking and Typing Rates

We observed speaking and typing rates of different categories of participants (speakers-cum-typists) for various items in the corpus using the spontaneous Punjabi language. Various categories of people participating in the evaluation included five different levels of schooling: ordinary uneducated, elementary/primary school, high school, university level, and post graduate. We define the speaking and typing rates as number of words spoken or typed *per five seconds*. We selected a predefined set of ten words and requested each participant to record and type. We observed an average of 4.8

words typed and 7.2 words spoken. It was also observed that at higher level of education, higher was the number of words spoken or typed. **Figure 6.18** illustrates the comparison of speaking and typing rates across different educational levels.

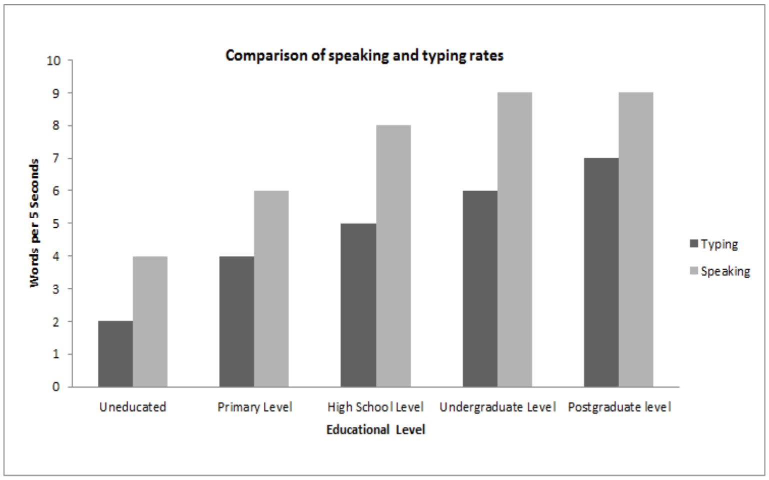

Figure 6.18: Comparison of speaking and typing rates

6.12.2. Typing Rates of Different Coding Schemes

We also compared the tying rates of selected items from the new corpus using three different alphabets. We compared the tying rates using ***PUNJARPAbet*** with the typing rates of the same items using the existing approaches of **IPA** and **ARPAbet**. We observed that on the average, 4.8 words were typed in case of ***PUNJARPAbet***, 3.2 words in case of **IPA,** and 3.8 average words were typed in case of **ARPAbet**. **Figure 6.19** illustrates the comparison of typing rates across different coding schemes and educational levels. As compared with **IPA** or **ARPAbet**, the participants consistently demonstrated better performance when ***PUNJARPAbet*** was employed. Whereas ***PUNJARPAbet*** was the clear winner (*first*), **IPA** was the *last*. The apparent reason is the fact that **IPA** requires special symbols whereas ***PUNJARPAbet*** does not.

6.12.3. Uniqueness

Vowel-dominant sentences included more *vowel symbols* (in the Punjabi language, these symbols are also known as *matras* or *accessory signs* or *diacritical marks* or *vowel signs*) as compared with the consonant-dominant sentences. Sentences with a wide variety of vocabulary, idioms and expressions were used in this evaluation. We define the typing rates as number of vowels and consonants *per five seconds* typed. We selected a predefined set of ten sentences in each of the two categories: vowel-dominant and consonant-dominant sentences. We requested each participant to type these selected items. We observed that on the average, 2.6 words were typed in case of **IPA,** three words were typed in case of **ARPAbet,** and four average words were typed in case of

PUNJARPAbet for *vowel-dominant sentences*. **Figure 6.20** illustrates the comparison of typing rates of vowel-dominant sentences across these three different coding schemes and educational levels.

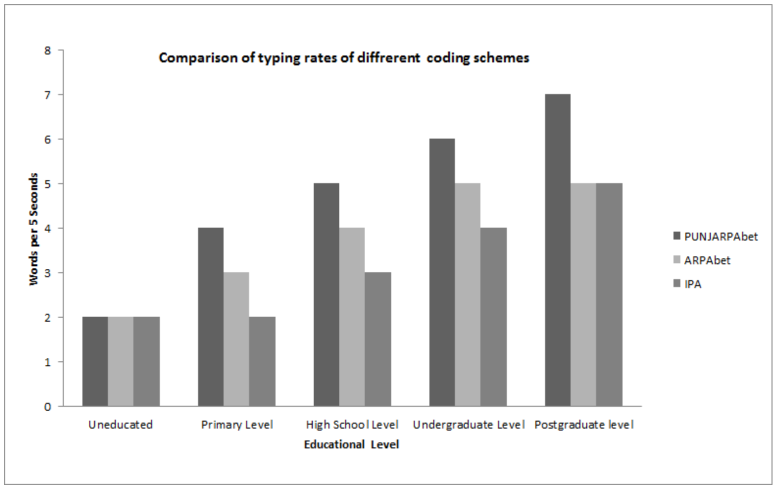

Figure 6.19: Comparison of typing rates of different coding schemes

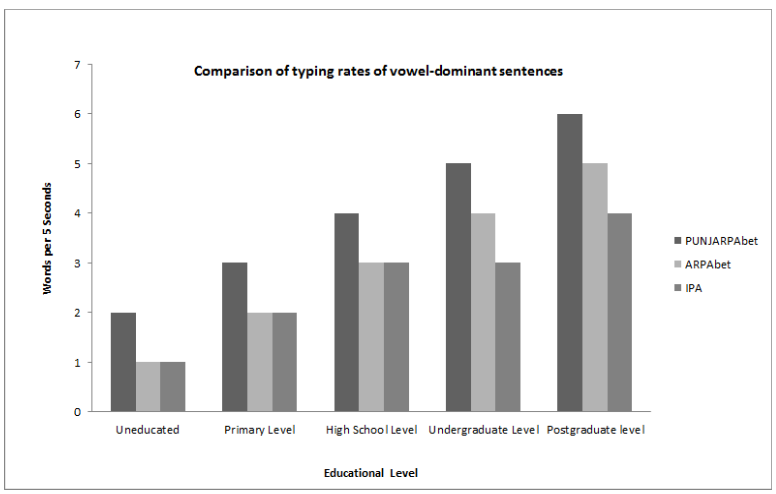

Figure 6.20: Comparison of typing rates of vowel-dominant sentences

Figure 6.21 illustrates a similar comparison of typing rates for *consonant-dominant sentences* for various categories of participants. We observed that on the average, 3.4 words were typed in case of **IPA,** five words were typed in case of **ARPAbet,** and six average words were typed in case of ***PUNJARPAbet*** for consonant-dominant sentences.

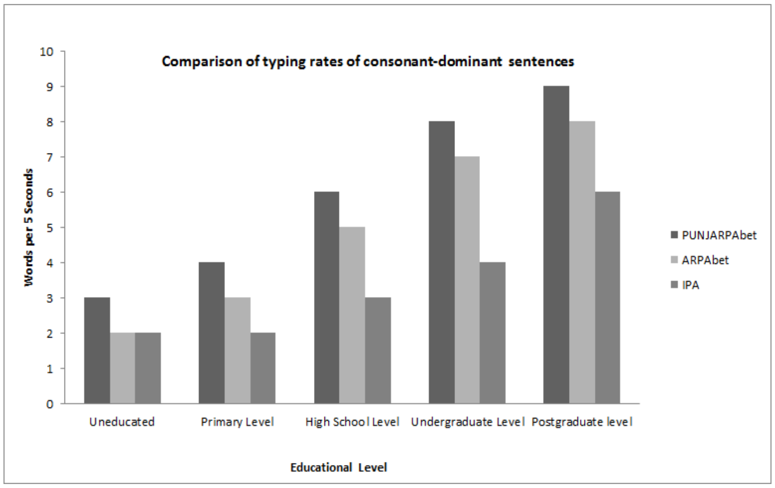

Figure 6.21: Comparison of typing rates of consonant-dominant sentences

The evaluation results in different evaluation areas graphically illustrated in four figures (**Fig. 6.18-6.21**) are summarized in this paragraph. The evaluation confirms the well-known fact that the speaking rate of a person is faster than the typing rate (**Fig. 6. 18**). **Figure 6.19** clearly confirms that the typing rates of various participants are much faster when ***PUNJARPAbet*** is used as the typing tool as compared with the traditional coding schemes (**IPA** or **ARPAbet**). The primary reason for ***PUNJARPAbet*** being faster is the fact that **IPA** requires special symbols for typing *vowel symbols* (also known as *matras* or *accessory signs* or *diacritical marks* or *vowel signs*). To further investigate the performance of the new coding scheme, we designed two more experiments. Whereas the words used in the first two experiments (see **Fig. 6.18 and 6.19**) are a general mixture of consonants and vowels, the sentences used in these two experiments are split in two categories: vowel-dominant and consonant-dominant sentences. Vowel-dominant sentences include more *vowel symbols* as compared with the consonant-dominant sentences. The typing rates for the consonant-dominant sentences (**Fig. 6.21**) are the *fastest* as compared with the general sentences (**Fig. 6.19**) and the vowel-dominant sentences (**Fig. 6.20**). The typing rates for the vowel-dominant sentences are the *slowest*. The average typing rates for general sentences, vowel-dominant sentences, and consonant-dominant sentences illustrated in **Fig. 6.19, 6.20 and 6.21** respectively are further summarized in **Table 6.12** to convincingly demonstrate that the ***PUNJARPAbet*** is the *best* in comparison to the other two schemes. ***PUNJARPAbet*** is comparatively better among ***all*** categories of speakers because it does not require the laborious, irritating, and time-consuming typing of the special symbols for vowels, nasalization, tones, and the diacritical marks. It is *especially* true in comparison with IPA where *two* diacritical marks over the ten vowel symbols are needed for the Punjabi language in Gurmukhi script. Further, ***PUNJARPAbet*** is also more efficient than **ARPAbet** because **ARPAbet** (single symbol version) requires frequent switching between lower-case and upper-case, and at present there are no symbols in the **ARPAbet** to represent at least 16 Punjabi speech sounds **(see Table 2.7, Chapter II)**

Even though the new phonetic coding scheme ***PUNJARPAbet*** developed in this work has been designed to encode a new text and speech corpora developed in Chapter IV, it should be clear that ***PUNJARPAbet*** is a versatile, efficient and convenient coding scheme for any language which has sounds similar to the ones found in the *Punjabi* speech.

Table 6.12: Summary of average typing rates

Coding Scheme	General	Vowels	Consonants
IPA	3.2	2.6	3.4
ARPAbet	3.8	3	5
PUNJARPAbet	4.8	4	6

6.13. CONCLUSION

The first part of this chapter is dedicated to the graphical analysis of the speech sentences synthesized in Chapter V. The software packages Praat and MATLAB have been extensively used to study the spectral characteristics of the synthetic speech along with the formant frequencies, pitch, and intensity. The quality of the synthesized speech for p = 12 was almost as intelligible as the original speech. As expected, the residual signals for p = 2 were much closer to the original sentence (because less information has been extracted out of it) than the residual signal for p = 12 (because more information has been extracted out of it). Even though 25 sentences (grouped into four distinct categories of vowels, nasals, tonemes, and special sentences) have been synthesized, only a limited number of representative graphs have been included in this thesis to keep the volume under control. Spectrographic analysis in this chapter also confirms the conclusions of Chapter V. In particular, the synthesized speech waveform FFT (for p = 12) is closer to the original speech waveform FFT than the synthesized speech waveform FFT (for p = 2). This is expected because the intelligibility of the synthesized speech for p = 12 is much closer to the original waveform (and much superior to that of the p = 2) than the intelligibility of the synthesized speech for p = 2. In the graphs for the pitch analysis, we can see that the intensity line is absent in the *pitch contour* for the *unvoiced regions*, whereas the intensity line is present (proportional to the loudness) for the *voiced regions* as expected. Whenever Praat, and MATLAB were used to plot graphs for the same variables (e.g., waveforms, pitch, and FFT), both packages generated similar results as expected.

The second part of this chapter is dedicated to the graphical evaluation of new phonetic alphabet (coding scheme) *PUNJARPAbet* designed in Chapter II. The evaluation results in four evaluation areas have been illustrated in the graphical analysis in four figures and one table in the evaluation section. Although ***PUNJARPAbet*** is capable of coding all examples related to all special features of the new corpus, yet only three examples areas (uniqueness, tonemes, and extended pronunciation) along with two tables have been used to clearly demonstrate that ***PUNJARPAbet*** is better than the other phonetic alphabets e.g., **IPA** and **ARPAbet**. ***PUNJARPAbet*** is an *all upper-case* coding scheme. It is consistent with the *all upper-case* version of the famous **ARPAbet** scheme. The new scheme is very easy to follow, and is the most suitable scheme for an ordinary computer keyboard as well as an ordinary typewriter. Unlike many other schemes (e.g., IPA), the ***PUNJARPAbet*** is faster and free from the laborious, irritating, and time-consuming necessities for dealing with the special symbols for vowels, nasalization, tones, and inserting diacritical marks (especially where two diacritical marks over the ten vowel signs are needed for the Punjabi language in Gurmukhi script). The graphical analysis summarized in figures and tables in this chapter clearly demonstrates that ***PUNJARPAbet*** is a versatile, efficient and convenient coding scheme not only for the Punjabi language, but also for any language which has sounds similar to the ones found in the Punjabi speech. ■

CHAPTER VII
SUMMARY AND CONCLUSIONS

This thesis describes the topic: **Speech Analysis and Synthesis of the Punjabi Language.** In this chapter, we summarize the whole work, highlighting the original contribution and main conclusions of this project, followed by the future directions.

7.1. SUMMARY AND CONCLUSION

The original contributions and conclusions of this research can be summarized as follows:

7.1.1. Phonetic Alphabet Development

The ***first*** issue in the present work is actual representation of the phonemes. In linguistics, the International Phonetic Alphabet (IPA) designed by International Phonetic Association (IPA) is used to represent the phonemes. However, the major limitation of this representation is that it needs some special symbols that are not readily available on computer keyboards [15, pp. 801]. To simplify this problem, ARPAbet representation came into existence as a result of the ARPA SUR project [15, pp. 527-529]. Since then, a number of coding schemes have been used in literature for international as well as Indian languages. The need for a new coding scheme becomes obvious when we investigate the existing coding schemes such as IPA, ARPAbet, ISCII, SAMPA (and its extended versions X-SAMPA and SAMPROSA), INSROT and wx-Roman. Most of these schemes prove unsuitable for the Punjabi language because most of these cannot be typed on a conventional typewriter or a computer keyboard; or most of these schemes are inconsistent (different books make use of the different symbols for the elements implying the possible difference in notation even within the IPA). The laborious, irritating, and time-consuming necessities for dealing with the special symbols for vowels, nasalization, tones, and inserting diacritical marks in most of these schemes (especially where two diacritical marks over the ten vowel signs are needed for the Punjabi language in Gurmukhi script) confirm the need for a new coding scheme such as the one designed in this work. In this work, a new phonetic alphabet consistent with the ARPAbet phonetic transcription of the Punjabi language has been developed. We have named the new alphabet as ***PUNJARPAbet*** by combining the words PUNJ + ARPAbet, the same way as the name PUNJAB has been derived by combining PUNJ + AAB.

The idea of the new scheme originated to address the following *four* issues:

1. The existing schemes (e.g., IPA) almost always require special symbols. It is not an easy task to find these symbols, or to combine the appropriate diacritical marks to these symbols.

2. While transferring data consisting of these symbols from one computer to another, it is not unusual to face the portability problems. Consequently, dealing with these symbols is laborious, irritating, and time-consuming.

3. No two authors agree on the representation of the Punjabi speech sounds as shown by **Table 2.6** consisting of Gill & Gleason [43], Bahri [13], and Dulai and Koul [34].

4. The symbols for at least 16 letters of the Punjabi language/Gurmukhi script do not exist in the ARPAbet.

Table 2.7 summarizes the new coding scheme. **Table 2.8** gives the complete template of the new coding scheme ***PUNJARPAbet***. The new scheme is very easy to use since all the symbols used in this scheme are readily available on an ordinary computer keyboard as well as on an ordinary typewriter. Consequently, the ***PUNJARPAbet*** is the most suitable coding scheme for transcribing the Punjabi language text corpora. ***PUNJARPAbet*** is capable of coding examples related to all special features of the new corpus.

PUNJARPAbet is an *all upper-case* coding scheme and is consistent with the *all upper-case* version of the famous coding scheme **ARPAbet** developed by the Advanced Research Projects Agency (ARPA). The new scheme is very easy to follow, and is the most suitable scheme for typing on an ordinary computer keyboard as well as an ordinary typewriter. Unlike many other schemes such as the famous *International Phonetic Alphabet* (**IPA),** the ***PUNJARPAbet*** is free from the laborious, irritating, and time-consuming necessities for dealing with the special symbols. By conducting the graphical evaluation, it has been clearly demonstrated in this work that ***PUNJARPAbet*** is a versatile, efficient and convenient coding scheme not only for the Punjabi language, but also for any language which has sounds similar to the ones found in the Punjabi speech.

7.1.2. New Corpus Development

A new text and speech corpus for the Punjabi speech processing has been developed in this work. This is the ***second*** most important contribution of this study. Speech sentences spoken by the adult male and female Punjabi speakers from ten districts of the *Malwa* region of the Punjab state of India were recorded for this corpus. This corpus consists of two parts: The first part consists of **52** sets of the Punjabi speech sentences. The second part of the corpus consists of **35** sets of single line folk songs (***bolis***). This corpus will be one of the most suitable corpora to be used in the Digital Speech Processing techniques of the Punjabi language (such as the classical linear prediction analysis and synthesis technique), because of the many new features of this corpus.

Some original features of this corpus are mentioned below:

1. Each item of the corpus is unique. Each sentence or ***boli*** in the corpus has been carefully designed so as to convey something new and special about the Punjabi language [13-14, 43, 48, 95-97], Malwai dialect [103, 112, 140], Gurmukhi script [13-14, 43, 48, 95-97, 103, 112, 140], Phonetics, vowels, consonants, and vowels signs (aka *matras* or *accessory signs* or *diacritical marks*) by using a wide variety of vocabulary, idioms and expressions. In particular, a special feature called **Anupras Alankar (ਅਨੁਪ੍ਰਾਸ ਅਲੰਕਾਰ)** has been used throughout the development of the corpus (*Anupras* means "alliteration").

2. All categories and phonetic characteristics of the speech sounds (e.g., voiced, unvoiced or voiceless, nasals, non-nasals, aspirated, unaspirated) have been recorded, and analyzed.

3. The words and sentences used in the corpus have been selected from books written by the *Sahitya-Academy Award* winner writers of the ***Malwa*** region (The Sahitya-Academy Award is the highest literary award administered by the Government of India).

4. Punjabi is a tonal language. *Phonemes* involving tones in a language are known as *Tonemes*. Several sets in the corpus have been designed to illustrate these *tonemes*: ਘ, ਝ, ਢ, ਧ, ਭ (voiced aspirates), and conjunct consonant ੍ਹ.

5. Several sentences in the corpus have been designed to demonstrate *reduplication*. Reduplication implies that the meaning of a word can change with the addition of the sign called (*ə́dək*) as in ਪਤਾ (means *address*) and ਪੱਤਾ (means *leaf*). Gill and Gleason [43] call it *gemination:* "Gemination is written by the sign /əddək/ above and before the consonant to be doubled." Bahri [13] calls this phenomenon as *"Long (or double) consonants*".

6. Several sentences in the corpus (set 45) have been designed to demonstrate that in these pairs of words, the meaning of the word changes with the addition of /ਅ/ at the end of the word, and its pronunciation is also extended. A new term ***Extended Pronunciation (ਲਮਕਵਾਂ ਉਚਾਰਣ)*** has been coined by the author for this feature of the Punjabi language.

7. Some lines of the popular folk songs have been used in the *original* form.

8. Some lines of the popular folk songs have been used in the *modified* form.

9. Some single line folk songs (***bolis***) have been recorded and analyzed.

10. Some new ***bolis*** have been written (the author is a creative writer, and has published five books of the original Punjabi poetry). The new ***bolis*** written by the author, end with the symbol *double dandi* (॥) to emphasize the fact that these ***bolis*** are original.

11. Some *ṭheṭh pendu shabads* (rustic words), and expressions that are slowly fading out from everyday use have been included in the corpus. Fading letters (e.g., **ਙ, ਞ**) have also been included.

12. Speech sentences spoken by a variety of speakers (based on sex and age) have been employed (adult *male* and *female* speakers of age range: 24 – 70 years have been recorded for the *speech corpus*.

13. Speech sentences spoken by *different* (15) Punjabi speakers from *different* villages and cities of *different* (ten) districts of the ***Malwa*** region of the Punjab state of India have been recorded.

14. In addition to *Malwain* (a female of the Malwa region), the names of about two dozen villages and cities of the ***Malwa*** region prominently appear in some of the ***bolis*** to highlight the fact that this work concentrates on the ***Malwa*** region of the Punjab state in India.

15. Since the ***Malwai*** people pronounce the names of places in slang form instead of their actual names, many items in the corpus include the slang names of cities and villages. Places named *Barnala, Faridkot, Jagraon, Moga, Mukatsar, Raikot, Ludhiana*, and *Amritsar* have been used in the corpus in their slang form.

16. Many popular names and nick-names for the ***Malwai*** males and females are included in various parts of the corpus.

17. Three young freedom fighters *Shaheed* Kartar Singh Sarabha, *Shaheed* Bhagat Singh, and *Shaheed* Udham Singh Sunam (*Shaheed* means *Martyr*), who sacrificed their lives during the independence struggle of India before 1947 are very popular amongst the youth of the ***Malwa*** region. The names of all three of these martyrs have been respectfully mentioned in several sentences and ***bolis*** of the corpus.

18. The names of the trees, weeds, and crops (either grown by seeding or naturally grown as weeds in the ***Malwa*** region) have been included in many items of the corpus.

19. Many birds, insects, and animals found in the ***Malwa*** region (*and* frequently mentioned in everyday conversations and communications of the ***Malwai*** population) have been included in many items of the corpus.

20. Males and females of the ***Malwa*** region are fond of wearing jewelry items generally made of silver and gold. Many jewelry items have been prominently mentioned in many sentences and ***bolis*** of the new corpus.

The fact that the new corpus is very rich and versatile due to a wide variety of its linguistic and cultural features mentioned here makes it an ideal corpus for any serious speech processing work in the Punjabi language.

7.1.3. Linear prediction Analysis and Synthesis of the Punjabi speech

This is the ***third*** major objective of this project. In the LP model of speech production, the current speech sample is predicted by using the linear combination of the past *p* speech samples. Each of the four control parameters (LP coefficients, voiced/unvoiced decision, pitch period for voiced sounds, and gain) can be determined directly from the speech waveform using more than one method, thereby making each analysis/synthesis project substantially different from every other project. In this work, *autocorrelation method* (for computing LP coefficients), *ZFF algorithm, and RAPT algorithms* (for computing V/UV decision and pitch), and *RMS method* (for computing Gain) have been used for computing the four control parameters of the linear prediction model of speech production. Final results (including informal perceptual listening tests, spectral characteristics, low bit rate transmission, and savings in the computation) reported in this work strongly confirm that the LPC technique is capable of generating high quality synthesized Punjabi speech output.

The quality of the processed speech was judged by the informal perceptual listening tests throughout this work. We used the *informal perceptual listening tests* mainly due to the absence of any other facilities for speech tests in most Digital Signal Processing laboratories. The second reason is that the *informal perceptual listening tests* are considered to be the best criteria by the author. The human ear, above everything else, still remains the decisive mechanism for the perception of any speech, whatsoever. In addition to many other speech researchers, Ghosh *et al.* recently confirmed this important fact experimentally that the auditory filter bank in human ear is a *near-optimal speech processor* for efficient speech communication between human beings [129, pp. 710].

Additional insight has been provided by the *spectrographic analysis* conducted using Praat and MATLAB where the *formants, intensity, pitch, V/UV contours,* and *FFT* of the speech waveforms have been plotted. It has been concluded that:

1. Number of poles $p = 12$ is sufficient to provide an adequate representation of speech signals. A slight degradation in the quality of the synthesized speech is noticeable when *p* is decreased to 8 and although poor in quality, speech can be synthesized with *p* as low as 2 **(Table 5.2).**

2. A Hamming window in the autocorrelation method improves the results, more than the implicit rectangular window.

3. Due to the limitations of the simplified all pole model, the quality of the nasal, plosive and voiced fricative sounds is not as good as that of the voiced, unvoiced and non-nasal sounds.

4. No significant improvement has been noticed in the overall performance of the speech synthesizer when different *pitch detection algorithms* were used. Therefore, the well-known result that *no single pitch detection algorithm is uniformly top-ranked across all environments* [90, 99] has been confirmed.

This project is a *successful* attempt to address the important issue of synthesizing high quality speech (*or* generating high quality *synthesized speech* or *synthetic speech*) in the *Punjabi* language.

The nature of this work is highly interdisciplinary. This work requires the knowledge of Computing Science, Information Technology, Electrical Engineering, Mathematics, Statistics, Linguistics, Phonetics, Punjabi Language, Gurmukhi Script, and the Malwai Dialect.

7.2. FUTURE DIRECTIONS

There are several possible directions and extensions of this work. ***Six*** most important extensions are mentioned below.

1. This work concentrates on the ***Malwai*** dialect of the Punjabi language. Punjabi University (Patiala, India) published a list of 31 dialects of the Punjabi language. It will be interesting to deal with the corpus designs and analysis/synthesis of the other dialects of the Punjabi language.

2. The comparisons of the results obtained for the projects on ***different dialects*** can also generate significant results. This comparison will be an important extension of this project.

3. This work concentrates on the ***Gurmukhi*** script of the Punjabi language. The comparisons of the results obtained for two different scripts (Gurmukhi and Shahmukhi) can also lead to important projects.

4. This work concentrates on the ***linear prediction*** analysis and synthesis of the Punjabi language. Other researchers have synthesized the Punjabi speech using synthesis techniques other than the linear prediction technique. The comparisons of the results

obtained for various synthesis techniques can be another fruitful extension of this work.

5. A comparative study of the classification of the Punjabi ***speech sounds, and phonemes*** by various authors can be an interesting project.

6. The speech and text ***corpus*** designed in this work consists of approximately 300 items (sentences, and ***bolis***), and at least twenty original features. It is our intent to convert this into an on-going project, and keep adding more items, and more unique features to the corpus.

Keywords: Computational Linguistics, Linear Prediction Analysis and Synthesis of Speech, Linear Prediction of Speech, LPC, Punjabi Speech Processing, Digital Speech Processing, Linguistics, Phonetics, Punjabi Language, PUNJARPAbet, ARPAbet, IPA, Phonetic Alphabet, Coding Scheme, Text Corpus; Speech Corpus, Punjabi Corpus, Punjabi Corpora.■

APPENDIX A
CORPUS (52 SETS)

(1) ੳ 1. ਓਏ ਉੱਲੂ! ਊਂਘਦਾ ਕਿਓਂ ਐਂ? ਉਂਗਲੀ ਫੜ!

oe Ullu! ṹgda kIõ ɛ̃? Ũggli phəṛ!
/OW EY - UH LL UW! UWn hG D AA - K IH OWn - AEn?
UHn GG L IY - PH AH RH!/

(2) ਓਹਨੂੰ ਊਧਮ ਸਿੰਘ ਸੁਨਾਮ ਦਾ ਬੁੱਤ ਦਿਖਾਓ।

ónũ údəm sĨ́g sUnam da bUtt dIkhao.
/OWh N UWn - UW hD AH M - S IHn hG - S UH N AA M - D AA - B UH TT -
D IH KH AA OW/

(3) ਅ 2. ਅਮਰ! ਐਂ ਕਰ, ਔਹ ਐਨਕ ਅੰਦਰ ਲੈ ਆ।

əmər! ɛ̃ kər, ɔ́ ɛnək ə̃dər lɛ a.
/AA M AH R! AEn - K AH R, AOh - AE N AH K - AHn D AH R - L AE - AA/

(4) ਆਈਏ ਹੱਥ ਮਿਲ਼ਾਈਏ, ਪੈਸਾ ਕੱਢ ਜਲੇਬੀ ਲਿਆਈਏ।

aie hətth mIḷaie pɛsa kə́ḍḍ jəlebi lIaie.
/AA IY EY - H AH TTH - M IH L AA IY EY, P AE S AA - K AH hD:D: -
J AH L EY B IY - L IH AA IY EY/

(5) ੲ 3. ਈਸ਼ਰ ਅਤੇ ਇੰਦਰ, ਇਕਵੰਜਾ ਇੱਟਾਂ ਏਥੇ ਲਿਆਓ।

iṣər əte Ĩdər, Ikvə̃ja Iṭṭã ethe lIao.
/IY SH AH R - AH T EY - IHn D AH R, IH K V AHn J AA - IH T:T: AAn -
EY TH EY - L IH AA OW/

(6) ਇੰਦਰ ਇਲਤੀ 'ਈਸ਼ਰ ਆਏ ਦਲਿੱਦਰ ਜਾਏ' ਗਾਉਂਦਾ ਸੀ।

Ĩdər Ilti 'iṣər ae dəlIddər jae' gaŨda si.
/IHn D AH R - IH L T IY 'IY SH AH R - AA EY - D AH L IH DD AH R -
J AA EY' - G AH UHn D AA - S IY/

(7) ਈਸ਼ਰ, ਇੱਕ ਇੱਕ ਕਰਕੇ ਇਕਵੰਜਾ ਇੱਟਾਂ ਏਥੇ ਲਿਆ!

iṣər, Ikk Ikk kərke Ikvə̃jja Iṭṭã ethe lIa!
/IY SH AH R, IH KK - IH KK - K AH R K EY - IH K V AHn J AA -
IH T:T: AAn - EY TH EY - L IH AA/

(8) ਸ 4. ਸ਼ੇਰੇ ਸੰਧੂ ਨੇ ਸੁੰਦਰ ਦੇ ਸਿਰ 'ਚ ਛੇ ਸੱਤ ਸੋਟੀਆਂ ਛੱਡੀਆਂ।

ṣere sə̃́du ne sŨdər de sIr ’c che sətt sotiã chəḍḍiã.
/SH EY R EY - S AHn hD UW - N EY - S UHn D AH R - D EY - S IH R - ’CH - CHH EY - S AH TT - S OW T: IYn - CHH AH D:D: IYn/

(9) ਸੇਵੇ ਸੈਣੀ ਨੇ ਸੌ ਸੋਮਵਾਰ ਸੰਘਣੀ ਲੱਸੀ ਪੀਤੀ।

seve sɛṇi ne sɔ somvar sə̃́gəṇi ləssi piti.
/S EY V EY - S AE N: IY - N EY - S AO - S OW M V AA R - S AHn hG AH N: IY - L AH SS IY - P IY T IY/

(10) ਕਿੱਥੇ ਸੰਤ-ਸੇਵਕ ਸੁੱਚਾ ਸਿਪਾਹੀ, ਕਿੱਥੇ ਸੌਣਾ ਸੂਮ!

kItthe sə̃t-sevək sUcca sIpahi, kItthe sɔṇa sum!
/K IH TTH EY- S AHn T -- S EY V AH K - S UH CHCH AA - S IH P AA H IY, K IH TTH EY - S AO N: AA - S UW M!/

(11) ਹ 5. ਬਹੁ, ਹਿੰਮਤ ਹੇਹਰ ਦੇ ਹਲ਼ਟ ਵਾਲ਼ਾ ਰਾਹ ਹੌਲ਼ੀ ਚਲਦੈ!

bəhu, hĨmmət hehər de həlt vaḷa rá hɔḷi cəldɛ!
/B AH H UW, H IHn MM AH T - H EY H AH R - D EY - H AH L T - V AA L AA - R AAh - H AO L IY - CH AH L D AE!/

(12) ਹੈਂਕੜੀ ਹੁਕਮਿਆਂ, ਹੱਦ ਹੋ ਗੀ?

hɛ̃kəṛi hukmIã, hədd ho gi?
/H AEn K AH RH IY- H UH K M IH AAn, H AH DD - H OW - G IY?/

(13)/(148) ਹਾਕਮ ਨੇ ਹੰਸ ਨੂੰ ਹਰਾਅ ਕੇ ਹਰਾ ਹੀਰਾ ਜਿੱਤਿਆ।

hakəm ne hə̃s nũ həraə ke həra hira jIttIa.
/H AA K AH M - N EY - H AHn S - N UWn - H AH R AA AH - K EY - H AH R AA - H IY R AA - J IH TT IH AA/

(14) ਕ 6. ਕਿਹੜੀ ਕਮਲ਼ੀ ਨੇ ਕਾਲ਼ੀ ਕੁੜਤੀ ਕੰਧੋਲ਼ੀ ’ਤੇ ਟੰਗੀ ਐ?

kéṛi kəmḷi ne kaḷi kuṛti kə̃́doḷi ’te tə̃gi ɛ?
/K EYh RH IY - K AH M L IY - N EY - K AA L IY - K UH RH T IY - K AHn hD OW L IY - ’T EY - T: AHn G IY - AE?/

(15) ਕਾਕਾ ਕੇਵਲ, ਕਾਂ ਕਾਂ ਨਾ ਕਰ, ਕੁੱਤੇ ਆਂਙੂੰ ਕੁੱਟੂੰ।

kaka kevəl, kã kã na kər, kutte ãŋũ kuṭṭũ.
/K AA K AA - K EY V AH L, K AAn - K AAn - N AA - K AH R, K UH TT EY - AAn NX UWn - K UH T:T: UWn/

(16) ਕੈਲਿਆ, ਕਿੱਥੇ ਕੋਲ ਦੀ ਕੂ ਕੂ, ਕਿੱਥੇ ਕੌਡ ਕਬੱਡੀ!

kɛlIa, kItthe kol di ku ku, kItthe kɔḍ kəbəḍḍi!
/K AE L IH AH, K IH TTH EY - K OW L - D IY - K UW - K UW, K IH TTH EY- K AO D: - K AH B AH D:D: IY/

(17) ਖ 7. ਖ਼ਸਮਾਂ ਖਾਣੀ ਨੇ ਖਰਾ ਖੋਟਾ ਖੂਹ ’ਚ ਪਾ ’ਤਾ।

xəsmã khaṇi ne khəra khoṭṭa khú ’c pa ’ta.
/X AH S M AAn - KH AA N: IY - N EY - KH AH R AA - KH OW T:T: AA - KH UWh - ’CH - P AA - ’TAA/

(18) ਓਏ ਖੋਤਿਆ, ਖੌਰੂ ਨਾ ਪਾ, ਖੀਰ ਖਾਹ।

oe khottIa, khɔru na pa, khir khá.
/OW EY - KH OW TT IH AA, KH AO R UW - N AA - P AA, KH IY R - KH AAh/

(19) ਖੜਕ ਸਿੰਘ ਖੰਡੇ ਦੀ ਖੇਡ ਦਾ ਖਿਡਾਰੀ ਹੈ।

khəṛk sĨ́g khə̃ḍe di khed da khIḍari hɛ.
/KH AH RH K - S IHn hG - KH AHn D: EY - D IY - KH EY D: - D AA - KH IH D: AA R IY - H AE/

(20) ਖੁੱਚਾਂ ’ਚ ਖਿੱਚਕੇ ਖੁਰਚਣਾ ਮਾਰਾਂ ਕਿ ਖੁੰਢਾ ਖੁਰਪਾ?

khUccã ’c khIccke khUrcəṇa marã kI khṸḍa khUrpa?
/KH UH CHCH AAn - ’CH - KH IH CHCH K EY - KH UH R CH AH N: AA - M AA R AAn - K IH - KH UHnh D: AA - KH UH R P AA?/

(21) ਗ 8. ਗੇਂਦੇ ਗੱਭਰੂ ਨੇ ਭਾਗੋ ਕੇ ਜਗੀਰੇ ਤੋਂ ਗੁੜ ਖਾਧਾ।

gẽde gə́bbəru ne pàgo ke jəgire tõ gUṛ kháda.
/G EYn D EY - G AH hBB AH R UW - N EY - Pl AA G OW - K EY - J AH G IY R EY - T OWn - G UH RH - KH AA hD AA/

(22) ਗਲਾਧੜ ਨੇ ਗੂੜ੍ਹ-ਗਿਆਨੀ ਤੋਂ ਗਾੜ੍ਹਾ ਦੁੱਧ ਛਕਿਆ।

gəládəṛ ne gúṛ-gIani tõ gáṛa dÚdd chəkIa.
/G AH L AA hD AH RH - N EY - G UW hRH -- G IH AA N IY - T OWn - G AA hRH AA - D UH hDD - CHH AH K IH AA/

(23) ਗਿੰਦਰ ਗੈਂਡਾ ਜਿਆ, ਗੌਂ ਵੇਲ਼ੇ ਈ ਗੱਲ ਗੌਲ਼ਦੈ!

gĨdər gɛ̃ḍa jIa, gɔ̃ veḷe i gəll gɔḷdɛ!
/G IHn D AH R - G AEn D: AA - J IH AA, G AOn - V EY L̲ EY - IY - G AH LL - G AO L̲ D AE!/

(24) ਘ 9. ਘੌਲ਼ ਕੀਤੀ ਤਾਂ ਘੋਟਣੇ ਨਾਲ਼ ਘੜੂੰ।

kɔ̀ḷ kiti tã kòṭəṇɛ naḷ kə̀ṛũ.
/Kl AO L̲ - K IY T IY - T AAn - Kl OW T: AH N: EY - N AA L̲ - Kl AH RH UWn/

(25) ਘੋਲ਼ ਘੁਲ਼ਨੈਂ ਤਾਂ ਘਿਓ ਛਕ, ਘੀਸੀ ਨਾ ਕਰਾ ਲੀਂ!

kòḷ kÙḷənɛ̃ tã kÌo chək, kíssi na kəra lĩ!
/Kl OW L̲ - Kl UH L̲ AH N AEn - T AAn - Kl IH OW - CHH AH K,

K IY hSS IY - N AA - K AH R AA - L IYn!/

(26) ਘੁੱਦੇ ਨੇ ਖੰਘੂਰੇ ਮਾਰ ਮਾਰ ਸੰਘ ਦਾ ਕੰਘਾ ਕਰਾ ਲਿਆ।

kÙdde ne khə̃gure mar mar sə̃g da kə̃ga kəra lIa.
/Kl UH DD EY - N EY - KH AHn hG UW R EY - M AA R - M AA R –
S AHn hG - D AA - K AHn hG AA - K AH R AA - L IH AA/

(27) ਬਘਿਆੜ ਮੇਘੇ ਘੁਮਿਆਰ ਦਾ ਘੋੜਾ ਖਾ ਗਿਆ।

bəgIàṛ mége kÙmIar da kòṛa kha gIa.
/B AH Gl IH AA RH - M EY hG EY - Kl UH M IH AA R - D AA –
Kl OW RH A - KH AA - G IH AA/

(28) ਘੱਟਾ ਘਰ ਸੰਘੋਲ਼ ਵਾਲ਼ਾ ਖੂਹ ਘੱਟ ਡੂੰਘੈ।

kə̃̀ṭa kər sə̃́goḷ vaḷa khú kəṭṭ ḍṹgɛ.
/Kl AHn T: AA - Kl AH R - S AHn hG OW L - V AA L AA - KH UWh -
Kl AH T:T: - D: UWn hG AE/

(29)/(149) ਘੜਾ ਮਾਘ ਭਰ ਭਰੂੰ ਤੇਰਾ ਮੱਘਰਾ, ਝਾਂਜਰਾਂ ਘੜਾਅ ਦੇ ਮਿੱਤਰਾ॥

kəṛa mág pər pərũ tera məggəra, cə̃̀jrã kəṛaə de mIttəra.
/Kl AH RH AA - M AA hG - Pl AH R - Pl AH R UWn - T EY R AA -
M AH hGG AH R AA, CHl AAn J R AAn - Kl AH RH AA AH - D EY -
M IH TT AH R AA./

(30) ਙ 10. ਕੰਙਣ ਛਣਕਾਉਂਦੀਏ! ਦੁੱਧ ’ਚ ਮੀਂਙਣਾ ਨਾ ਪਾ।

kə̃ŋəṇ chəṇkaŨdie! dÚdd ’c miŋəṇa na pa.
/K AHn NX AH N: - CHH AH N: K AA UHn D IY EY! D UH hDD - ’CH -
M IYn NX AH N: AA - N AA - P AA/

(31) ਚ 11. ਚੇਤੂ ਚੌਰੇ ਨੇ ਚਕਚੂੰਧਰ ਚਲਾਅ ਕੇ ਚਾੜ੍ਹਤਾ ਚੰਦ?

cetu cɔre ne cəkcṹdər cəlaə ke cáṛta cə̃d?
/CH EY T UW - CH AO R EY - N EY - CH AH K CH UWn hD AH R -
CH AH L AA AH - K EY - CH AA hRH T AA - CH AHn D?/

(32) ਚੋਰਾ! ਚੈਂ ਚੈਂ ਚੀਂ ਚੀਂ ਛੱਡ, ਚੂਕਣੇਂ ’ਚ ਚਾਰ ਠੋਕੂੰ!

cora! cɛ̃ cɛ̃ cĩ cĩ chəḍḍ, cukṇẽ ’c car ṭhokũ!
/CH OW R AA! CH AEn - CH AEn - CH IYn - CH IYn - CHH AH D:D:,
CH UW K N: EYn - ’CH - CH AA R - TH: OW K UWn/

(33) ਚਾਚਾ ਚੰਦਰਿਆ, ਚਿੱਤ ਚੰਗਾ ਰੱਖ, ਚੁੱਲ੍ਹਾ ਤਾਂ ਬਲ਼ਦੈ!

caca cə̃drIa, cItt cə̃ga rəkkh, cÚlla tã bəḷdɛ!
/CH AA CH AA - CH AHn D R IH AA, CH IH TT - CH AHn G AA -
R AH KKH, CH UH hLL AA - T AAn - B AH L D AE!/

(34) ਛ 12. ਛੱਜ ਤਾਂ ਬੋਲੇ, ਛਾਣਨੀ ਕੀ ਬੋਲੇ?

chəjj tã bole chaṇni ki bole?
/CHH AH JJ - T AAn - B OW L EY, CHH AA N: N IY - K IY - B OW L EY?/

(35) ਛੋਲਿਆਂ ਦੇ ਖੇਤ 'ਚੋਂ ਛੀਂਬਾ-ਸੱਪ ਨਿੱਕਲਿਆ।

chollIã de khet 'cõ chĩba səpp nIkkəḷIa.
/CHH OW LL IH AAn - D EY - KH EY T - 'CH OWn - CHH IYn B AA --
S AH PP - N IH KK AH L IH AA/

(36) ਛਿੰਦੇ ਨੇ ਛੱਪੜ 'ਚੋਂ ਛੇਤੀ ਛੇਤੀ ਛੇ ਕੱਛੂ ਫੜੇ।

chĨde ne chəppəṛ 'cõ cheti cheti che kəcchu phəṛe.
/CHH IHn D EY - N EY - CHH AH PP AH RH - 'CH OWn - CHH EY T IY -
CHH EY T IY - CHH EY - K AH CHCHH UW - PH AH RH EY/

(37) ਜ 13. ਜਗਦੀ ਮਘਦੀ ਜਾਗੋ, ਜਿੱਤ ਲੀ ਜੀਤੋ ਨੇ॥

jəgdi mə́gdi jago, jItt li jito ne.
/J AH G D IY - M AH hG D IY - J AA G OW, J IH TT - L IY - J IY T OW -
N EY./

(38) ਜੋਤੀ ਜਿੰਦਲ ਦੇ ਜੂਠੇ ਜੱਗ ਨੂੰ ਜੰਗਾਲ ਲੱਗ ਗੀ।

jotti jĨdəl de juṭhe jəgg nũ jə̃gal ləgg gi.
/J OW TT IY - J IHn D AH L - D EY - J UW TH: EY - J AH GG - N UWn -
J AHn G AA L - L AH GG - G IH/

(39) ਜੁਆਲੇ ਦੀ ਜੱਤ 'ਚ, ਜੂੰਆਂ ਈ ਜੂੰਆਂ।

jUale di jətt 'c, jũã i jũã.
/J UW AA L EY - D IH - J AH TT - 'CH, J UWn AAn - IY - J UWn AAn/

(40) ਜਿੰਦਰੋ ਦੀ ਜਠਾਣੀ ਨੇ ਜੌੜੇ ਜੁਆਕ ਜੰਮੇ।

jĨdəro di jəṭhani ne jɔṛe jUak jə̃mme.
/J IHn D AH R OW - D IY - J AH TH: AA N: IY - N EY - J AO RH EY -
J UW AA K - J AHn MM EY/

(41) ਝ 14. ਮਝੈਲੋ! ਮੱਝ, ਝੋਟੀ ਦਾ ਝਗੜਾ ਝੱਟ ਪੱਟ ਨਬੇੜੋ।

mə́jɛlo! mə́jj cò̀ṭṭi da cə̀gṛa cə̀ṭ pəṭ nəbeṛo.
/M AH hJ AE L OW! M AH hJJ, CHl OW T:T: IY - D AA -
CHl AH G RH AA - CHl AH T:T: - P AH T:T: - N AH B EY RH OW/

(42) ਝੰਡਾ, ਮਝੇਰੂ ਜਿਆ, ਝੱਜੂ ਪੌਣ ਗਿੱਝ ਗਿਐ।

cə̃̀ḍḍa, mə́jeru jIa, cə̀jju pɔṇ gĺjj gIɛ.
/CHl AHn D:D: AA - M AH hJ EY R UW - J IH AA, CHl AH JJ UW –
P AO N: - G IH hJJ - G IH AE/

(43) ਢ 15. ਚੰਨੇ ਨੂੰ ਚੰਨਾ ਸਾਹਮਣਾ, ਉੱਤੇ ਕਾਂਞਣ ਸਿੱਧੀ ਸਤੀਰ। (ਕਾਂਞਣ = ਹਲ਼ਟ)

cə̃nne nũ cə̃nna sámṇa, utte kãɲəṇ sÍddi sətir.
/CH AHn NN EY - N UWN - CH AHn NN AA - S AAh M N: AA, U TT EY - K AAn NJ AH N: - S IH hDD IY - S AH T IY R/

(44) ਜੰਞ ਚੜ੍ਹਦੀ ਹੈ ਅਲਬੇਲੇ ਦੀ।

jə̃ɲ cə́ṛdi hɛ əlbele di.
/J AHn NJ - CH AH hRH D IY - H AE - AH L B EY L EY - D IY/

(45) ਟ 16. ਟੁੱਕ-ਟੇਰ ਨੇ ਟਟੀਹਰੀ ਆਂਙੂੰ ਅਸਮਾਨ ਥੰਮ੍ਹਿਆ।

ṭUk-ṭek ne ṭəṭíri ãŋũ əsman ṭhə̃́mmIa.
/T: UH KK -- T: EY R - N EY - T: AH T: IYh R IY - AAn NX UWn - AH S M AA N - TH AH hMM IH AA/

(46) ਟਿਕ ਜਾ ਟਹਿਲਿਆ, ਟੱਟੂ ਆਂਙੂੰ ਟੀਟਣੇ ਨਾ ਮਾਰ।

ṭIk ja ṭɛ́lIa ṭəṭṭu ãŋũ ṭiṭəṇe na mar.
/T: IH K - J AA - T: AEh L IH AA, T: AH T:T: UW - AAn NX UWn - T: IY T: N: EY - N AA - M AA R/

(47) ਟੇਟੂਏ, ਟੂਟੀਆਂ ਦਾ ਟਟਬੈਰ ਨਾ ਖੜ੍ਹਾ ਕਰੋ।

ṭeṭue ṭuṭIã da ṭəṭbɛr na khə́ṛa kəro.
/T: EY T: UW EY, T: UW T: IY AAn - D AA - T: AH T: B AE R - N AA - KH AH hRH AA - K AH R OW/

(48) ਠ 17. ਠਾਕਰ ਠੇਠਰਾ, 'ਠਾਰਾਂ ਠਾਣਿਆਂ 'ਚ ਠੱਗਿਆ ਗਿਐਂ!

ṭhakər ṭhəṭhera, 'ṭharã ṭhaṇIã 'c ṭhəggIa gIɛ̃!
/TH: AA K AH R - TH: EY TH: AH R AA, 'TH: AA R AAn - TH: AA N: IH AAn - 'CH - TH: AH GG IH AA - G IH AE!/

(49) ਠੂਹ-ਠਾਹ ਛੱਡ, ਠੀਕ ਹੋ ਕੇ ਠੁੱਕ ਨਾਲ਼ ਰਹਿ।

ṭhú-ṭhá chəḍḍ, ṭhik ho ke ṭhUkk naḷ rɛ́.
/TH: UWh -- TH: AAh - CHH AH DD, TH: IY K - H OW - K EY - TH: UH KK - N AA L̲ - R AEh/

(50) ਝੂਠ ਨਾ ਬੋਲ, ਪੀਂਘ ਝੂਟ!

cùṭh na bol, pĩ́g cùt!
/CHl UW TH: - N AA - B OW L, P IYn hG - CHl UW T:!/

(51) ਡ 18. ਵੱਡਿਆ ਭਲਵਾਨਾ, ਡੋਲੂ 'ਚੋਂ ਦੁੱਧ ਡੱਫ ਲੈ!

vəḍḍIa pə̀lvana, ḍollu 'cõ dÚdd ḍəpph lɛ!
/V AH D:D: IH AA - Pl AH L V AA N AA, D: OW L UW - 'CH OWn - D UH hDD - D: AH PPH - L AE!/

(52) ਡਰਾਕਲ਼ਾ, ਠੰਢ ਤੋਂ ਡਰ ਨਾ, ਡੰਡ ਕੱਢ।

ḍərakḷa, ṭhə̃́ḍ tõ ḍər na, ḍə̃ḍ kə́ḍḍ.
/D: AH R AA K L AA, TH: AHn hD: - T OWn - D: AH R - NAA, D: AHn D: - K AH hD:D:/

(53) ਡੋਗਰਾ, ਡੌਰੂ ਵੱਜੂ ਤਾਂ ਡੰਡ ਵੀ ਪਊ!

ḍogra, ḍɔru vəjju tã ḍə̃ḍ vi pəu.
/D: OW G R AA, D: AO R UW - V AH JJ UW - T AAn - D: AHn D: - V IY - P AH UW!/

(54) ਢ 19. ਢੱਕਣਾ, ਯਾਰੀ ਐ ਕਿ ਛੋਲਿਆਂ ਦਾ ਵੱਢ?

ṭə̀kkəṇa, yari ɛ kI chollIã da və́ḍḍ?
/T:l AH KK AH N: AA, Y AA R IY - AE - K IH - CHH OW L IH AAn - D AA - V AH hD:D:?/

(55) ਢਿੱਡਲ਼ ਢਾਡੀ ਨੇ ਢੱਡ ਢੂੰਡੀ ਕਿ ਕਾਢ ਕੱਢੀ?

ṭÌḍḍəḷ ṭàḍḍi ne ṭə̀ḍḍ ṭũ̀ḍi kI káḍ kə́ḍḍi?
/T:l IH D:D: AH L - T:l AA D:D: IY - N EY - T:l AH D:D: - T:l UWn D: IY - K IH - K AA hD: - K AH hD:D: IY?/

(56) ਢਿੱਡਲ਼ਾ, ਆਹ ਢੋਲੀ ਕੱਢਿਐ? ਲੱਤਾਂ ਵੱਢ ਦੂੰ!

ṭÌḍḍəḷa, á tòli kə́ḍḍIɛ? lattã və́ḍḍ dũ!
/T:l IH D:D: AH L AA, AAh - T:l OW L IY- K AH hD:D: IH AE? L AH TT AAn - V AH hD:D: - D UWn!/

(57) ਢੇਰੂ ਨੇ ਢੋਲ ਦੇ ਡਾਢੇ ਵੱਟ ਕੱਢੇ।

ṭèru ne ṭòl de ḍáḍe vəṭṭ kə́ḍḍe.
/T:l EY R UW - N EY - T:l OW L - D EY - D: AA hD: EY - V AH T:T: - K AH hD:D: EY/

(58) ਕੱਢੋ ਢੇਰੂ ਨੂੰ, ਢਿੱਡ ਨਾ ਵੱਢਿਆ ਢੂਹੀ ਸਣੇ ਢੋਲਕੀ ਆਂਡੂੰ!

kə́ḍḍo ṭèru nũ, tÌḍḍ na və́ḍḍIa ṭùhi səṇe tòlki ãŋũ!
/K AH hD:D: OW - T:l EY R UW - N UWn, T:l IH D:D: - N AA - V AH hD:D: IH AA - T:l UW H IY - S AH N: EY - T:l OW L K IY- AAn NX UWn!/

(59) ਢੱਗੇ ਦੇ ਚੂੰਢੀਆਂ ਨਾ ਵੱਢ ਕੁੰਢਿਆ, ਢਿੰਬਰੀ ਟੈਟ ਕਰ ਦੂੰ!

ṭə̀gge de cṹḍiã na və́ḍḍ kṸḍḍIa, ṭÌ̃bəri ṭɛṭ kər dũ!
/T:l AH GG EY - D EY - CH UWn hD: IY AAn - N AA - V AH hD:D: - K UHn hD: IH AA, T:l IHn B AH R IY - T: AE T: - K AH R - D: UWn!/

(60) ਮੁੱਢੋਂ-ਸੁੱਢੋਂ ਕੰਮ ਕਰ ਢੰਗ ਨਾਲ਼, ਮੱਘੇ ਕੱਢਦਾ ਫਿਰਦੈਂ!

mÚḍḍõ-sÚḍḍõ kə̃mm kər ṭə̀g naḷ, mə́gge kə́ḍḍda phIrdɛ̃́!

/M UH hD:D: OWn -- S UH hD:D: OWn - K AHn MM - K AH R - T:l AHn G - N AA L, M AH hGG EY - K AH hD:D: D AA - PH IH R D EYn!/

(61) ਣ 20. ਮਣਕੇ ’ਤੇ ਮਣਕਾ, ਠਾਹ ਮਣਕਾ।

mәṇke ’te mәṇka, ṭhá mәṇka.
/M AH N: K EY - ’T EY - M AH N: K AA, TH: AAh - M AH N: K AA/

(62) ਭੈਣੇਂ, ਰਾਣੋ ਦੀ ਨਣਦ ਤੇ ਦਰਾਣੀ ਨੂੰ ਮਿਲਣੈਂ!

pὲṇe, raṇo di nәṇәd te dәraṇi nũ mIlṇɛ̃!
/Pl AE N: EYn, R AA N: OW - D IY - N AH N: AH D - T EY - D AH R AA N: IY - N UWn - M IH L N: AEn!/

(63) ਢਾਣੀ ਨੂੰ ਪੁਰਾਣੇ ਠਾਣੇ ਜਾਣਾ ਪੈਣੈ।

ṭàni nũ pUraṇe ṭhaṇe jaṇa pɛṇɛ.
/T:l AA N: IY - N UWn - P UH R AA N: EY - TH: AA N: EY - J AA N: AA - P AE N: AE/

(64) ਤ 21. ਤਰਸੇਮੋ, ਤੂੰ ਤੋਤਕੜੇ ਬੰਦ ਕਰਕੇ ਤੱਕਲ਼ਾ ਸਿੱਧਾ ਕਰ।

tәrsemo, tũ totkәṛe bə̃d kәrke tәkkәḷa sÍdda kәr.
/T AH R S EY M OW, T UWn - T OW T K AH RH EY - B AHn D - K AH R K EY - T AH KK AH L AA - S IH hDD AA - K AH R/

(65) ਤਨ ਦਾ ਤਾਰੂ ਤੋਤਾ, ਤਰਜ਼ਾਂ ਤੀਹ ਲਾਵੇ॥

tәn da tarU tota, tәrzã tí lave.
/T AH N - D AA - T AA R UW - T OW T AA, T AH R Z AAn - T IHh - L AA V EY./

(66) ਨਾ ਤਿੰਨਾਂ ’ਚ, ਨਾ ਤੇਰ੍ਹਾਂ ’ਚ।

na tInnã ’c, na térã ’c.
/N AA - T IHn NN AAn - ’CH, N AA - T EY hR AAn - ’CH/

(67) ਤੂਤ ’ਤੇ ਤਿੰਨ ਤਿੱਤਰ ਬੈਠੇ ਸੀ।

tut ’te tInn tIttәr bɛṭhe si.
/T UW T - ’T EY - T IHn NN - T IH TT AH R - B AE TH: EY - S IY/

(68) ਨਾ ਤੋਤਾ ਨਾ ਤਿੱਤਰ, ਨਾ ਤਰ ਨਾ ਤਰਬੂਜ਼।

na tota na tIttәr, na tәr na tәrbuz.
/N AA - T OW T AA - N AA - T IH TT AH R, N AA - T AH R - N AA - T AH R B UW Z/

(69) ਤੂਤਕ, ਤੂਤਕ, ਤੂਤਕ, ਤੂਤੀਆਂ, ਹੇ ਜਮਾਲੋ!

tutәk, tutәk, tutәk, tutiã, he jәmalo!
/T UW T AH K, T UW T AH K, T UW T AH K, T UW T IY AAn,

H EY - J AH M AA L OW!/

(70) ਥ 22. ਥਥਲ਼ਾ ਥਾਣੇਦਾਰ ਥਥਲ਼ੌਂਦਾ ਹੈ।

thəthḷa thaṇedar thəthḷaũda hɛ.
/TH AH TH L AA - TH AA N: EY D AA R - TH AH TH L AOn D AA - H AE/

(71) ਥੰਮ੍ਹਣਾ, ਥਾਲ਼ੀ ਚੱਕ, ਰੋਟੀ ਥੱਪ, ਪਾਥੀਆਂ ਪੱਥ।

thə̃́mmṇa, thaḷi cəkk, roṭi thəpp, pathiã pətth.
/TH AHn hM N: AA, TH AA L IY - CH AH KK, R OW T IY - TH AH PP,
P AA TH IY AAn - P AH TTH/

(72) ਦ 23. ਦੁੱਲੂ ਦੀ ਦਾਦੀ ਦੇ ਦੋ ਦੰਦ ਦੁਖਦੇ ਨੇ।

dUllu di daddi de do də̃d dUkhde ne.
/D UH LL UW - D IY - D AA D IY - D EY - D OW - D AHn D -
D UH KH D EY - N EY/

(73) ਦਿੱਲੀ ਦਿਆ ਦੁਕਾਨਦਾਰਾ, ਦੁੱਧ ਨੀ ਦੀਂਹਦਾ?

dIlli dIa dUkandara, dÚdd ni dĩ́da?
/D IH LL IY - D IH AA - D UH K AA N D AA R AA, D UW hDD -
N IY - D IYnh D AA?/

(74) ਬੰਦੈਂ, ਤਾਂ ਦਸ ਮੀਲ ਦੂਰ ਦੌੜਕੇ ਦਿਖਾ!

bə̃dɛ̃, tã dəs mil dur dəṛke dIkha!
/B AHn D AEn, T AAn - D AH S - M IY L - D UW R - D AO RH K EY -
D IH KH AA!/

(75) ਧ 24. ਪਾਂਧੀ ਦਾ ਪੰਧ ਪੱਧਰਾ, ਧੁੰਦ ਧਰਮਾਂ ਦੀ ਵੱਧ॥

pā́di da pə̃́d pə́ddəra, tÙ̃dd tə̀rəmã di və́dd.
/P AAn hD IY - D AA - P AHn hD - P AH hDD AH R AA, Tl UWn DD -
Tl AH R AH M AAn - D IY - V AH hDD./

(76) ਬੁੱਧੂਆ, ਧੀਰਜ ਨਾਲ਼ ਸਿੱਧਾ ਤੁਰ।

bÚddua, tìrəj naḷ sÍdda tUr.
/B UH hDD UW AA, Tl IY R AH J - N AA L - S IH hDD AA - T UH R/

(77) ਨ 25. ਨਿੰਮੋ ਦੀ ਨੂੰਹ ਦੇ ਨੱਕ ’ਤੇ ਨੌਂ ਟੰਕੇ ਲੱਗੇ।

nĨmmo di nū́ de nəkk ’te nə̃ ṭə̃ke ləgge.
/N IHh MM OW - D IY - N UWnh - D EY - N AH KK - ’T EY - N AOn -
T AHn K EY - L AH GG EY/

(78) ਜੁਆਨੋ, ਨਲ਼ਕਾ ਨੀਵੀਂ ਨੁੱਕਰ ’ਚ ਨਾ ਹੋਵੇ।

jUano, nəḷka nivĩ nUkkər ’c na hove.
/J UH AA N OW, N AH L K AA - N IY V IYn - N UH KK AH R - ’CH -

N AA - H OW V EY/

(79) ਪ 26. ਪੰਚ ਪਰਵਾਨ, ਪੰਚ ਪਰਧਾਨ।

pə̃c pərvan, pə̃c pərdàn.
/P AHn CH - P AH R V AA N, P AHn CH - P AH R Dl AA N/

(80) ਪੂਰਨਾ, ਪੱਠੇ ਵੱਢ ਕੇ ਆਪੇ ਪੀਂਘ ਝੂਟ ਲੀਂ!

purna, paṭṭhe və́ḍḍ ke ape pĩ́g cùt lĩ!
/P UW R N AA, P AH T:TH: EY - V AH hD:D: - K EY - AA P EY - P IYn hG - CHl UW T: - L IYn!/

(81) ਪੁੱਤ, ਪਸ਼ੂ-ਪੰਛੀਆਂ ਨੂੰ ਪਿੰਡ ਦਾ ਪੌਣ ਪਾਣੀ ਪੋਂਹਦੈ।

pUtt, pəṣu-pə̃chiã nũ pĨḍ da pɔṇ paṇi pṍdɛ.
/P UH TT, P AH SH UW -- P AHn CHH IY AAn - N UWn - P IHn D: - D AA - P AO N: - P AA N: IY - P OWnh D AE/

(82) ਫ 27. ਫਕੀਰੀਏ ਦਾ ਫੁੱਫੜ ਫਰੀਦਕੋਟੋਂ ਆਇਆ ਸੀ।

phəkirie da phUphəṛ phəridkoṭõ aIa si.
/PH AH K IY R IY EY - D AA - PH UH PH AH RH -
PH AH R IY D K OW T: OWn - AA IH AA - S IY/

(83) ਫੁੰਮਣ ਫੁਕਰਾ ਫੇਰ ਕੀ ਫੰਨੂ ਖੋਹ ਦੂ!

phŨməṇ phUkra pher ki phənnũ khó du.
/PH UHn M AH N: - PH UH K R AA - PH EY R - K IY - PH AH NN UH -
KH OWh - D UW/

(84) ਫੋੜੇ-ਫਿਣਸੀਆਂ ਨੇ ਫੱਗੂ ਦੇ ਫੰਘ ਜੇ੍ਹ ਕੁਤਰ 'ਤੇ।

phoṛe-phIṇsiã ne phəggu de phə̃g jé kUtər 'te.
/PH OW RH EY -- PH IH N: S IY AAn - N EY - PH AH GG UW - D EY -
PH AHn hG - hJ EY - K UH T AH R - 'T EY/

(85) ਫਿੱਟੇ ਮੂੰਹ! ਫੰਨੇ ਖ਼ਾਂ ਫੌਜੀ ਨੇ ਫੱਟ ਭੋਇੰ ਫੂਕ 'ਤੀ!

phIṭṭe mṹ! phə̃nne xã phɔji ne phəṭṭ pòẽ phuk 'ti!
/PH IH T:T: EY - M UWnh! PH AHn NN EY - X AAn - PH AO J IY - N EY -
PH AH T:T: - Pl OW IHn - PH UW K - 'T IY!/

(86) ਬ 28. ਬੁੱਢ-ਵਲ੍ਹੇਟ ਹੋ ਕੇ ਅਨੋਭੜ ਬਣਦੈਂ?

bÚḍḍ-vә́leṭ ho ke ənóbəṛ bəṇdɛ̃?
/B UHh D:D: -- V AH hL EY T: - H OW - K EY - AH N OW hB AH RH -
B AH N: D AEn?/

(87) ਬੇਵਕੂਫ਼ ਬੁੱਧੂਆ, ਬੰਦਾ ਬਣਨੈਂ ਕਿ ਬਾਂਦਰ?

bevkuf bÚddua, bə̃da bəṇnɛ̃ kI bãdər?

/B EY V K UW F - B UH hDD UW AA, B AHn D AA - B AH N: N AEn -
K IH - B AAn D AH R?/

(88) ਬੋਲ਼ਿਆ ਬੱਦਲ਼ਾ! ਬੂਰੇ ਛੋਟੇ ਆਂਞੂੰ ਬੋਂਦਲ਼ਿਆ ਫਿਰਦੈਂ?

boḷIa bəddəḷa! bure còṭe ãŋũ bɔ̃dḷIa phIrdɛ̃?
/B OW L IH AA - B AH DD AH L AA! B UW R EY - CHl OW T: EY -
AAn NX UWn - B AOn D L IH AA - PH IH R D AEn?/

(89) ਭ 29. ਭੌਂਦੂ ਭੌਂਕੜ ਭੋਲਾ, ਭੋਲ਼ਾ ਭੰਡਾਰੀ ਹੈ।

pɔ̃̀ḍu pɔ̃̀kəṛ pòlla, pòḷa pə̃̀ḍari hɛ.
/Pl AOn D UW - Pl AOn K AH RH - Pl OW LL AA, Pl OW L AA -
Pl AHn D: AA R IY - H AE/

(90) ਭੰਡਾ ਭੰਡਾਰੀਆ, ਕਿੰਨਾ ਕੁ ਭਾਰ!

pə̃̀ḍa pə̃̀ḍaria, kĨnna kU pàr!
/Pl AHn D: AA - Pl AHn D: AA R IY AA, K IHn NN AA - K UH - Pl AA R!/

(91) ਭਿੰਦੋ ਭਾਬੀ ਭੈੜਾ ਭੂਕਣਾ ਭੰਨ ਕੇ ਭੁੱਲ ਗੀ।

PĨ̀do pàbi pɛ̀ṛa pùkəṇa pə̃̀nn ke pÙll gi.
/Pl IHn D OW - Pl AA B IY - Pl AE RH AA - Pl UW K AH N: AA -
Pl AHn NN - K EY - Pl UH LL - G IY/

(92) ਭੱਜਕੇ ਭਾਈ ਨੂੰ ਭੇਜ, ਭੂਰੀ ਗੱਭਣ ਮੱਝ ਰੰਭਦੀ ਸੀ।

pə̀jjke pài nũ pèj, pùri gə́bbəṇ mə́jj rə̃́bədi si
/Pl AH JJ K EY - Pl AA IY - N UWn - Pl EY J, Pl UW R IY -
G AH hBB AH N: - M AH hJJ - R AHn hB AH D IY - S IY/

(93) ਭੈੜੇ ਅੰਭੀ ਨੂੰ ਪੋਰਸ ਕਿਓਂ ਲੱਭਿਆ?

pɛ̀ṛe ə̃́bi nũ poras kIõ lə́bbIa?
/Pl AE RH EY - AHn hB IY - N UWn - P OW R AH S - K IH OWn -
L AH hBB IH AA?/

(94)/(150) ਭਰਾ ਜੀ! ਫੂਕ ਭਰਾਅ ਲੀ?

pə̀ra ji! phuk pə̀raə li?
/Pl AH R AA - J IY! PH UW K - Pl AH R AA AH - L IY?/

(95) ਮ 30. ਮੱਘਰ ਦੀ ਮਾਂ, ਮਾਮਾ ਮਾਮੀ, ਮਾਸੀ ਮਾਸੜ, ਮੇਲੇ ਗਏ।

mə́ggər di mã, mama mami, massi masəṛ, mele gəe.
/M AH hGG AH R - D IY- M AAn, M AA M AA - M AA M IY,
M AA SS IY - M AA S AH RH, M EY L EY - G AH EY/

(96) ਮੁਕਸਰ ਮੌਜਾਂ ਮਾਨਣ ਨੂੰ ਮੰਤਰ ਪੜ੍ਹਨੇ ਆਂ?

mUksər mɔjã manəṇ nũ mə̃tər pə́ṛne ã?

/M UH K S AH R - M AO J Aan - M AA N AH N: - N Uwn - M AHn T AH R - P AH hRH N EY - AAn?/

(97) ਮੁੰਡਿਆ! ਮੂੰਹ-ਮੁਲ੍ਹਾਜ਼ਾ ਛੱਡ! ਮੌਲੀ-ਮ੍ਹੈਂਸ ਦਾ ਮਹਿੰਗਾ ਮੁੱਲ ਵੱਟ।
mŨḍIa! mű-mÚlaza chəḍḍ! mɔlli-mɛ̃́s da mɛ̃́ga mUll vəṭṭ.
/M UHn D: IH AA! M UWnh -- M UH hL AA Z AA - CHH AH D:D:!
M AO LL IY -- hM AEn S - D AA - M AEnh G AA - M UH LL - V AH T:T:/

(98)/(151) ਮਿੰਦੋ ਮੁਟਿਆਰ ਨੇ ਮੂੰਹ ਮਟਕਾਅ ਕੇ ਮਟਕਾ ਭੰਨਿਆਂ।
mĨdo mUṭIar ne mű məṭkaə ke məṭka pə̀nnIa.
/M IHn D OW - M UH T: IH AA R - N EY - M UWnh - M AH T: K AA AH - K EY - M AH T: K AA - Pl AH NN IH AAn/

(99) ਯ 31. ਯੱਭਲ਼ਾ! ਯਰਕ ਨਾ, ਯਾਰਾਂ ਦੇ ਯੱਕੇ ’ਤੇ ਚੜ੍ਹ ਜਾ।
yə́bbəḷa! yərk na, yarã de yəkke ’te cə́ṛ ja.
/Y AH hBB AH L̲ AA! Y AH R K - N AA, Y AA R AAn - D EY -
Y AH KK EY - ’T EY - CH AH hRH - J AA/

(100) ਰ 32. ਰੋਡੇ ਰਾਹੀ ਨੂੰ ਰੇਤੇ ’ਚੋਂ ਰੰਗਦਾਰ ਰੀਠੇ ਲੱਭੇ।
roḍe rahi nũ rete ’cõ rə̃gdar riṭhe lə́bbe.
/R OW D: EY - R AA H IY - N UWn - R EY T EY - ’CH OWn -
R AHn G D AA R - R IY TH: EY - L AH hBB EY/

(101) ਰਿਆ੍ਹ ਢਾਂਡੀ ਰਾਤ ਰੋਹੀ ’ਚ ਰਿੰਗਦੀ ਰਹੀ।
rIá ṭằḍḍi rat rohi ’c rĨgdi rəhi.
/R IH AAh - T:l AAn D: IY - R AA T - R OW H IY - ’CH - R IHn G D IY - R AH H IY/

(102) ਲ 33. ਲਹੌਰੇ ਦੀ ਲੰਞੀ ਲੱਤ ਲਹੂ ਲੁਹਾਣ ਹੋ ਗੀ।
ləhɔre di lə̃ŋi lətt lə̃hu lUhaṇ ho gi.
/L AH H AO R EY - D IY - L AHn NX IY - L AH TT - L AH H UW -
L UH H AA N: - H OW - G IY/

(103) ਲਾਲੇ ਦੀ ਲਾਲੀ ਦੇ ਮੂੰਹ ’ਤੇ ਲਾਲੀ ਸੀ।
lale di lali de mű ’te lalli si.
/L AA L EY - D IY - L AA L IY - D EY - M UWnh - ’T EY - L AA LL IY - S IY/

(104) ਲਾਲਾ ਜੀ! ਲਾ ਲਾ, ਲਾ ਲਾ ਹੋ ਗੀ।
lala ji! la la, la la ho gi.
/L AA L AA - J IY! L AA - L AA, L AA - L AA - H OW - G IY/

(105) ਗੇਲੋ, ਕਿੱਲੋ ਆਲੂ ਤੇ ਚਾਲ਼ੀ ਕੁ ਲੌਂਗ ਲੈ ਲੀਂ।

gello, kIllo allu te caḷi kU lɔ̃g lɛ lĩ.
/G EY LL OW, K I LL OW - AA LL UW - T EY - CH AA L IY - K UH -
L AOn G - L AE - L IYn/

(106) ਵ 34. ਵਣਜਾਰਿਆ, ਬਾਵਿਆਂ ਵਿਹੜੇ ਵੰਙਾਂ ਵੇਚਦੈਂ ਕਿ ਵੰਝਲੀਆਂ?

/vəṇjarIa, bavIã vére və̃ŋã vecdɛ̃ kI və̃́jliã?
V AH N: J AA R IH AA, B AA V IH AAn - V EYh RH EY - V AHn NX AAn -
V EY CH D AEn - K IH - V AHn hJ L IY AAn?/

(107) ਵਹਿੜਕੇ ਦੀ ਵੱਖੀ ’ਚ ਵਗ੍ਹਾਵਾਂ ਵੱਟਾ ਮਾਰਿਆ।

vɛ́ṛke, di vəkkhi ’c vəgávã vəṭṭa marIa.
/V AEh RH K EY - D IY - V AH KKH IY - ’CH - V AH G AAh V AAn -
V AH T:T: AA - M AA R IH AA/

(108) ਐਵੇਂ ਨੀ ਬਾਂਦਰ ਵੰਝ ’ਤੇ ਚੜ੍ਹਾਈਦਾ ਹੁੰਦਾ।

ɛvẽ ni bãdər və̃́j ’te cə́ṛaida hŨda.
/AE V EYn - N IY - B AAn D AH R - V AHn hJ - ’T EY -
CH AH hRH AA IY D AA - H UHn D AA/

(109) ੜ 35. ਪੜ੍ਹਾਕੂ ਨੂੰ ਕਾੜ੍ਹਨੀ ਦਾ ਦੁੱਧ ਪਿਆਓ।

pə́ṛaku nũ káṛni da dÚdd pIao.
/P AH hRH AA K UW - N UWn - K AA hRH N IY - D AA - D UH hDD -
P IH AA OW/

(110) ਦੁਖਦੀ ਜਾੜ੍ਹ ਨੇ ਅੜਿੱਕਾ ਪਾ ’ਤਾ।

dUkhdi jáṛ ne əṛIkka pa ’ta.
/D UH KH D IY - J AA hRH - N EY - AH RH IH KK AA - P AA - ’T AA/

(111) ਲੜੋ ਨਾ, ਚੜ੍ਹਨ ਦਿਓ, ਜਿਹੜਾ ਘੋੜੀ ਚੜ੍ਹੂ।

ləṛo na, cə́ṛn dIo, jéṛa kòṛi cə́ṛu.
/L AH RH OW - N AA, CH AH hRH N - D IH OW, J EYh RH AA -
Kl OW RH IY- CH AH hRH UW/

(112) ਸ਼ 36. ਸ਼ਰਮਾ ਜੀ, ਸ਼ਾਨਦਾਰ ਸ਼ਰਬਤ ਛਕੋ।

ṣərma ji, ṣandar ṣərvət chəko.
/SH AH R M AA - J IY, SH AA N D AA R - SH AH R B AH T -
CHH AH K OW/

(113) ਸਿੰਘ ਜੀ, ਸੰਗੋ ਸ਼ਰਮਾਓ ਨਾ, ਸ਼ਕੰਜਵੀ ਛਕੋ।

sÍ̃g ji, sə̃go ṣərmao na, ṣəkə̃jvi chəko.
/S IHn hG - J IY, S AHn G OW - SH AH R M AA OW - N AA,
SH AH K AHn J V IY - CHH AH K OW/

(114)/(152) ਸ਼ਰਮਾਂ ਵਾਲ਼ਾ ਸ਼ਰਮਾ ਸ਼ਰਮਾਅ ਗਿਆ।

ṣərmã vaḷa ṣərma ṣəṛmaə gIa.
/SH AH R M AAn - V AA L AA - SH AH R M AA - SH AH R M AA AH - G IH AA/

(115) ਸ਼ਾਹ ਜੀ, ਸਾਹੋ ਸਾਹ ਹੋਏ ਓਂ, ਸੁੱਖ ਐ?

ṣá ji, saho sá hoe õ, sUkkh ɛ?
/SH AAh - J IY, S AA H OW - S AAh - H OW EY - OWn, S UH KHH - AE?

(116) ਕਿਸ਼ਨ ਸ਼ਾਹ ਨੇ ਸ਼ੇਰ ਮਾਰਕੇ ਛੇ ਸੇਰ ਘਿਓ ਜਿੱਤਿਆ।

KIṣən ṣá ne ṣer mar ke che ser kÌo jIttIa.
/K IH SH AH N - SH AAh - N EY - SH EY R - M AA R K EY - CHH EY- S EY R - Kl IH OW - J IH TT IH AA/

(117) ਸ਼ੌਂਕੀ ਸ਼ੇਖ਼ਚਿਲੀ ਨੇ ਸ਼ੋਸ਼ਾ ਛੱਡਿਆ।

ṣɔ̃ki ṣexcIli ne ṣoṣa chəḍḍIa.
/SH AOn K IY - SH EY X CH IH L IY - N EY - SH OW SH AA - CHH AH D:D: IH AA/

(118) ਸ਼ਸ਼ੋਪੰਜ ਛੱਡ, ਸ਼ੀਸ਼ੇ ਸਾਹਮਣੇ ਸ਼ਕਲ ਦੇਖ।

ṣəṣopə̃j chəḍḍ, ṣiṣe sámṇe ṣəkəl dekh.
/SH AH SH OW P AHn J - CHH AH D:D:, SH IY SH EY - S AAh M N: EY - SH AH K AH L - D EY KH/

(119) ਖ਼ 37. ਖ਼ਸਮਾਂ ਖਾਣੀਏ, ਖ਼ੁਸ਼ਕ ਜੇ ਖ਼ਤ ਨਾ ਲਿਖਿਆ ਕਰ।

xəsəma khaṇie, xUṣk je xət na lIkhIa kər.
/X AH S AH M AAn - KH AA N: IY EY, X UH SH K - J EY - X AH T - N AA - L IH KH IH AA - K AH R/

(120) ਖੁਸ਼ੀਏ ਨੇ ਖ਼ੂਨੀ ਖ਼ੰਜਰ ਖ਼ਰੀਦੀ!

khUṣie ne xuni xə̃jər xəridi!
/KH UH SH IY EY- N EY - X UW N IY - X AHn J AH R - X AH R IY D IY!/

(121) ਖ਼ੂੰਖ਼ਾਰ ਖੀਵੇ ਖ਼ਾਨ ਖੋਜੀ ਦਾ ਖ਼ੂਨ ਖੌਲਿਆ।

xũxar khive xan khoji da xun khɔlIa.
/X UWn X AA R - KH IY V EY - X AA N - KH OW J IY - D AA - X UW N - KH AO L IH AA/

(122) ਗ਼ 38. ਗ਼ਦਰ ਗੂੰਜਿਆ ਤਾਂ, ਗ਼ੁਲਾਮੀ ਗੈਬ ਹੋ ਜੂ।

gədər gũjIa, tã gUlami gɛb ho ju.
/G AH D AH R - G UWn J IH AA - T AAn, G UH L AA M IY - G AE B - H OW - J UW/

(123) ਜ਼ 39. ਜ਼ਖ਼ਮੀ ਹੋ ਜੇਂ ਗਾ, ਜੇ ਚੱਲ ਗਿਆ ਜਾਦੂ ਜਿੰਦੂਆ॥

zəxmi ho jẽ ga, je cəll gIa jaddu jĨdua.
/Z AH X M IY - H OW - J EYn - G AA, J EY - CH AH LL - G IH AA -
J AA D UW - J IHn D UW AA./

(124) ਜ਼ਿੰਦਗੀ ਜ਼ੁਲਮੀਂ ਦੀ, ਜ਼ਖ਼ਮੀ ਹੋਊ ਜ਼ਰੂਰ॥

zĨdgi zUlmi di, zəxmi hou zərur.
/Z IHn D G IY - Z UH L M IYn - D IY, Z AH X M IY - H OW UW -
Z AH R UW R./

(125) ਜ਼ਹਿਰੀ ਜ਼ੈਲਦਾਰ ਜਲ਼ਿਆ ਜਿਆ ਜਾਂਦੈ।

zέri zɛldar jəḷÍa Jia jãdɛ.
/Z AEh R IY - Z AE L D AA R - J AH L IH AA - J IH AA - J AAn D AE/

(126) ਲੋਕਾਂ ਦਾ ਰਾਜ ਪਾਪੀਆਂ ਦੇ ਰਾਜ਼ ਖ੍ਹੋਲੂ।

lokã da raj papiã de raz khólu.
/L OW K AAn - D AA - R AA J - P AA P IY AAn - D EY - R AA Z –
hKH OW L UW/

(127) ਫ਼ 40. ਫ਼ਰੇਬੀ ਫ਼ਰੰਗੀ ਨੂੰ ਫ਼ਰਜ਼ਾਂ ਨਾਲ਼ ਕੀ?

fərebi fərə̃gi nu fərzã naḷ ki?
/F AH R EY B IY - F AH R AHn G IY - N UWn - F AH R Z AAn - N AA L -
K IY?/

(128) ਫ਼ਸਲ ਫ਼ਕੀਰਾਂ ਦੀ, ਅਰਸ਼ ਫ਼ਰਸ਼ ਵਿੱਚ ਉੱਗਦੀ॥

fəsəl fəkirã di, ərṣ fərṣ vIcc Uggdi.
/F AH S AH L - F AH K IY R AAn - D IY, AH R SH - F AH R SH -
V IH CHCH - UH GG D IY./

(129) ਲ਼ 41. ਗਲ਼ ਗਲ਼ ਪਾਣੀ, ਗਲ ਗਲ ਖਾਣੀ।

gəḷ gəḷ paṇi, gəl gəl khaṇi.
/G AH L - G AH L - P AA N: IY, G AH L - G AH L - KH AA N: IY/

(130) ਮਲ਼ ਮਲ਼ ਨ੍ਹਾਉਂਦੀ, ਮਲ ਮਲ ਪਾਉਂਦੀ।

məḷ məḷ nɔ̃́di, məl məl paũdi.
/M AH L - M AH L - hN AOn D IY, M AH L - M AH L - P AA UHn D IY/

(131) ਮਲ਼ ਮਲ਼ ਨ੍ਹਾਉਂਦੀ ਦੇ, ਗਲ਼ ਗਲ਼ ਆ ਗਿਆ ਪਾਣੀ॥

məḷ məḷ nɔ̃́di de, gəḷ gəḷ a gIa paṇi.
/M AH L - M AH L - hN AOn D IY - D EY, G AH L - G AH L - AA -
G IH AA - P AA N: IY./

(132) ਗੇਲੇ ਨੇ ਗਲ਼ੋਂ ਗਲ਼ਾਮਾਂ ਲਾਹੁਣ ਵਾਲ਼ੀ ਗੱਲ ਕੀਤੀ।

gelle ne gəḷõ gəḷamã láUṇ vaḷi gəll kiti.
/G EY L EY - N EY - G AH L OWn - G AH L AA M AAn - L AAh UH N: - V AA L IY - G AH LL - K IY T IY/

(133)/(157) ਤਲਾਅ ’ਚ ਨਾ ਨਾਹ, ਪਕੌੜੇ ਤਲ਼ਾਅ।

təlaə ’c na ná, pəkɔṛe təḷaə.
/T AH L AA AH - ’CH - N AA - N AAh, P AH K AO RH EY - T AH L AA AH/

(134) ਅਕਾਲੀ ਦਲ, ਦਾਲ਼ ਦਲ਼।

əkali dəl, daḷ dəḷ.
/AH K AA L IY - D AH L, D AA L - D AH L/

(135) ਬਿੰਦੋ ਬੋਲ਼ੀ ਨੂੰ ਗਿੱਧੇ ਦੀ ਕੋਈ ਬੋਲੀ ਨੀਂ ਆਉਂਦੀ!

bĨdo boḷi nũ gÍdde di koi bolli ní aŨdi!
/B IHn D OW - B OW L IY - N UWn - G I hDD EY - D IY - K OW IY - B OW L IY - N IYn - AA UHn D IY!/

(136) ਬਾਲ ਪਿੱਛੇ ਭੱਜਣਾ ਛੱਡਕੇ ਅੱਗ ਬਾਲ਼।

bal pIcche pə̀jjəṇa chəḍḍke əgg baḷ.
/B AA L - P IH CHH EY - Pl AH JJ AH N: AA - CHH AH D:D: K EY - AH GG - B AA L/

(137) ਗੋਲ਼ੀ ਲਿਆਵਾਂ? ਗੋਲੀ ਆਂ ਤੇਰੀ?

goḷi lIavã? golli ã teri?
/G OW L IY - L IH AA V AAn? G OW L IY - AAn - T EY R IY?/

42. ਪੈਰ ’ਚ ਹਾਹਾ (ਹ / ੍ਹ):

(138) ਗੱਲ ਸੁਣ, ਗਲ਼ ਤੇ ਗੱਲ੍ਹ ਦਾ ’ਲਾਜ ਕਰਾਲੀਂ ਛੇਤੀ!

gəll sUṇ, gəḷ te gə́ll da ’laj kəralĩ cheti!
/G AH LL - S UH N:, G AH L - T EY - G AH hLL - D AA - ’L AA J - K AH R AA L IYn - CHH EY T IY!

(139) ਵਰ ਹਾਣ ਦਾ ਕੁੜੀ ਨੂੰ ਮਿਲ਼ ਜੇ, ਟਿੱਬੀ ਉਤੇ ਮੀਂਹ ਵਰ੍ਹ ਜੇ॥

vər haṇ da kUṛi nũ mIḷ je, ṭIbbi Utte mĩ́ və́r je.
V AH R - H AA N: - D AA - K UH RH IY - N UWn - M IH L - J EY, /T IH BB IY - UH TT EY - M IHnh - V AH hR - J EY./

(140) ਕੰਨ ਦੀ ਜੜ੍ਹ ’ਚ ਚਪੇੜ ਜੜ।

kə̃nn di jə́ṛ ’c cəpeṛ jəṛ.
/K AHn N - D IY - J AH hRH - ’CH - CH AH P EY RH - J AH RH/

(141) ਬੁਲ ਬੁਲ ਦੇ ਬੁੱਲ੍ਹ ਹਿੱਲੇ।

bUl bUl de bÚll hIlle.
/B UH L - B UH L - D EY - B UH hLL - H IH LL EY/

43. ਪੈਰ 'ਚ ਰਾਰਾ (ਰ / ਰ੍):

(142) ਸ਼੍ਰੋਮਣੀ ਕਵੀ ਨੇ ਪ੍ਰਸੰਨ ਹੋ ਕੇ ਗ੍ਰੰਥ ਰਚਿਆ।

ṣromṇi kəvi ne prsə̃nn ho ke grə̃th rəcIa.
/SH R OW M N: IY - K AH V IY - N EY - P R S AHn NN - H OW - K EY - G R AHn TH - R AH CH IH AA/

(143) ਬ੍ਰਹਮ ਕ੍ਰਿਸ਼ਨ ਨੇ ਚੌਥੀ ਸ਼੍ਰੇਣੀ ਨੂੰ ਪ੍ਰਸ਼ਨ ਪੁੱਛੇ।

brə́m krIsən ne cɔthi ṣreṇi nũ prəṣən pUcche.
/B R AHh M - K R IH SH AH N - N EY - CH AO TH IY - SH R EY N: IY - N UWn - P R AH SH AH N - P UH CHCHH EY/

(144) ਬੜਾ ਨਟਖਟ ਹੈ ਕ੍ਰਿਸ਼ਨ ਘਨੱਈਆ।

bəṛa nəṭkhəṭ hɛ krIṣən kə̀nəia.
/B AH RH AA - N AH T: KH AH T: - H AE - K R IH SH AH N - Kl AH NN AH IY AA/

(145) ਸਾਧੂ ਸਿੰਘ, ਸਿਹਤਮੰਦ, ਸ਼੍ਰੋਮਣੀ ਸਾਹਿਤਕਾਰ ਹੈ।

sádu sĨ́g, sehətmə̃d, ṣromṇi sahItkar hɛ.
/S AA hD UW - S IHn hG, S EY H AH T M AHn D, SH R OW M N: IY - S AA H IH T K AA R - H AE/

44. ਪੈਰ 'ਚ ਵਾਵਾ (ਵ / ਵ੍):

(146) ਦਰੋਪਤੀ ਦਾ ਸ੍ਵੰਬਰ, ਅਰਜਨ ਦਾ ਸ੍ਵੈਮਾਨ।

dəropti da svə̃bər, ərjan da svɛman.
/D AH R OW P T IY - D AA - S V AHn B AH R, AH R J AH N - D AA - S V AE M AA N/

(147) ਸ੍ਵੈ-ਵਿਸ਼ਵਾਸ ਤੋਂ ਬਿਨਾਂ ਬੰਦਾ ਹੈ ਕੀ?

svɛ-vIṣvas tõ bInã bə̃da hɛ ki?
/S V AE -- V IH SH V AA S - T OWn - B IH N AAn - B AHn D AA - H AE - K IY?/

45. ਲਮਕਵਾਂ ਉਚਾਰਣ:

(148)/(13) ਹਾਕਮ ਨੇ ਹੰਸ ਨੂੰ ਹਰਾਅ ਕੇ ਹਰਾ ਹੀਰਾ ਜਿੱਤਿਆ।

hakəm ne hə̃s nũ həraə ke həra hira jIttIa.
/H AA K AH M - N EY - H AHn S - N UWn - H AH R AA AH - K EY - H AH R AA - H IY R AA - J IH TT IH AA/

(149)/(29) ਘੜਾ ਮਾਘ ਭਰ ਭਰੂੰ ਤੇਰਾ ਮੱਘਰਾ, ਝਾਂਜਰਾਂ ਘੜਾਅ ਦੇ ਮਿੱਤਰਾ॥

kə̀ṛa mág pə̀r pə̀rũ tera mə́ggəra, cə̀jrã kə̀ṛaə de mIttəra.
/Kl AH RH AA - M AA hG - Pl AH R - Pl AH R UWn - T EY R AA - M AH hGG AH R AA, CHl AAn J R AAn - Kl AH RH AA AH - D EY - M IH TT AH R AA./

(150)/(94) ਭਰਾ ਜੀ! ਫੂਕ ਭਰਾਅ ਲੀ?

pə̀ra ji! phuk pə̀raə li?
/Pl AH R AA - J IY! PH UW K - Pl AH R AA AH - L IY?/

(151)/(98) ਮਿੰਦੋ ਮੁਟਿਆਰ ਨੇ ਮੂੰਹ ਮਟਕਾਅ ਕੇ ਮਟਕਾ ਭੰਨਿਆਂ।

mĨdo mUṭIar ne mṹ məṭkaə ke məṭka pə̀nnIa.
/M IHn D OW - M UH T: IH AA R - N EY - M UWnh - M AH T: K AA AH - K EY- M AH T: K AA - Pl AH NN IH AAn/

(152)/(114) ਸ਼ਰਮਾਂ ਵਾਲ਼ਾ ਸ਼ਰਮਾ ਸ਼ਰਮਾਅ ਗਿਆ।

ṣərmã vaḷa ṣərma ṣəṛmaə gIa.
/SH AH R M AAn - V AA L̲ AA - SH AH R M AA - SH AH R M AA AH - G IH AA/

46. ਸੁਰ (tone):

(153) ਪਾਣੀ ਪੀ ਕੇ ਚੱਕੀ ਪੀਹ।

paṇi pi ke cəkki pí.
/P AA N: IY - P IY - K EY - CH AH KK IY - P IYh/

(154) ਚਾਹ ਪੀ ਕੇ ਚਾਅ ਨਾਲ਼ ਚੱਕੀ ਪੀਹ।

cá pi ke caə naḷ cəkki pí.
/CH AAh - P IY - K EY, CH AA AH - N AA L̲ - CH AH KK IY - P IYh/

(155) ਤੂੰ ਵੀ ਵੀਹ ਰੁਪੱਈਏ ਲੈ ਲਾ।

tũ vi ví rUpəie lɛ la.
/T UWn - V IY - V IYh - R UH PP AH IY EY - L AE - L AA/

(156) ਵਾਹ ਭਗਵਾਨ, ਕਿਸੇ ਨੂੰ ਤੱਤੀ ਵਾ ਨੀਂ ਲੱਗੀ!

vá pə̀gvan, kIse nũ tətti va nĩ ləggi!
/V AAh - Pl AH G V AA N, K IH S EY - N UWn - T AH TT IY - V AA - N IYn - L AH GG IY!/

(157)/(133) ਤਲਾਅ 'ਚ ਨਾ ਨਾਹ, ਪਕੌੜੇ ਤਲ਼ਾਅ।

təlaə 'c na ná, pəkoṛe təḷaə.
/T AH L AA AH - 'CH - N AA - N AAh, P AH K AO RH EY - T AH L̲ AA AH/

47. ਮਾਤਰਾ / matras (ə : a :: I : i :: U : u :: o : ɔ :: e : ɛ)

(158) ਕੰਮ ਕਰ ਕੇ ਕਾਰ ’ਚ ਝੂਟੇ ਲਈਂ।

kə̃mm kər ke kar ’c cùṭe ləĩ.
/K AHn MM - K AH R - K EY - K AA R - ’CH - CHl UW T: EY - L AH IYn/

(159) ਚਿਰ ਨਾ ਲਾ ਸਾਗ ਚੀਰ।

cIr na la, sag cir.
/CH IH R - N AA - L AA, S AA G - CH IY R/

(160) ਓਏ ਸੂਰ, ਸੁਰ ’ਚ ਗਾ!

oe sur, sUr c ga!
/OW EY - S UW R, S UH R - ’CH - G AA!/

(161) ਲੀੜੇ ਧੋਣ ਦਾ ਕੰਮ ਛੱਡ ਕੇ, ਮੇਰੀ ਧੌਣ ਮਲ਼।

liṛe tòṇ da kə̃mm chəḍḍ ke, meri tɔ̀ṇ məḷ.
/L IY RH EY - Tl OW N: - D AA - K AHn MM - CHH AH D:D: - K EY,
M EY R IY - Tl AO N: - M AH L/

(162) ਸੈਰ ਕਰ ਕੇ ਸੇਰ ਦੁੱਧ ਪੀਓ।

sɛr kər ke ser dÚdd pio.
/S AE R - K AH R - K EY- S EY R - D UH hDD - P IY OW/

(163) 48. ਘੁੰਮ ਘੁਮਾਅ ਕੇ ਕੀਤੀ ਗੱਲ, ਗੁੰਮ ਗੁਆਚ ਗੀ।

kÙmm kÙmaə ke kiti gəll, gŨmm gUac gi.
/Kl UHn MM - Kl UH M AA AH - K EY - K IY T IY - G AH LL, G UHn MM -
G UH AA CH - G IY/

(164) ਸੰਘਣੇ ਬਾਗ਼ ’ਚ ਬਾਘ-ਬਘੇਲੇ ਆ ਈ ਟਪਕਦੇ ਨੇ।

sə̃́gṇe bag ’c bág-bəgèlle a i ṭəpəkde ne.
/S AHn hG N: EY - B AA G - ’CH - B AA hG -- B AH Gl EY L EY - AA - IY -
T AH P AH K D EY - N EY/

(165) ਮਸੂਲ ਚੁੰਗੀ ’ਚੋਂ ਪੈਸੇ ਬਚਾ ਕੇ ਮ੍ਹੈਂਸ ਚੁੰਘੀ।

məsul cŨgi ’cõ pɛse bəchaə ke mɛ̃s cŰgi.
/M AH S UW L - CH UHn G IY - ’CH OWn - P AE S EY - B AH CH AA AH -
K EY - hM AEn S - CH UHn hG IY/

(166) ਗੋਲ਼ ਕਰੋ, ਘੋਲ਼ ਜਿੱਤੋ।

goḷ kəro, kòḷ jItto.

/G OW L - K AH R OW, Kl OW L - J IH TT OW/

(167) ਗੱਲ ਗੋਲ਼ ਗੱਭਰੂਆ, ਘੋਲ਼ ਨਾ ਕਰ।

gəll gɔḷ gə́bbərua, kɔ̀ḷ na kər.
/G AH LL - G AO L - G AH hBB AH R UW AA, Kl AO L - N AA - K AH R/

(168) 49. ਗੋਡਾ ਸੁੱਜਿਆ, ਤਾਂ ਹਸਪਤਾਲ ਸੁੱਝਿਆ।

goḍḍa sUjjIa, tã həspətal sÚjjIa.
/G OW D:D: AA - S UH JJ IH AA, T AAn - H AH S P AH T AA L -
S UH hJJ IH AA/

(169) ਬੁਝੜਾ, ਜੱਟ ਨੇ ਝੱਟ ਬਦਲੇ ਦਾ ਝੰਡਾ ਚੱਕ ਲੈਣੈ।

bújṛa, jəṭṭ ne cə̀ṭṭ bədle da cə̃̀ḍḍa cəkk lɛṇe!
/B UW hJ RH AA, J AH T:T: - N EY - CHl AH T:T: - B AH D L EY - D AA -
CHl AHn D: AA - CH AH KK - L AE N: AE!/

(170) 50. ਗੰਡਾ ਸਿੰਘ ਨੇ ਗੰਢਾ ਖਾਧਾ।

gə̃ḍa sÍ̃g ne gə̃́ḍa kháda.
/G AHn D: AA - S IHn hG - N EY - G AHn hD: AA - KH AA hD AA/

(171) ਸੁੰਢ ਦੇ ਡੱਬੇ ’ਚ ਸੁੰਡ ਪੈ ਗੇ।

sṸḍ de ḍəbbe ’c sŨd pɛ ge.
/S UHn hD: - D EY - D: AH BB EY - ’CH - S UHn D: - P AE - G EY/

(172) ਕੁੰਢੀ-ਮੁੱਸ ਦੇ ਸੰਗਲ਼ ਦੀ ਕੁੰਡੀ ਟੁੱਟਗੀ।

kṸḍi-mɛ̃́s de sə̃gəḷ di kŨḍi ṭUṭṭgi.
/K UHn hD: IY -- hM AEn S - D EY - S AHn G AH L - D IY - K UHn D: IY -
T: UH T:T: G IY/

(173) ਢੂਹੀ ’ਚ ਟੇਢੀ ਖੂੰਡੀ ਠੋਕਾਂ, ਕਿ ਖੁੰਢੀ ਕਿਰਪਾਨ ?

ṭùhi ’c ṭéḍi khũḍi ṭhokã, kI khṸḍi kIrpan ?
/Tl UW H IY - ’CH - T EY hD: IY - KH UWn D: IY - TH: OW K AAn,
K IH - KH UHn hD: IY - K IH R P AA N?/

(174) ਵੱਡੀ ਕੁੜੀ ਨੇ ਛੱਲੀ ਚੂੰਡੀ, ਤਾਂ ਨਿੱਕੀ ਨੇ ਚੂੰਢੀ ਵੱਢੀ।

vəḍḍi kUṛi ne chəlli cũḍi, tã nIkki ne cṹḍi və́ḍḍi.
/V AH D:D: IY - K UH RH IY - N EY - CHH AH LL IY - CH UWn D: IY,
T AA N - N IH KK IY - N EY- CH UWn hD: IY - V AH hD:D: IY/

(175) 51. ਧੀਦੋ, ਗੰਧਕ ਦੇ ਗੰਦ ਦੀ ਗੰਧ ਤੋਂ ਬਚ।

tìdo, gə̃́dək de gə̃d di gə̃́d tõ bəc.
/Tl IY D OW, G AHn hD AH K - D EY - G AHn D - D IY -
G AHn hD - T OWn - B AH CH/

(176) ਦਾਵਾ ਕਰਨੈਂ, ਕਿ ਧਾਵਾ ਬੋਲਣੈਂ?

dava kərnɛ̃, kI tàva boləṇɛ̃?
/D AA V AA - K AH R N AEn, K IY - Tl AA V AA - B OW L AH N: AEn?/

(177) ਆਰੀ ਦਾ ਦੰਦਾ ਤਿੱਖਾ ਕਰਨ ਦਾ ਧੰਦਾ ਸਿੱਖ!

ari da də̃da tIkkha kərən da tə̃̀da sIkkh!
/AA R IY - D AA - D AHn D AA - T IH KKH AA - K AH R AH N - D AA - TL AHn D AA- S IH KKH!

(178) ਦੌਣ ਕਸਕੇ ਧੌਣ ਧੋ ਲੀਂ।

dɔṇ kəs ke tɔ̀ṇ tò lĩ.
/D AO N: - K AH S K EY - Tl AO N: - Tl OW - L IYn/

(179) 52. ਪਹਿਲਾਂ ਡੱਬੀ ਭਾਲ਼, ਫੇਰ ਅੱਗ ਬਾਲ਼।

pέlã ḍəbbi pàḷ, pher əgg baḷ.
/P AEh L AAn - D: AH BB IY - Pl AA L, PH EY R - AH GG - B AA L/

(180) ਬਾਣਾ ਪਹਿਨਿਐ, ਤਾਂ ਭਾਣਾ ਮੰਨ।

baṇa pέnIɛ, tã pàṇa mə̃nn.
/B AA N: AA - P AEh N IH AE, T AAn - Pl AA N: AA - M AHn NN/ ■

APPENDIX B
CORPUS (35 SETS: ਬੋਲੀਆਂ)

(1) ੳ ਉਧਮ ਵੀਰੇ ਦੀ, ਧੁੰਮ ਲੰਡਨ ਵਿੱਚ ਪੈ ਗੀ॥

údəm vire di, tÙmm lə̃ḍən vIcc pɛ gi.
/UW hD AH M - V IY R EY - D IY, Tl UH MM - L AHn D: AH N -
V IH CHCH - P AE - G IY./

(2) ਉੱਘ ਸੁੱਘ ਨਾ ਨਿੱਕਲ਼ੀ, ਕਿੱਧਰ ਉੱਧਲ਼ਗੀ ਬਚਨੋ॥

Úgg sÚgg na nIkkḷi, kÍddər Úddəḷgi bəcəno.
/UH hGG - S UH hGG - N AA - N IH KK L̲ IY, K IH hDD AH R -
UH hDD AH L̲ G IY - B AH CH AH N OW./

(3) ਓਦੋਂ ਕਿਓਂ ਨਾ ਆਇਓਂ ਮਿੱਤਰਾ, ਜਦੋਂ ਰੰਗ ਸੀ ਸਰ੍ਹੋਂ ਦੇ ਫੁੱਲ ਵਰਗਾ

odõ kIõ na aIõ mIttəra, jədõ rə̃g si sərṍ de phUll vərga
/OW D OWn - K IH OWn - N AA - AA IH OWn - M IH TT AH R AA,
J AH D OWn - R AHn G - S IY - S AH hR OWn - D EY - PH UH LL -
V AH R G AA/

(4) ਅ ਅੱਖ ਪਟਵਾਰਨ ਦੀ, ਜਿਉਂ ਇੱਲ੍ਹ ਦੇ ਆਲ੍ਹਣੇ ਆਂਡਾ

əkkh pəṭvarən di, jIõ Íll de áləṇe ãḍa
/AH KKH - P AH T: V AA R AH N - D IY, J IH OWn - IH hLL - D EY -
AA hL AH N: EY-AAn D: AA/

(5) ਆਹ ਲੈ ਨੱਤੀਆਂ ਘੜਾਅ ਲੀਂ ਪਿੱਪਲ਼-ਪੱਤੀਆਂ, ਕਿਸੇ ਕੋਲ਼ੇ ਗੱਲ ਨਾ ਕਰੀਂ

á lɛ nəttiã kə̀ṛaə lĩ pIppəḷ-pəttiã, kIse koḷe gəll na kərĩ
/AAh - L AE - N AH TT IY AAn - Kl AH RH AA AH - L IYn -
P IH PP AH L̲ -- P AH TT IY AAn, K IH S EY - K OW L̲ EY - G AH LL -
N AA - K AH R IHn/

(6) ਆਹ ਲੈ ਫੜ ਮਿੱਤਰਾ, ਬਾਂਕਾਂ ਮੇਚ ਨਾ ਆਈਆਂ

á lɛ phəṛ mIttəra, bãkã mec na aiã
/AAh - L AE - PH AH RH - M IH TT AH R AA, B AAn K AAn - M EY CH -
N AA - AA IY AAn/

(7) ੲ ਇੱਕ ਤੇਰਾ ਰੰਗ ਮੁਸ਼ਕੀ, ਦੂਜਾ ਡਾਹ ਲਿਆ ਗਲ਼ੀ ਵਿੱਚ ਚਰਖਾ

Ikk tera rə̃g mUṣki, duja dá lIa gəḷi vIcc cərkha
/IH KK - T EY R AA - R AHn G - M UH SH K IY, D UW J AA - D: AAh -
L IH AA - G AH L̲ IY - V IH CHCH - CH AH R KH AA/

(8) ਇੱਕ ਤੇਰੀ ਜਿੰਦ ਬਦਲੇ, ਮਿਹਣੇ ਸਾਰੇ ਮੈਂ ਟੱਬਰ ਦੇ ਸਹਿੰਦੀ

Ikk teri jĨd bədəle, méṇe sare mɛ̃ ṭəbbər de sɛ̃́di
/IH KK - T EY R IY - I IHn D - B AH D AH L EY, M EY hN: EY - S AA R EY - M AEn - T: AH BB AH R - D EY - S AEnh D IY/

(9) ਸ ਸੂਟ ਪਟਿਆਲ਼ਾ-ਸ਼ਾਹੀ, ਪੈਰਾਂ ਵਿੱਚ ਝਾਂਜਰਾਂ

suṭ pəṭIaḷa - ṣahi, pɛrã vIcc cã̀jrã
/S UW T: - P AH T: IH L AA -- SH AA H IY, P AE R AAn - V IH CHCH - CHl AAn J R AAn/

(10) ਸੱਤ ਰੰਗੀ ਛੀਂਟ ਦੇਖ ਕੇ, ਜੱਟੀ ਹੱਟੀ ’ਤੇ ਸ਼ਰਾਬਣ ਹੋਈ

sətt rə̃gi chĩṭ dekh ke, jəṭṭi həṭṭi ’te ṣərabəṇ hoi
/S AH TT - R AHn G IY - CHH IYn T: - D EY KH K EY, J AH T:T: IY - H AH T:T: IY - ’T EY - SH AH R AA B AH N: - H OW IY/

(11) ਸਾਧੂ ਹੁੰਦੇ ਰੱਬ ਵਰਗੇ, ਘੁੰਡ ਕੱਢ ਕੇ ਖ਼ੈਰ ਨਾ ਪਾਈਏ

sádu hŨde rəbb vərge, kŨ̀ḍ kə́ḍḍ ke xɛr na paie
/S AA hD UW - H UHn D E - R AH BB - V AH R G EY, Kl UHn D: - K AH hD:D: - K EY - X AE R - N AA - P AA IY EY/

(12) ਸੁਘੜ ਸੁਡੌਲ ਸੁਨੱਖੀ, ਢੋਲਣਾ ਨਹੀਂ ਲੱਭਣੀ॥

sÚgəṛ sUḍɔl sUnəkkhi, ṭòlṇa nəhĩ lə́bbəṇi.
/S UH hG AH RH - S UH D: AO L - S UH N AH KKH IY, T:l OW N: AA - N AH H IHn - L AH hBB N: IY./

(13) ਹ ਹਾਰੀਂ ਨਾ ਮਲਵੈਣੇ, ਗਿੱਧਾ ਹਾਰ ਗਿਆ

harĩ na məlvɛṇe, gĺdda har gIa
/H AA R IYn - N AA - M AH L V AE N: EY, G IH hDD AA - H AA R - G IH AA/

(14) ਹਾਕਾਂ ਮਾਰਦੇ ਬੱਕਰੀਆਂ ਵਾਲ਼ੇ, ਦੁੱਧ ਪੀ ਕੇ ਜਾਈਂ ਜੈ ਕੁਰੇ

hakã marde bəkkəriã vaḷe, dÚdd pi ke jaĩ jɛ kUre
/H AA K AAn - M AA R D EY - B AH KK AH R IY AAn - V AA L EY, D UH hDD - P IY - K EY - J AA IYn - J AE - K UH R EY/

(15) ਹੱਸ ਕੇ ਨਾ ਲੰਘ ਵੈਰੀਆ, ਮੇਰੀ ਸੱਸ ਭਰਮਾਂ ਦੀ ਮਾਰੀ

həss ke na lə̃́g vɛria, meri səss pə̀rəmã di mari
/H AH SS - K EY - N AA - L AHn hG - V AE R IY AA, M EY R IY - S AH SS - Pl AH R AH M AAn - D IY - M AA R IY/

(16) ਕ ਕਿਹੜੀ ਐਂ ਤੂੰ ਸਾਗ ਤੋੜਦੀ, ਹੱਥ ਸੋਚ ਕੇ ਗੰਦਲ਼ ਨੂੰ ਪਾਈਂ

kéṛi ɛ̃ tũ sag toṛdi, hətth soc ke gə̃dəḷ nũ paĩ
/K EYh RH IY - AEn - T UWn - S AA G - T OW RH D IY, H AH TTH -

S OW CH - K EY - G AHn D AH L - N UWn - P AA IYn/

(17) ਕੋੜੀ ਨਿੰਮ ਨੂੰ ਪਤਾਸੇ ਲਗਦੇ, ਵਿਹੜੇ ਛੜਿਆਂ ਦੇ

kɔṛi nĨmm nũ pətase ləgde, véṛe chəṛIã de
/K AO RH IY - N IHn MM - N UWn - P AH T AA S EY - L AH G D EY,
V EYh RH EY - CHH AH RH IH AAn - D EY/

(18) ਕਦੇ ਹਾਕ ਨਾ ਚੰਦਰੀਏ ਮਾਰੀ, ਚੂੜੇ ਵਾਲ਼ੀ ਬਾਂਹ ਕੱਢ ਕੇ

kəde hak na cə̃dərie mari, cuṛe vaḷi bầ kə́ḍḍ ke
/K AH D EY - H AA K - N AA - CH AHn D AH R IY EY - M AA R IY,
CH UW RH EY - V AA L IY - B AAnh - K AH hD:D: - K EY/

(19) ਖ ਖਸਮਾਂ ਨੂੰ ਖਾਣ ਕੁੜੀਆਂ, ਘੜਾ ਚੱਕ ਲੂੰ ਮੌਣ ’ਤੇ ਧਰ ਕੇ

khəsmã nũ khaṇ kUṛiã, kə̀ṛa cəkk lũ mɔṇ ’te tə̀r ke
/KH AH S M AAn - N UWn - KH AA N: - K UH RH IY AAn - Kl AH RH AA -
CH AH KK - L UWn - M AO N: - ’T EY - Tl AH R - K EY/

(20) ਖੌਰੇ ਰਾਏਕੋਟੀ ਨੇ ਜੀਤੋ, ਕਿਹੜੀ ਚਾਟ ’ਤੇ ਲਾਈ

khɔre raekoṭi ne jito, kéṛi caṭ ’te lai
/KH AO R EY - R AA EY K OW T: IY - N EY - J IY T OW, K EYh RH IY -
CH AA T: - ’T EY - L AA IY/

(21) ਗ ਗੱਡੀ ਚੜ੍ਹਦੀ ਭਨਾਅ ਲਏ ਗੋਡੇ, ਚਾਅ ਮੁਕਲਾਵੇ ਦਾ

gəḍḍi cə́ṛdi pə̀naə ləe goḍḍe, caə mUklave da
/G AH D:D: IY - CH AH hRH D IY - Pl AH N AA AH - L AH EY -
G OW D:D: EY, CH AA AH - M UH K L AA V EY - D AA/

(22) ਗਲ਼ ਲੱਗ ਕੇ ਵੀਰ ਦੇ ਰੋਈ, ਭਾਬੋ ਮੈਨੂੰ ਝਿੜਕ ਦਿੱਤਾ

gəḷ ləgg ke vir de roi, pàbo mɛnũ cÌṛək dItta
/G AH L - L AH GG - K EY - V IY R - D EY - R OW EY, Pl AA B OW -
M AE N UWn - CHl IH RH AH K - D IH TT AA/

(23) ਘ ਘੁੰਡ ਕੱਢ ਲਾ ਪੱਤਣ ’ਤੇ ਖੜ੍ਹੀਏ, ਪਾਣੀਆਂ ਨੂੰ ਅੱਗ ਲੱਗ ਜੂ

kŨ̀ḍ kə́ḍḍ la pəttəṇ ’te khəṛie, paṇiã nũ əgg ləgg ju
/Kl UHn D: - K AH hD:D: - L AA - P AH TT AH N: - ’T EY -
KH AH hRH IY EY, P AA N: IY AAn - N UWn - AH GG - L AH GG - J UW/

(24) ਘੁੱਟ ਪਾਣੀ ਪਿਆ ਦੇ ਨੀ, ਸੋਹਣੀਏਂ ਘੜਾ ਭਰੇਂਦੀਏ ਨਾਰੇ

kÙṭṭ paṇi pIa de ni, sóṇiẽ kə̀ṛa pə̀rẽdie nare
/Kl UH T:T: - P AA N: IY - P IH AA - D EY - NIY, S OWh N: EYn -
Kl AH RH AA- Pl AH EYn D IY EY- N AA R EY/

(25) ਘੁੱਦੂ ਪਿੰਡ ਨਾ ਸੰਘੇੜੇ ਜਾਣੀ, ਟਿੱਬਿਆਂ ’ਚ ਪੈਣ ਕੱਸੀਆਂ

kÙddu pÌḍ na sə̃gerẹ jaṇi, ṭIbbIã 'c pɛṇ kəssiã
/Kl UH DD UW - P IHn D: - N AA - S AHn hG EY RH EY - J AA N: IY,
T: IH BB IH AAn - 'CH - P AE N: - K AH SS IY AAn/

(26) ਘਰ ਜਾ ਘੁੱਟੀ ਸੰਘੀ, ਘੁੱਦੇ ਰੰਘੜ ਦੀ॥

kər ja kÙṭṭi sə̃gi, kÙdde rə̃geṛ di.
/Kl AH R - J AA - Kl UH T:T: IY - S AHn hG IY, Kl UH DD EY -
R AHn hG AH RH - D IY./

(27) ਘੁੱਗੂਆ ਟਾਹਲੀ 'ਤੇ, ਘੁੱਗੀ ਕਰੇ ਘੂੰ ਘੂੰ

kÙggua ṭáli 'te, kÙggi kəre kũ̀ kũ̀
/Kl UH GG UW AA - T: AAh L IY - 'T EY, Kl UH GG IY - K AH R EY -
Kl UWn - Kl UWn/

(28) ਘੁੰਡ ਕੱਢ ਪੀਂਘ ਝੂਟਦੀ, ਵਾਲ਼ ਸੰਘਣੇ ਕਲੋਲਾਂ ਕਰਦੇ॥

kŨ̀ḍ kə́ḍḍ pĩ́g cùṭdi, vaḷ sə̃́gṇe kəlolã kərde.
/Kl UHn D: - K AH hD:D: - P IYn hG - CHl UW T: D IY, V AA L -
S AHn hG N: EY - K AH L OW L AAn - K AH R D EY./

(29) ਙ ਕੰਙਣ ਛਣਕਾਉਂਦੀਏ ਨੀ, ਕਾਹਤੋਂ ਦੁੱਧ 'ਚ ਮੀਂਙਣਾ ਪਾਉਂਦੀ॥

kə̃ŋṇ chəṇkaũdie ni! kátõ dÚdd 'c miŋəṇa paŨdi.
/K AHn NX N: - CHH AH N: K AAUHn D IY EY - N IY, K AAh T OWn -
D UH hDD - 'CH - M IY NX AH N: AA - P AA UHn D IY./

(30) ਚ ਚੜ੍ਹ ਜਾ ਬੋਤੇ 'ਤੇ, ਮੰਨ ਲੈ ਭੌਰ ਦੀ ਆਖੀ

cə́ṛ ja bote 'te, mə̃nn lɛ pɔ̀r di akhi
/CH AH hRH - J AA - B OW T EY - 'T EY, M AHn NN - L AE - Pl AO R -
D IY - AA KH IY/

(31) ਚੰਨ ਭਾਵੇਂ ਨਿੱਤ ਚੜ੍ਹਦਾ, ਸਾਨੂੰ ਸੱਜਣਾਂ ਦੇ ਬਾਝ ਹਨੇਰਾ

cə̃nn pàvẽ nItt cə́ṛda, sanũ səjjəṇã de báj hənera
/CH AHn NN - Pl AA V EYn - N IH TT - CH AH hRH D AA, S AA N UWn -
S AH JJ AH N: AAn - D EY- B AA hJ - H AH N EY R AA/

(32) ਚਿੱਟੇ ਦੰਦ ਹੱਸਣੋ ਨਹੀਂ ਰਹਿੰਦੇ, ਲੋਕੀ ਭੈੜੇ ਸ਼ੱਕ ਕਰਦੇ

cIṭṭe də̃d həssəṇo nəhĩ rɛ̃́de, loki pɛ́ṛe ṣəkk kərde
/CH IH T:T: EY - D AHn D - H AH SS AH N: OW - N AH H IHn -
R AEnh D EY, L OW K IY - Ph AE RH EY - SH AH KK - K AH R D EY/

(33) ਚੱਲ ਚੱਲੀਏ ਜਰਗ ਦੇ ਮੇਲੇ, ਮੁੰਡਾ ਤੇਰਾ ਮੈਂ ਚੱਕ ਲੂੰ

cəll cəllie jərəg de mele, mŨḍa tera mɛ̃ cəkk lũ
/CH AH LL - CH AH LL IY EY - J AH R AH G - D EY - M EY L EY,

M UHn D: AA - T EY R AA - M AEn - CH AH KK - L UWn/

(34) ਛ ਛੇੜ ਕੇ ਭਰਿੰਡਾਂ-ਰੰਗੀਆਂ, ਕਿੱਥੇ ਜਾਏਂਗਾ ਬੂਬਨਿਆਂ ਸਾਧਾ

cheṛ ke pərĪḍã rɔ̃giã, kItthe jaẽga bubənIã sáda
/CHH EY RH - K EY - Pl AH R IHn D: AAn -- R AHn G IY AAn,
K IH TTH EY - J AA EYn G AA - B UW B AH N IH AAn - S AA hD AA/

(35) ਛੋਟਾ ਦਿਓਰ ਬੜਾ ਟੁੱਟ-ਪੈਣਾ, ਹੱਸਦੀ ਦੇ ਦੰਦ ਗਿਣਦਾ

choṭa dIor bəṛa ṭUṭṭ-pɛṇa, həssədi de dɔ̃d gIṇda
/ CHH OW T: AA - D IH OW R - B AH RH AA - T: UH T:T: -- P AE N: AA,
H AH SS AH D IY - D EY - D AHn D - G IH N: D AA/

(36) ਛੜਿਆਂ ਨੇ ਦਿੱਲੀ ਲੁੱਟੀ, ਦੁਪਹਿਰੇ ਦੀਵਾ ਬਾਲ਼ ਕੇ

chəṛIã ne dIlli lUṭṭi, dUpére diva baḷ ke
/CHH AH RH IH AAn - N EY - D IH LL IY - L UH T:T: IY,
D UH P AEh R EY - D IY V AA - B AA L - K EY/

(37) ਛੜੇ ਦਾ ਕਿਹੜਾ ਪੁੱਤ ਮਰਜੂ, ਕਾਹਤੋਂ ਕੱਢਦੀ ਚੰਦਰੀਏ ਗਾਲ਼ਾਂ

chəṛe da kéṛa pUtt mərju, kató́ kə́ḍḍədi cɔ̃ḍərie gaḷã
/ CHH AH RH EY - D AA - K EYh RH AA - P U TT - M AH R J UW,
K AAh T OWn- K AH hD:D: AH D IY-

(38) ਜ ਜੁੱਤੀ ਖੱਲ ਦੀ ਮਰੋੜਾ ਨਹੀਂ ਝੱਲਦੀ, ਤੋਰ ਪੰਜਾਬਣ ਦੀ

jUtti khəll di məroṛa nəhĩ cə̀lldi, tor pɔ̃jabəṇ di
/J UH TT IY - KH AH LL - D IY - M AH R OW RH AA - N AH H IYn -
CHl AH LL D IY, T OW R - P AHn J AA B AH N: - D IY/

(39) ਜਿਓਣਾ ਮੌੜ ਦੁਖੀਆਂ ਦਾ ਬੇਲੀ, ਸ਼ਾਹਾਂ ਦੀ ਹਵੇਲੀ ਲੁੱਟਦਾ॥

jIoṇa mɔṛ dUkhiã da beli, ṣahã di həveli lUṭṭda.
/J IH OW N: AA - M AO RH - D UH IY AAn - D AA - B EY L IY,
SH AA H AAn - D IY - H AH V EY L IY - L UH T:T: D AA./

(40) ਜੈਤੋ ਦਾ ਕਿਲਾ ਟਪਾ ਦੂੰ, ਜੇ ਕੱਢੀ ਮਾਂ ਦੀ ਗਾਲ਼ ਵੇ

jɛto da kIla ṭəpa dũ, je kə́ḍḍi mã di gaḷ ve
/J AE T OW - D AA - K IH L AA - T: AH P AA - D UWn, J EY -
K AH hD:D: IY - M AAn - D IY - G AA L - V EY/

(41) ਜੱਟੀ ਕੋਟਕਪੂਰੇ ਦੀ, ਤੇ ਬ੍ਰਾਮਣ ਅੰਬਰਸਰ ਦਾ

jəṭṭi koṭkəpure di, te báməṇ ɔ̃bərsər da
/J AH T:T: IY - K OW T: K AH P UW R EY - D IY, T EY - hB AA M AH N: -
AHn B AH R S AH R - D AA/

(42) ਝ ਝੂਟ ਲੈ ਬਿੱਲੋ, ਨੀ ਮੁੰਡਾ ਪੀਂਘ ਦਾ ਹੁਲਾਰਾ

cùṭ lɛ bIllo, ni mŨḍḍa pı̃g da hUlara
/CHl UW T: - L AE - B IH LL OW, N IY - M UHn D:D: AA - P IYn hG - D AA - H UH L AA R AA/

(43) ਝੁਮਕੇ ਝੂਟੇ ਲੈਂਦੇ, ਪੱਖੀ ਝੱਲਦੀ ਦੇ॥

cÙmke cùṭe lɛ̃de, pəkkhi cə̀ldi de.
/CHl UH M K EY - CHl UW T: EY - L AEn D EY, P AH KKH IY - CHl AH L D IY - D EY./

(44) ਝਗੜਾ ਝਾਂਜਰ ਦਾ, ਝੁੱਡੂਓ, ਕੈਦ ਕਰਾ ਦੂ॥

cə̀gṛa cã̀jər da, cÙḍḍuo, kɛd kəraə du.
/CHl AH G RH AA - CHl AAn J AH R - D AA, CHl UH D:D: UW OW, K AE D - K AH R AA AH - D UW./

(45) ਞ ਜੰਞ ਚੜ੍ਹਗੀ ਸਰਾਭੇ ਕਰਤਾਰ ਦੀ, ਛੇ ਸਰਬਾਲ੍ਹੇ ਸਜਗੇ॥

jə̃ɲ cə́ṛgi sərábe kərtar di, che sərbále səjge.
/J AHn NJ - CH AH hRH G IY - S AH R AA hB EY - K AH R T AA R - D IY, CHH EY - S AH R B AA hL EY - S AH J G EY./

(46) ਟ ਟੋਲੀ ਆਉਂਦੀ ਛੜਿਆਂ ਦੀ, ਨਾਲ਼ਾ ਟੰਗ ਲੈ ਘੁੰਗਰੂਆਂ ਵਾਲ਼ਾ

ṭolli aŨdi chəṛIã di, naḷa ṭə̃g lɛ kÙ̃gəruã vaḷa
/T OW LL IY - AA UHn D IY - CHH AH RH IH AAn - D IY, N AA L AA - T: AHn G - L AE - Kl UHn G AH R UW AAn - V AA L AA/

(47) ਟੁੱਟ ਕੇ ਨਾ ਬਹਿ ਜੀਂ ਵੀਰਨਾ, ਭੈਣਾਂ ਵਰਗਾ ਸਾਕ ਨਾ ਕੋਈ

ṭUṭṭ ke na bɛ́ jı̃ virna, pɛ̀ṇã vərga sak na koi
/T: UH T:T: - K EY - N AA - B AEh - J IYn - V IY R N AA, Pl AE N: AAn - V AH R G AA - S AA K- N AA- K OW IY/

(48) ਠ ਚੜ੍ਹਿਆ ਜੇਠ ਮਹੀਨਾ, ਠਾਠ ਠਠੇਰੇ ਦੀ॥ (ਠਠੇਰਾ = ਪਿੱਤਲ ਦੇ ਭਾਂਡੇ ਬਣਾਉਣ ਵਾਲਾ)

cə́ṛIa jeṭh məhina, ṭhaṭh ṭhəṭhere di.
/CH AH hRH IH AA - J EY TH: - M AH H IY N AA, TH: AA TH: - TH: AH TH: EY R EY - D IY./

(49) ਡ ਡਰ ਡਰ ਕੇ ਜਿਉਂ ਨਾ ਹੀਰੇ, ਸਹਿਤੀ ਵੀ ਮੁਰਾਦ ਪਾਊਗੀ॥

ḍər ḍər ke jIŨ na hire, séti vi mUrad paugi.
/D: AH R - D: AH R - K EY - J IH UHn - N AA - H IY R EY, S AEh T IY - V IY - M UH R AA D - P AA UW G IY./

(50) ਡੋਡਿਆਂ ਦਾ ਕੇਸ ਬਣਿਆ, ਦੇਖੋ ਡੁੱਡੇ ਅਮਲੀ ਦੇ ਕਾਰੇ॥

ḍoḍIã da kes bəṇIa, dekho ḍUḍḍe əmli de kare.
/D: OW D: IH AAn - D AA - K EY S - B AH N: IH AA, D EY KH OW - D: UH D:D: EY - AH M L IY - K AA R EY./

(51) ਡੌਂਡੀ ਪਿੱਟ ਨਾ ਚੁਬਾਰੇ ਚੜ੍ਹਕੇ, ਤੇਰੀ ਮੇਰੀ ਨਹੀਂ ਨਿਭਣੀ॥

ḍɔ̃ḍi pIṭṭ na cUbare cə́ṛke, teri meri nəhĩ nÍbəṇi.
/D: Aon D: IY - P IH T:T: - N AA - CH UH B AA R EY - CH AH hRH K EY, T EY R IY - M EY R IY - N AH H IYn - N IH hB AH N: IY./

(52) ਢ ਢਾਈ ਦਿਨ ਨਾ ਜਵਾਨੀ ਨਾਲ਼ ਚੱਲਦੀ, ਕੁੜਤੀ ਮਲ ਮਲ ਦੀ

ṭài dIn na jəvani naḷ cəlldi, kUṛti məl məl di
/T:l AA IY - D IH N - N AA - J AH V AA N IY - N AA L̲ - CH A LL D IY, K UH RH T IY - M AH L - M AH L - D IY/

(53) ਢੋਲ ਸ਼ਰਾਬੀ ਨਾਲ਼, ਗੋਰੀਏ ਨਾ ਲੜ ਨੀ

ṭòl ṣərabi naḷ, gorie na ləṛ ni
/T:l OW L - SH AH R AA B IY - N AA L̲, G OW R IY EY - N AA - L AH RH - N IY/

(54) ਢਿੱਲੋਂ ਕੱਢਦਾ ਗੇੜੇ, ਪਾਣੀ ਪੀ ਠੰਢਾ॥

ṭÌllõ kə́ḍḍəda geṛe, paṇi pi ṭhə̃́ḍa.
/T:l IH LL OWn - K AH hD:D: AH D AA - G EY RH EY, P AA N: IY - P IY - TH: AAn hD: AA./

(55) ਢੋਲ ਰੰਗੀਲੇ ਨੇ, ਨੱਢੀਓਂ ਹੀਰ ਬਣਾ ’ਤੀ॥

ṭòl rə̃gile ne, nə́ḍḍiõ hir bəṇa ’ti.
/T:l OW L - R AHn G IY L EY - N EY, N AH hD:D: IY OWn - H IY R - B AH N: AA - ’T IY./

(56) ਣ ਸੁਹਣੀ ਨਣਦ ਕਹੇ ਭਰਜਾਈਏ, ਜਾਣੀ-ਜਾਣ ਜਾਣ ਗਿਆ॥

sóṇi nəṇəd kəhe pə̀rjaie, jaṇi-jaṇ jaṇ gIa.
/S OWh N: IY - N AH N: AH D - K AH H EY - Pl AH R J AA IY EY - J AA N: IY -- J AA N: - J AA N: - G IH AA./

(57) ਤ ਤੇਰੇ ਲੌਂਗ ਦਾ ਪਿਆ ਲਿਸ਼ਕਾਰਾ, ਹਾਲ਼ੀਆਂ ਨੇ ਹਲ਼ ਡੱਕ ਲੇ

tere lɔ̃g da pIa lIṣkara, haḷiã ne həḷ ḍəkk le
/T EY R EY - L AOn G - D AA - P IH AA - L IH SH K AA R AA, H AA L̲ IY AAn - N EY - H AH L̲ - D: AH KK - L EY/

(58) ਤੋਰ ਸ਼ੁਕੀਨਣ ਦੀ, ਤੂੰ ਕੀ ਜਾਣਦੀ ਭੇਡੇ

tor ṣUkinəṇ di, tũ ki jaṇdi pèḍe
/T OW R - SH UH K IY N AH N: - D IY, T UWn - K IY - J AA N: D IY - Pl EY D: EY/

(59) ਤੁੰਮਿਆਂ ਦੀ ਵੇਲ ਵੱਢ ਕੇ, ਜੱਟ ਬੀਜਦੇ ਖੇਤ ਵਿੱਚ ਨਰਮਾ

tŨmmIã di vel vә́ḍḍ ke, jәṭṭ bijde khet vIcc nәrma
/T UHn MM IH AAn - D IY - V EY L - V AH hD:D: - K EY, J AH T:T: -
B IY J D EY- KH EY T- V IH CHCH- N AH R M AA/

(60) ਤਿੰਨ ਪਿੰਡ ਕੰਜਰਾਂ ਦੇ- ਮੋਹੀ, ਜਾਂਗਪੁਰ, ਦਾਖਾ

tĨnn pĨd kə̃jrã de: mohi, jãgpUr, dakha
/T IHn NN - P IHn D: - K AHn J R AAn - D EY -- M OW H IY,
J AAn G P UH R, D AA KH AA/

(61) ਥ ਥਲ਼ ਵਿੱਚ ਭੁੱਜਦੀ ਨੂੰ, ਮਿਲ਼ ਪੁੰਨਣਾਂ ਰੱਬ ਬਣਕੇ॥

thәḷ vIcc pÙjjәdi nũ, mIḷ pŨnnәṇa rәbb bәṇke.
/TH AH L - V IH CHCH - Pl UH JJ D IY - N UWn, M IH L -
P UHn NN AH N: AA - R AH BB - B AH N: K EY./

(62) ਥਾਂ ਥਾਂ ਥੱਪੜ ਪੈਂਦੇ, ਥੰਮ੍ਹਣ ਥਥਲ਼ੇ ਦੇ॥

thã thã thәppeṛ pɛ̃de, thə̃́mmәṇ thәthḷe de.
/TH AAn - TH AAn - TH AH PP AH RH - P AEn D EY,
TH AHn hMM AH N: - TH AH TH L EY - D EY./

(63) ਦ ਦਿਓਰ ਵਸਣ ਨਾ ਦੇਵੇ, ਸੁਹਣੀ ਭਾਬੋ ਨੂੰ

dIor vәsәṇ na deve, sóṇi pàbo nũ
/ D IH OW R - V AH S AH N: - N AA - D EY V EY, S OWh N: IY -
Pl AA B OW - N UWn/

(64) ਦਰਸ਼ਨ ਦੇਹ ਦੀਪੋ, ਦੇ ਦੇ ਸ਼ੌਂਕ ਦੇ ਗੇੜੇ॥

dәrshәn dé dipo, de de ṣɔ̃k de geṛe.
/D AH R SH AH N - D EYh - D IY P OW - D EY - D EY - SH AOn K - D EY -
G WY RH EY./

(65) ਧ ਧਨ ਕੁਰ ਦੌਧਰ ਦੀ, ਲੱਕ ਪਤਲਾ ਬਦਨ ਦੀ ਭਾਰੀ

tә̀n kUr dɔ́dәr di, lәkk pәtla bәdәn di pàri
/Tl AH N - K UH R - D AO hD AH R - D IY, L AH KK - P AH T L AA -
B AH D AH N - D IY - Pl AA R IY/

(66) ਧੰਦੇ ਵਧਗੇ ਧਨ ਕੁਰੇ ਤੇਰੇ, ਕੰਧਾਂ ਵਿੱਚ ਕੈਦ ਹੋ ਗਈ॥

tə̃̀de vә́dge tә̀n kUre tere, kə̃́dã vIcc kɛd ho gәi.
/Tl AHn D EY - V AH hD G EY - Tl AH N - K UH R EY - T EY R EY,
K AHn hD AAn - V IH CHCH - K AE D - H OW - G AH IY./

(67) ਧਮਕ ਪਵੇ ਸਰਕਾਰੇ, ਅਣਖ ਪੰਜਾਬਣ ਦੀ॥

tә̀mәk pәve sәrkare, әṇәkh pə̃jabәṇ di.

/Tl AH M AH K - P AH V EY - S AH K AA R EY, AH N: AH KH -
P AHn J AA B AH N: - D IY./

(68) ਨ ਨੀ ਪਟਿਆਲ਼ੇ ਵਾਲ਼ਾ ਰਾਜਾ, ਬੋਲੀ ਹੋਰ ਬੋਲਦਾ

ni pəṭIaḷe vaḷa raja, bolli hor bolda
/N IY - P AH T: IH AA L EY - V AA L AA - R AA J AA, B OW LL IY -
H OW R - B OW L D AA/

(69) ਨਾਭੇ ਦੀਏ ਬੰਦ ਬੋਤਲੇ, ਤੈਨੂੰ ਪੀਣਗੇ ਨਸੀਬਾਂ ਵਾਲ਼ੇ

Nábe die bə̃d botəle, tɛnũ piṇge nəsibã vaḷe
/N AA hB EY - D IY EY - B AHn D - B OW T AH L EY, T AE N UWn -
P IY N: G EY - N AH S IY B AAn - V AA L EY/

(70) ਨੀ ਮਾਏ ਤੇਰੇ ਕੰਮ ਨਾ ਮੁੱਕੇ, ਕੰਠੇ ਵਾਲ਼ਾ ਆ ਗਿਆ ਪਰਾਹੁਣਾ

ni mae tere kə̃mm na mUkke, kə̃ṭhe vaḷa a gIa pəráUṇa
/N IY - M AA EY - T EY R EY - K AHn MM - N AA - M UH KK EY,
K AHn TH: EY - V AA L AA - AA - G IH AA - P AH R AAh UH N: AA/

(71) ਪ ਪੌੜੀ ਛੜਿਆਂ ਦੀ, ਝਾਂਜਰ ਪਾ ਪਾ ਚੜ੍ਹਦੀ

pɔṛi chəṛIã di, cə̃jər pa pa cə́ṛdi
/P AO RH IY - CHH AH RH IH AAn - D IY, CHl AAn J AH R - P AA -
P AA - CH AH hRH D IY/

(72) ਪਾ ਕੇ ਲੱਪ ਸੁਰਮਾ, ਤੇਰਾ ਕੰਮ ਕੀ ਸਾਧ ਦੇ ਡੇਰੇ

pa ke ləpp sUrma, tera kə̃mm ki sád de ḍere
/P AA - K EY - L AH PP - S UH R M AA, T EY R AA - K AHn MM - K IY -
S AA hD - D EY - D EY R EY/

(73) ਪਾਣੀ ਮੰਗੇ ਦੁੱਧ ਦਿੰਦੀਆਂ, ਜੱਗ ਜਿਉਂਣ ਵੱਡੀਆਂ ਭਰਜਾਈਆਂ

paṇi mə̃ge dÚdd dĨdiã, jəgg jIũṇ vəḍḍiã pə̀rjaiã
/P AA N: IY - M AHn G EY - D UH hDD - D IHn D IY AAn, J AH GG -
J IH UWn N: - V AH D:D: IY AAN - Pl AH R J AA IY AAn/

(74) ਫ ਫੁੱਲ ਵਾਂਗੂੰ ਰਹਿਣ ਖਿੜੀਆਂ, ਜਿਨ੍ਹਾਂ ਭਾਬੀਆਂ ਦੇ ਦਿਓਰ ਕੁਆਰੇ

phUll vãgũ réṇ khIṛiã, jÍna pàbiã de dIor kUare
/PH UH LL - V AAn G UWn - R AEh N: - KH IH RH IY AAn, J IH hN AA -
Pl AA B IY AAn - D EY - D IH OW R - K UH AA R EY/

(75) ਫਾਂਸੀ ਹਾਰਗੀ, ਫੌਜ ਹਰ ਜਾਣੀ, ਫੇਰ ਤੇਰੀ ਵਾਰੀ ਰਾਣੀਏ॥

phãsi hargi, phɔj hər jaṇi, phe teri vari raṇiẽ.
/PH AAn S IY - H AA R G IY, PH AO J - H AH R - J AA N: IY, PH EY R -
T EY R IY - V AA R IY - R AA N: IY EYn./

(76) ਬ ਬੁੜ੍ਹਾ ਬੁੜ੍ਹੀ ਨੂੰ ਘੜੀਸੀ ਜਾਵੇ, ਲੁੱਦੇਹਾਣੇ ’ਟੇਸ਼ਣ ’ਤੇ

bÚṛa bÚṛi nũ kə̀ṛisi jave, lUddehaṇe ’ṭeṣəṇ ’te
/B UH hRH AA - B UH hRH IY - N UWn - Kl AH RH IY S IY - J AA V EY,
L UH DD EY H AA N: EY - ’T: E SH AH N: - ’T EY/

(77) ਬਾਝ ਨਸੀਬਾਂ ਦੇ, ਘੁੱਟਕੇ ਜੱਫੀ ਨਾ ਪੈਂਦੀ

báj nəsibã de, kÙṭṭke jəpphi na pɛ̃di
/B AA hJ - N AH S IY B AAn - D EY, Kl UH T:T: K EY - J AH PPH IY -
N AA - P AEn D IY/

(78) ਬਾਝ ਨਸੀਬਾਂ ਦੇ, ਬੁਝਣ ਝਨਾਂ ਦੇ ਦੀਵੇ॥

báj nəsibã de, bÚjəṇ cə̀nã de dive.
/B AA hJ - N AH S IY B AAn - D EY, B UH hJ AH N: - CHl AH N AAn -
D EY - D IY V EY./

(79) ਬਚਨਾ ਫਰੀਦਕੋਟੀਆ, ਜੀਹਨੇ ਪੁਲ਼ਸ ਕੁੱਟੀ ਸੀ ਸਾਰੀ

bəcəna phəridkoṭia, jíne pUḷəs kUṭṭi si sari
/B AH CH AH N AA - PH AH R IY D K OW T: IY AA, J IY hN EY -
P UH L̲ AH S - K UH T:T: IY - S IY - S AA R IY/

(80) ਭ ਭਰ ਭਰ ਵੰਡ ਮੁੱਠੀਆਂ, ਗੋਰੇ ਰੰਗ ਨੇ ਸਦਾ ਨੀ ਰਹਿਣਾ

pə̀r pə̀r və̃ḍ mUṭhiã, gore rə̃g ne səda ni rɛ́ṇa
/Pl AH R - Pl AH R - V AHn D: - M UH TH: IYn, G OW R EY - R AHn G -
N EY - S AH D AA - N IY - R AEh N: AA/

(81) ਕਿਵੇਂ ਚਾਂਭਲ਼ੀਆਂ ਭੂਆ ਤੇ ਭਤੀਜੀਆਂ, ਕਿਵੇਂ ਮਿਲ਼ਗੋਭਾ ਬਣੀਆਂ॥

kIvẽ cã́bəḷiã pùa te pə̀tijiã, kIvẽ mIḷgóba bəṇiã.
/K IH V EYn - CH AAn hB AH L̲ IY AAn - Pl UW AA - T EY -
Pl AA T IY J IY AAn, K IH V EYn - M IH L̲ G OW hB AA -
B AH N: IY AAn./

(82) ਭਿੱਜਗੀ ਭਾਗਭਰੀ, ਸਾਂਭ ਲਈਂ ਭਰਜਾਈਏ॥

pÌjjgi pàgpə̀ri, sã́b ləĩ pə̀rjaie.
/Pl IH JJ G IY - Pl AA G Pl AA R IY, S AAn hB - L AH IYn -
Pl AH R J AA IY EY./

(83) ਊਧਮ, ਭਗਤ, ਸਰਾਭੇ, ਫਾਂਸੀ ਹੱਸ ਚੜ੍ਹਦੇ॥

údəm, pə̀gət, sərábe, phãsi həss cə́ṛde.
/UW hD AH M, Pl AH G AH T, S AH R AA hB EY, PH AAn S IY - H AH SS -
CH AH hRH D EY./

(84) ਭਾਰਤ-ਭੂਮੀ ਨੂੰ, ਲੱਭਿਆ ਭਗਤ, ਸਰਾਭਾ॥

pàrət-pùmi nũ, lə́bIa pə̀get, sərába.
/Pl AA R AH T -- Pl UW M IY - N UWn, L AH hB IY AA - Pl AH G AH T,
S AH R AA hB AA./

(85) ਮ ਮੇਲੇ ਮੁਕਸਰ ਦੇ, ਚੱਲ ਚੱਲੀਏ ਨਣਦ ਦਿਆ ਵੀਰਾ

mele mUksər de, cəll cəllie nəṇəd dIa vira
/M EY L EY - M UH K S AH R - D EY, CH AH LL - CH AH LL IY EY -
N AH N: AH D - D IY AA - V IY R AA/

(86) ਮੋਟਰ ਮਿੱਤਰਾਂ ਦੀ, ਚੱਲ ਬਰਨਾਲ਼ੇ ਚੱਲੀਏ

moṭər mIttərã di cəll, bərnaḷe cəllie
/M OW T: AH R - M IH TT AH R AAn - D IY, CH AH LL -
B AH R N AA L̲ EY - CH AH LL IY EY/

(87) ਮੁੰਡਾ ਰੋਹੀ ਦੀ ਕਿੱਕਰ ਦਾ ਜਾਤੂ, ਵਿਆਹ ਕੇ ਲੈ ਗਿਆ ਤੂਤ ਦੀ ਛਿਟੀ

mŨḍa rohi di kIkkər da jatu, vIá ke lɛ gIa tut di chIṭi
/M UHn D: AA - R OW H IY - D IY - K IH KK AH R - D AA - J AA T UW,
V IH AAh - K EY - L AE - G IH AA - T UW T - D IY - CHH IH T: IY/

(88) ਮੋਦਨ ਕੌਂਕਿਆਂ ਦਾ, ਜੀਹਨੇ ਕੁੱਟ ’ਤੀ ਪੰਡੋਰੀ ਸਾਰੀ

modən kɔ̃kIã da, jíne kUṭṭ ’ti pə̃ḍori sari
/M OW D AH N - K AOn K IH AAn - D AA, J IY hN EY - K UH T:T: - ’T IY -
P AHn D: OW R IY - S AA R IY/

(89) ਮੁਣਸ਼ੀ ਡਾਂਗੋਂ ਦਾ, ਡਾਂਗ ਰਖਦਾ ਗੰਡਾਸੀ ਵਾਲ਼ੀ

mUṇəṣi ḍãgõ da, dãg rəkhda gə̃dassi vaḷi
/M UH N: AH SH IY - D: AAn G OWn - D AA, D: AAn G - R AH KH D AA -
G AHn D: AA SS IY - V AA L̲ IY/

(90) ਯ ਯਾਰ ਹੋਣਗੇ ਮਿਲ਼ਨਗੇ ਆਪੇ, ਦਿਲ ਨੂੰ ਟਿਕਾਣੇ ਰੱਖੀਏ

yar hoṇge mIḷnge ape, dIl nũ tIkaṇe rəkhie
/Y AA R - H OW N: G EY - M IH L̲ N G EY - AA P EY, D IH L - N UWn -
T IH K AA N: EY- R AH KH IY EY/

(91) ਯਾਰ ਜਾਣਗੇ ਯੱਕੇ ’ਤੇ ਚੜ੍ਹਕੇ, ਯੱਭਲ਼ਾਂ ਨੂੰ ਪਊ ਤੁਰਨਾ॥

yar jaṇge yəkke ’te cə́ṛke, yə́bbəḷã nũ pəu tUrna.
/Y AA R - J AA N: G EY - Y AH KK EY - ’T EY - CH AH hRH K EY,
Y AH hBB AH L̲ AAn - N UWn - P AH UW - T UH R N AA./

(92) ਰ ਰੰਗ ਦੇ ਕਾਲ਼ੇ ਨੂੰ, ਮੋਗਿਓਂ ਕਲੀ ਕਰਾਈਏ

rə̃g de kaḷe nũ, mogIõ kali kəraie
/R AHn G - D EY - K AA L EY - N UWn, M OW G IH OWn - K AH L IY -
K AH R AA IY EY/

(93) ਰਾਂਝਾ ਜੋਗੀ ਹੋ ਗਿਆ, ਕੰਨੀਂ ਮੁੰਦਰਾਂ ਪਾਈਆਂ

rā̃́ja jogi ho gIa, kə̃nnĩ mŨdərã paiã
/R AAn hJ AA - J OW G IY - H OW - G IH AA, K AHn NN IYn -
M UHn D AH R AAn - P AA IY AAn/

(94) ਰਾਣੋ ਤੇਰੀ ਗੱਲ੍ਹ ਵਰਗਾ, ਨੀ ਮੈਂ ਬੇਰੀਆਂ ’ਚੋਂ ਬੇਰ ਲਿਆਂਦਾ

raṇo teri gə́ll vərga, ni mɛ̃ beriã ’cõ ber lIãda
/R AA N: OW - T EY R IY - G AH hLL - V AH R G AA, N IY - M AEn -
B EY R IY AAn - CH OWn - B EY R - L IH AAn D AA/

(95) ਲ ਲੁੱਦੇਹਾਣੇ ਕੋਲ਼ ਦੁੱਗਰੀ, ਰੀਸ ਦਿੱਲੀ ਦੀ ਕਰਦੀ

lUddehaṇe koḷ dUggəri, ris dIlli di kərdi
/L UH DD EY H AA N: EY - K OW L - D UH GG AH R IY, R IY S -
D IH LL IY - D IY - K AH R D IY/

(96) ਲੱਦੀ ਜਾਂਦੇ ਐ ਕੜਬ ਦੇ ਟਾਂਡੇ, ਰਸ ਲੈ ਗੇ ਪਿੰਡ ਦੇ ਮੁੰਡੇ

ləddi jãde ɛ kəṛəb de ṭãḍe, rəs lɛ ge pĨḍ de mŨḍe
/L AH DD IY - J AAn D IY - AE - K AH RH AH B - D EY - T: AAn D: EY,
R AH S - L AE - G EY - P IHn D: - D EY - M UHn D EY/

(97) ਲੱਕ ਤੇਰਾ ਪਤਲਾ ਜਿਹਾ, ਭਾਰ ਸਹਿਣ ਨਾ ਜੋਗਾ

ləkk tera pətla jIha, pàr sɛ́ṇ na joga
/L AH KK - T EY R AA - P AH T L AA - J IH H AA, Pl AA R - S AEh N: -
N AA - J OW G AA/

(98) ਲੱਡੂ ਵੰਡਦੀ ਕਚਹਿਰੀਓਂ ਨਿੱਕਲ਼ਾਂ, ਪਹਿਲੀ ਪੇਸ਼ੀ ਯਾਰ ਛੁੱਟ ਜੇ

ləḍḍu və̃ḍdi kəcɛ́riõ nIkkəḷã, pɛ́li peṣi yar chUṭ je
/L AH D:D: UH - V AHn D: D IY - K AH CH AEh R IY OWn -
N IH KK LL AAn, P AEh L IY - P EY SH IY - Y AA R - CHH UH T:T: - J EY/

(99)/(#139) ਵਰ ਹਾਣ ਦਾ ਕੁੜੀ ਨੂੰ ਮਿਲ਼ ਜੇ, ਟਿੱਬੀ ਉਤੇ ਮੀਂਹ ਵਰ੍ਹ ਜੇ॥

vər haṇ da kUṛi nũ mIḷ je, ṭIbbi Utte mĩ́ vər je.
/V AH R - H AA N: - D AA - K UH RH IY - N UWn - M IH L - J EY,
T IH BB IY - UH TT EY - M IHnh - V AH hR - J EY/

(100) ਵਿੱਚ ਜਗਰਾਵਾਂ ਦੇ, ਲਗਦੀ ਰੋਸ਼ਨੀ ਭਾਰੀ

vIcc jəgravã de, ləgdi roṣni pàri
/V IH CHCH - J AH G R AA V AAn - D EY, L AH G D IY - R OW SH N IY - Pl AA R IY/

(101) ਵਸਣ ਸ਼ਰੀਕਾਂ ਦਾ, ਨਾਭੇ ਦੀ ਸਰਦਾਰੀ

vəsəṇ ṣərikã da, nábe di sərdari
/V AH S AH N: - SH AH R IY K AAn - D AA, N AA hB EY - D IY - S AH R D AA R IY/

(102) ੜ ਪੌੜੀ ਚੜ੍ਹਗੀ ਮੜਕ ਨਾਲ ਲੜ ਕੇ, ਕਾੜ ਕਾੜ ਬੂਹਾ ਭੰਨਗੀ॥

pɔṛi cə́ṛgi məṛək naḷ ləṛ ke, kaṛ kaṛ buha pə̀nngi.
/P AO RH IY - CH AH hRH G IY - M AH RH AH K - N AA L - L AH RH - K EY, K AA RH - K AA RH - B UW H AA - Pl AHn NN G IY./

(103) ਖੜਕਾ ਦੜਕਾ ਹੋ ਜੁ ਕੁੜੀਏ! ਨਾ ਖੜਕਾਅ ਨੀ ਕੁੰਡਾ॥

khəṛka dəṛka ho ju kuṛie! na khəṛkaə ni kŨḍḍa.
/KH AH RH K AA - D AH RH K AA - H OW - J UW - K UH RH IY EY! N AA - KH AH RH K AA AH - N IY - K UHn D:D: AA./

■

APPENDIX C
LEVINSON-DURBIN RECURSIVE ALGORITHM

A brief description of the Levinson-Robinson algorithm is given below. If a Toeplitz matrix is involved, then the computational work required to solve a set of simultaneous equations involving Toeplitz matrix can be reduced by taking advantage of the special properties of such a matrix (see Section 5.2.1.1 for these properties). The efficient solution is provided by Levinson-Robinson or Levinson-Durbin recursive algorithm proposed by N. Levinson [71], reformulated for computer programming by E.A. Robinson [91], and later improved by Durbin [15, 24, 74-76, 79, 82-83, 87-89, 99].

A $p \times p$ Toeplitz matrix is of the form:

$$[R] = \begin{bmatrix} R(0) & R(1) & R(2) & \cdots\cdots & R(p-1) \\ R(1) & R(0) & R(1) & \cdots\cdots & R(p-2) \\ R(2) & R(1) & R(0) & \cdots\cdots & R(p-3) \\ \cdots\cdots & \cdots\cdots & \cdots\cdots & \cdots\cdots & \cdots\cdots \\ \cdots\cdots & \cdots\cdots & \cdots\cdots & \cdots\cdots & \cdots\cdots \\ R(p-1) & R(p-2) & R(p-3) & \cdots\cdots & R(0) \end{bmatrix}$$

Clearly it does not involve p^2 distinct elements but only p distinct elements R(j); j = 0, 1, 2, …, $p-1$. Suppose we want to solve the following set of simultaneous equations (called Normal equations):

$$a_0 R(0) + a_1 R(1) + ... + a_{p-1} R(p-1) = b_0$$
$$a_0 R(1) + a_1 R(0) + ... + a_{p-1} R(p-2) = b_1$$
....
$$a_0 R(p-1) + a_1 R(p-2) + ... + a_{p-1} R(0) = b_{p-1}$$

where a_j $(0 \le j \le p-1)$ are the only unknown quantities (in our case linear prediction coefficients) or some other similar coefficients). It implies that *in matrix form*, we have to solve:

[R] [A] = [B]

where:

[R] = $p \times p$ Toeplitz matrix

[A] = Column vector $[a_0, a_1, a_2, \cdots, a_{p-1}]^T$

[B] = Column vector $[b_0, b_1, b_2, \cdots, b_{p-1}]^T$

Starting from the following initial conditions (at step *n = 1*):
$f_{00} = 1; \alpha_0 = R(0); \beta_0 = R(1); a_{00} = b_0 / R(0); \gamma_0 = a_{00} R(1);$ we proceed recursively from steps n = 2 to *p*. The final values obtained ($a_p, 0; a_p, 1; \cdots, a_p, p-1$) represent the desired p coefficients $a_j \, (0 \le j \le p-1)$.

■

APPENDIX D
SIFT ALGORITHM

The SIFT (Simplified Inverse Filter Tracking) algorithm for the voiced/unvoiced (V/UV) decision and the pitch extraction was designed by Markel [75] in 1972. Its description can be found in almost every speech processing book [e.g., 15, 75-76, 82, 83, 87-89, 99]. The SIFT algorithm is based on Eq. (5.5) and Eq. (5.15) given as:

$$e_n = s_n - \hat{s}_n = s_n + \sum_{j=1}^{p} a_j s_{n-j} = G \cdot u_n \tag{D.1}$$

and

$$E(Z) = A(Z) \cdot S(Z) \cdot \tag{D.2}$$

In the statement form, it implies that to the extent that s_n is the output of a system well represented by an all pole model, e_n is a good approximation to the excitation function to the same extent and that if s_n is inverse filtered through A(Z), the output will be the prediction error or residual error e_n, expected to be large at the beginning of each pitch period for voiced sounds and noise-like for unvoiced sounds. Assuming that speech $\{s_n\}$ is sampled at the sampling frequency f_s = 10 kHz (appropriate adjustments can be easily made for different f_s), and that the pitch period lies in the range 2.5 – 15.5 ms, the SIFT can be described in the following steps:

(i) The speech signal $\{s_n\}$ is lowpass filtered through a third order elliptic filter [75-76] with cut off frequency close to l kHz and the effective sampling frequency is reduced to 2 kHz by decimation (dropping 4 out of every 5 samples) to reduce further computations.

(ii) The above output is then pre-emphasized by passing through a single-zero filter $1-z^{-1}$ to preserve the spectral characteristics of only the vocal tract [12, 74-76] and multiplied by a Hamming window:

$$u_k = w_k \cdot (s_{5k+4} - s_{5(k-1)+4}); \quad 0 \le k \le (\frac{N}{5} - 1) \tag{D.3}$$

Where $\{s_n\}$ is nonzero only for $0 \le n \le N$-1, N is equal to 400 samples and the Hamming window is

$$w_k = 0.54 - 0.46\, cos[2\pi k/(\frac{N}{5} - 1)];\ \ 0 \le k \le (\frac{N}{5} - 1)$$
$$= 0; \qquad\qquad\qquad\qquad \text{otherwise}$$

(D.4)

(iii) $\{u_k\}$ is analyzed by the autocorrelation method (sec. 3.1) to design a fourth-order inverse filter (as p = 4 is sufficient) to model the signal in (0-l kHz) frequency range. $\{u_k\}$ is then inverse filtered to give $\{d_k\}$ which obviously is the residual error for the fourth order linear predictor. $\{d_k\}$ will have an approximately flat spectrum [74-76, 87-89, 99].

(iv) The autocorrelation of $\{d_k\}$ is calculated and the largest autocorrelation peak in the desired pitch range (2.5 – 15.5 ms) is obtained. Variable threshold is used and if a peak crosses the variable threshold, its location is taken as the pitch period. Information on the previous two frames is retained for error detection. The autocorrelation sequence is interpolated parabolically in the region of the maximum value for obtaining the additional resolution in the pitch value. A frame is declared to be unvoiced if the autocorrelation peaks are small and fall below the variable threshold values.

(v) If the error detection process finds an unvoiced frame surrounded by voiced frames, it is declared to be voiced with pitch period equal to the average of the pitch periods of the two surrounding voiced frames because an isolated unvoiced frame such as this is impossible to exist.

(vi) The input sequence $\{s_n\}$ is 400 samples (40 ms) and there is a 2 to 1 overlap of input data implying that 40 ms sequences are processed in 20 ms increments.

SIFT has influenced almost every pitch detection algorithm, designed after the year 1972, *in particular*, the Robust Algorithm for Pitch Tracking (*RAPT*), that has also been used in this work.

■

APPENDIX E
SPEECH SENTENCES SYNTHESIZED

1. VOWELS (5 sentences): ੳ ਅ ੲ, ਚਿਰ / ਚੀਰ, ਸੁਰ / ਸੂਰ (# 1, 2, 3, 24, 25)

ੳ 1. ਓਏ ਉੱਲੂ! ਊਂਘਦਾ ਕਿਓਂ ਐਂ? ਉਂਗਲੀ ਫੜ!

oe Ullu! ű̃gda kIõ ɛ̃? Ũggli phəṛ!
/OW EY - UH LL UW! UWn hG D AA - K IH OWn - AEn?
UHn GG L IY - PH AH RH!/

ਅ 2. ਅਮਰ! ਐਂ ਕਰ, ਔਹ ਐਨਕ ਅੰਦਰ ਲੈ ਆ।

əmər! ɛ̃ kər, ɔ́ ɛnək ə̃dər lɛ a.
/AA M AH R! AEn - K AH R, AOh - AE N AH K - AHn D AH R - L AE - AA/

ੲ 3. ਈਸ਼ਰ ਅਤੇ ਇੰਦਰ, ਇਕਵੰਜਾ ਇੱਟਾਂ ਏਥੇ ਲਿਆਓ।

iṣər əte Ĩdər, Ikvə̃ja Iṭṭã ethe lIao.
/IY SH AH R - AH T EY - IHn D AH R, IH K V AHn J AA - IH T:T: AAn -
EY TH EY - L IH AA OW/

24. **ਚਿਰ** ਨਾ ਲਾ, ਸਾਗ **ਚੀਰ**।

cIr na la, sag cir.
/CH IH R - N AA - L AA, S AA G - CH IY R/

25. ਓਏ **ਸੂਰ**, **ਸੁਰ** ’ਚ ਗਾ!

oe sur, sUr c ga!
/OW EY - S UW R, S UH R - ’CH - G AA!/

2. NASALS (5 sentences): ਙ ਞ ਣ ਨ ਮ (# 30, 34, 35, 11, 12)

ਨ 11. ਨਿੰਮੋ ਦੀ ਨੂੰਹ ਦੇ ਨੱਕ ’ਤੇ ਨੌਂ ਟੰਕੇ ਲੱਗੇ।

nĨmmo di nű̃ de nəkk ’te nɔ̃ ṭə̃ke ləgge.
/N IHh MM OW - D IY - N UWnh - D EY - N AH KK - ’T EY - N AOn -
T AHn K EY - L AH GG EY/

ਮ 12. ਮੱਘਰ ਦੀ ਮਾਂ, ਮਾਮਾ ਮਾਮੀ, ਮਾਸੀ ਮਾਸੜ, ਮੇਲੇ ਗਏ।

məggər di mã, mama mami, massi masəṛ, mele gəe.
/M AH hGG AH R - D IY- M AAn, M AA M AA - M AA M IY,
M AA SS IY - M AA S AH RH, M EY L EY - G AH EY/

ਙ 30. ਕੰਙਣ ਛਣਕਾਉਂਦੀਏ ਨੀ! ਕਾਹਤੋਂ ਦੁੱਧ ’ਚ ਮੀਂਙਣਾ ਪਾਉਂਦੀ॥

kə̃ŋəṇ chəṇkaŨdie! dÚdd ’c miŋəṇa na pa.
/K AHn NX AH N: - CHH AH N: K AA UHn D IY EY! D UH hDD - ’CH -
M IYn NX AH N: AA - N AA - P AA/

ਞ 34. ਜੰਞ ਚੜ੍ਹਗੀ ਸਰਾਭੇ ਕਰਤਾਰ ਦੀ, ਛੇ ਸਰਬਾਲ੍ਹੇ ਸਜਗੇ॥

jə̃ɲ cə́ṛgi sərábe kərtar di, che sərbále səjge.
/J AHn NJ - CH AH hRH G IY - S AH R AA hB EY - K AH R T AA R - D IY,
CHH EY - S AH R B AA hL EY - S AH J G EY./

ਣ 35. ਸੁਹਣੀ ਨਣਦ ਕਹੇ ਭਰਜਾਈਏ, ਜਾਣੀ-ਜਾਣ ਜਾਣ ਗਿਆ॥

sóṇi nəṇəd kəhe pə̀rjaie, jaṇi-jaṇ jaṇ gIa.
/S OWh N: IY - N AH N: AH D - K AH H EY - Pl AH R J AA IY EY -
J AA N: IY -- J AA N: - J AA N: - G IH AA./

3. TONEMES (6 sentences): ਘ×2 ਝ ਢ ਧ ਭ (# 6, 9, 22, 33, 36, 38)

ਘ 6. ਬਘਿਆੜ ਮੇਘੇ ਘੁਮਿਆਰ ਦਾ ਘੋੜਾ ਖਾ ਗਿਆ।

bəgIàṛ mége kÙmIar da kòṛa kha gIa.
/B AH Gl IH AA RH - M EY hG EY - Kl UH M IH AA R - D AA –
Kl OW RH A - KH AA - G IH AA/

ਢ 9. ਢੱਗੇ ਦੇ ਚੂੰਢੀਆਂ ਨਾ ਵੱਢ ਕੁੰਢਿਆ, ਢਿੰਬਰੀ ਟੈਟ ਕਰਦੂੰ!

ṭə̀gge de cű̃ḍiã na və́ḍḍ kŰḍḍIa, ṭÎ̀bəri ṭɛṭ kər dũ!
/T:l AH GG EY - D EY - CH UWn hD: IY AAn - N AA - V AH hD:D: -
K UHn hD: IH AA, T:l IHn B AH R IY - T: AE T: - K AH R - D: UWn!/

22. ਘੜਾ ਮਾਘ ਭਰ ਭਰੂੰ ਤੇਰਾ ਮੱਘਰਾ, ਝਾਂਜਰਾਂ ਘੜਾਅ ਦੇ ਮਿੱਤਰਾ॥

kə̀ṛa mág pə̀r pə̀rũ tera mə́ggəra, cà̃jrã kə̀ṛaə de mIttəra.
/Kl AH RH AA - M AA hG - Pl AH R - Pl AH R UWn - T EY R AA -
M AH hGG AH R AA, CHl AAn J R AAn - Kl AH RH AA AH - D EY -

M IH TT AH R AA/

ਝ 33. ਬਾਝ ਨਸੀਬਾਂ ਦੇ, ਬੁਝਣ ਝਨਾਂ ਦੇ ਦੀਵੇ॥

báj nəsibã de, bÚjəṇ cə̀nã de dive.
/B AA hJ - N AH S IY B AAn - D EY, B UH hJ AH N: - CHl AH N AAn - D EY - D IY V EY./

ਧ 36. ਧੰਦੇ ਵਧਗੇ ਧਨ ਕੁਰੇ ਤੇਰੇ, ਕੰਧਾਂ ਵਿੱਚ ਕੈਦ ਹੋ ਗਈ॥

tə̃̀de və́dge tə̀n kUre tere, kə̃́dã vIcc kɛd ho gəi.
/Tl AHn D EY - V AH hD G EY - Tl AH N - K UH R EY - T EY R EY, K AHn hD AAn - V IH CHCH - K AE D - H OW - G AH IY./

ਭ 38. ਭਾਰਤ-ਭੂਮੀ ਨੂੰ, ਲੱਭਿਆ ਭਗਤ, ਸਰਾਭਾ॥

pàrət-pùmi nũ, lə́bIa pə̀get, səraba.
/Pl AA R AH T -- Pl UW M IY - N UWn, L AH hB IY AA - Pl AH G AH T, S AH R AA hB AA./

4. SPECIAL SENTENCES (9 sentences): (# 4, 7, 8, 10, 18, 19, 39, 41, 83)

ਹ 4. ਹਾਕਮ ਨੇ ਹੰਸ ਨੂੰ ਹਰਾਅ ਕੇ ਹਰਾ ਹੀਰਾ ਜਿੱਤਿਆ।

hakəm ne hə̃s nũ həraə ke həra hira jIttIa.
/H AA K AH M - N EY - H AHn S - N UWn - H AH R AA AH - K EY - H AH R AA - H IY R AA - J IH TT IH AA/

ਛ 7. ਛਿੰਦੇ ਨੇ ਛੱਪੜ 'ਚੋਂ ਛੇਤੀ ਛੇਤੀ ਛੇ ਕੱਛੂ ਫੜੇ।

chĨde ne chəppəṛ 'cõ cheti cheti che kəcchu phəṛe.
/CHH IHn D EY - N EY - CHH AH PP AH RH - 'CH OWn - CHH EY T IY - CHH EY T IY - CHH EY - K AH CHCHH UW - PH AH RH EY/

ਠ 8. ਠੂਹ-ਠਾਹ ਛੱਡ, ਠੀਕ ਹੋ ਕੇ ਠੁੱਕ ਨਾਲ਼ ਰਹਿ।

ṭhú-ṭhá chəḍḍ, ṭhik ho ke ṭhUkk naḷ rɛ́.
/TH: UWh -- TH: AAh - CHH AH DD, TH: IY K - H OW - K EY - TH: UH KK - N AA L̲ - R AEh/

ਤ 10. ਤਰਸੇਮੋ, ਤੂੰ ਤੋਤਕੜੇ ਬੰਦ ਕਰਕੇ ਤੱਕਲ਼ਾ ਸਿੱਧਾ ਕਰ।

tərsemo, tũ totkəṛe bə̃d kərke təkkəḷa sÍdda kər.
/T AH R S EY M OW, T UWn - T OW T K AH RH EY - B AHn D -
K AH R K EY - T AH KK AH L AA - S IH hDD AA - K AH R/

ਲ਼ 18. ਮਲ਼ ਮਲ਼ ਨ੍ਹਾਉਂਦੀ, ਮਲ ਮਲ ਪਾਉਂਦੀ।

məḷ məḷ nɔ̃́di, məl məl paũdi.
/M AH L - M AH L - hN AOn D IY, M AH L - M AH L - P AA UHn D IY/

19. ਵਰ ਹਾਣ ਦਾ ਕੁੜੀ ਨੂੰ ਮਿਲ਼ ਜੇ, ਟਿੱਬੀ ਉਤੇ ਮੀਂਹ ਵਰ੍ਹ ਜੇ॥

vər **haṇ** da kUṛi nũ mIḷ je, ṭIbbi Utte **mĩ́ vә́r** je.
V AH R - H AA N: - D AA - K UH RH IY - N UWn - M IH L - J EY,
/T IH BB IY - UH TT EY - M IHnh - V AH hR - J EY/

ਯ 39. ਯਾਰ ਜਾਣਗੇ ਯੱਕੇ ’ਤੇ ਚੜ੍ਹਕੇ, ਯੱਭਲ਼ਾਂ ਨੂੰ ਪਊ ਤੁਰਨਾ॥

yar jaṇge yəkke ’te cә́ṛke, yә́bbəḷã nũ pəu tUrna.
/Y AA R - J AA N: G EY - Y AH KK EY - ’T EY - CH AH hRH K EY,
Y AH hBB AH L AAn - N UWn - P AH UW - T UH R N AA./

ੜ 41. ਪੌੜੀ ਚੜ੍ਹਗੀ ਮੜਕ ਨਾਲ ਲੜਕੇ, ਕਾੜ ਕਾੜ ਬੂਹਾ ਭੰਨਗੀ॥

pɔṛi cә́ṛgi məṛək naḷ ləṛ ke, kaṛ kaṛ buha pə̃̀nngi.
/P AO RH IY - CH AH hRH G IY - M AH RH AH K - N AA L -
L AH RH - K EY, K AA RH - K AA RH - B UW H AA - Pl AHn NN G IY./

ਫ 83. ਫੁੰਮਣ ਫੁਕਰਾ ਫੇਰ ਕੀ ਫੰਨੂ ਖੋਹ ਦੂ!

phŨməṇ phUkra pher ki phənnũ khó du.
/PH UHn M AH N: - PH UH K R AA - PH EY R - K IY - PH AH NN UH -
KH OWh - D UW/

■

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