Real Time Processing of GPS Data Using DSP Techniques

A Dissertation submitted in fulfillment of the requirements for the Degree
of

MASTER OF ENGINEERING
in
Electronic Instrumentation & Control Engineering

Submitted by

Barindervir Kaur
801351003

Under the Guidance of
Dr. Sangeeta Kamboj
Assistant Professor, EIED

2015

Electrical and Instrumentation Engineering Department
Thapar University, Patiala
(Declared as Deemed-to-be-University u/s 3 of the UGC Act., 1956)
Post Bag No. 32, Patiala – 147004
Punjab (India)

DECLARATION

I hereby certify that the work which is presented in dissertation entitled, "**Real Time Processing of GPS Data Using DSP Techniques**" in partial fulfillment of the requirements for the award of the degree of **Master of Engineering** in **Electronics (Instrumentation & Control)**, submitted to Electrical & Instrumentation Engineering Department of Thapar University, Patiala is as authentic record of my own work carried under the supervision of **Dr. Sangeeta Kamboj**, Assistant Professor, Electrical and Instrumentation Engineering Department, Thapar University, Patiala, Punjab. It refers others researcher's work which are duly listed in the reference section. The matter contained in this dissertation has not been submitted, neither in part nor in full to any other degree to any other university or institute except as reported in text and references.

Barinder virkaur

Place: PATIALA

(Barindervir Kaur)

Date: 14-07-2015

Roll No: 801351003

It is certified that the above statement made by the student is correct to the best of my knowledge and belief.

(Dr. Sangeeta Kamboj)

Date: 14/7/2015

Assistant Professor

Electrical & Instrumentation Engineering Department

Thapar University, Patiala

Countersigned by:

Head
Electrical & Instrumentation Engineering Department
Thapar University, Patiala

Dean (Academic Affairs)
Thapar University, Patiala

ACKNOWLEDGEMENT

First of all, I would like to express my gratitude to **Dr. Sangeeta Kamboj, Assistant Professor**, Electrical and Instrumentation Engineering Department (EIED), Thapar University, Patiala for her patient guidance and support. I am truly very fortunate to have the opportunity to work with her. I found her guidance to be extremely valuable.

I am also thankful to our **HEAD OF THE DEPARTMENT, Dr. Ravinder Agarwal** as well as **PG Coordinator, Mr. Nirbhowjap Singh, Assistant Professor**, Electrical and Instrumentation Engineering Department.

I would like to thank entire faculty and staff of Electrical and Instrumentation Engineering Department and then my friends Kushwinder, Sachpreet, Simar, Money, Jiwan and Priyanka, who devoted their valuable time and helped me in all possible ways towards successful completion of this work. I thank all those who have contributed directly or indirectly to this work.

Lastly, I would also like to thank my parents and brother for their years of unyielding love and encourage. They have always wanted the best for me and I admire their determination and sacrifice.

Barinder vir Kaur

Date: 14-07-2015
BARINDERVIR KAUR

Place: Patiala
M.E. (EICE) 2nd Year

801351003

TABLE OF CONTENTS

Contents **Page No.**

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVATIONS

AMRDEC-Army Aviation and Missile Research, Development, and Engineering Centre

ASIC-Application Specific Integrated Circuit

BASS- bases of synchronizing signal

BDIM-Bad data identification and modification technique

DSP-Digital Signal Processor

DLL- Delay Lock Loops

ECEF -Earth-Centered Earth-Fixed coordinate frame

EKF-Extended Kalman Filter

FPGA-Field Programmable Gate array

GPS- Global Positioning System

IF-Intermediate Frequency

IMU- inertial measurement unit

LOS- line of sight

PSP-Precise Positioning Service

PRN- Pseudo-Random Noise

SPS-Standard Positioning Service

VDLL- vector delay lock loop

ABSTRACT

The Navstar Global positioning system is all weather, space based navigation system developed by the department of defense to satisfy the requirements for the military forces for accurately determining their position, velocity and time in common reference system, anywhere on or near earth on continuous basis. It is used in various applications such as agriculture, navigation, Mapping and Surveying, Military. The major problems in GPS measurements may be due to tall buildings, high mountains, and overhead foliage. The positioning data provided directly by the satellites are subject to variety of error sources such as thermal noise, tropospheric delays, multipath error, ephemeris errors, satellite clock errors and ionospheric delays before they are processed into position and time solution in the GPS receiver.

The work is based on case studies. An experimental set up is made using two standard handheld GPS receivers. The effect of weather and altitude of particular location is also considered.DSP techniques such as Bad Data identification and modification and Kalman filter are used to enhance the accuracy of GPS measurements. In the work the combination of DSP technique Kalman filter after Bad Data identification and modification technique significantly reduced the errors in GPS measurements.

CHAPTER 1

INTRODUCTION

1.1 Overview

From several years, Global Positioning Satellites are revolving in the orbit of earth to provide navigation facilities on sea, in the air and on land. Millions of Global Positioning System (GPS) devices are in use all over the world, in various applications such as agriculture, navigation, Mapping and Surveying, Military [1]. Irrespective of the application, the fundamental function of the GPS device remains same i.e. to obtain the accurate position and timing information anywhere in the world. The major problems to GPS navigation is blockage of satellite reception by tall buildings, high mountains, and foliage overhead, which creates difficulties in its method of working. GPS system is based on the computing of latitude from the GPS receiver to the multiple satellites by multiplying the time delay that a GPS signal needs to travel from the satellites to the receiver with velocity of light. The position of the receiver is computed on the basis of the distance from at least four or five satellites [2]. The whole operation of the GPS receiver includes the analog and digital processing of the GPS signal. The analog processing consists of amplification and filtering. The analog to digital conversion is performed on analog portion of the GPS receiver and thus the digital processing can be executed either on Application Specific Integrated Circuit (ASIC) or Digital Signal Processor (DSP) and a Field Programmable Gate Array (FPGA) or microprocessor. Inherent the GPS signals will be affected with thermal noise, multipath propagation. Various error sources such as tropospheric delays, multipath error, Ephemeris errors, Satellite clock errors and Ionospheric delays, GPS signal noise and Receiver noise are the factors that affect the GPS accuracy. In the available literature some DSP techniques were used to reduce error in GPS measurements.

The work is based on case studies. An experimental set up is made using two standard handheld GPS receivers. The effect of weather and altitude of particular location is also considered. The raw GPS measurements are not so accurate that these GPS measurements can be used directly. Thus the raw GPS measurements are processed using combination of DSP techniques such as Kalman filter and Kalman filter after BDIM.

1.2. Aim of Work

The proposed work is based on case studies. An experimental work is done for two cases considered. The effect of weather and altitude of the particular place is also considered. Estimated GPS altitude measurements can be used to evaluate overhead conductor sag in power transmission lines.

The objectives of present work are given as:

1. To conduct experiment for collection of GPS data in real time.

2. Refinement of raw GPS height difference in real time so that the processed GPS measurements can be used for overhead conductor sag measurement using combination of DSP techniques such as:

a) Kalman filter

b) Kalman filter after BDIM.

3. Comparison of results obtained using Kalman filter and Kalman filter after BDIM

1.3 Outline of Thesis

This thesis consists of 6 chapters which have been introduced as follows to get an overview of the study carried out.

Chapter 1 describes overview of thesis work. The objective of the proposed work is also given in the chapter.

Chapter 2 presents review on available work for the thesis.

Chapter 3 is the introductory chapter of GPS (Global Positioning System) and DSP Techniques. In the chapter the structure, working and errors of GPS has been discussed and Kalman filter detail is also described

Chapter 4 presented the experimental set up and explanation of the GPS logger block diagram

Chapter 5 considers various cases under study. The output of DSP techniques: Kalman filter and Kalman filter after BDIM has been presented in the chapter.

Chapter 6 presents some concluding remarks of work. Scope for future work has been suggested in the chapter

.

CHAPTER 2

LITERATURE REVIEW

Peter H. Dana (1997) presents précis of the Global Positioning System (GPS) operation and basic features of GPS and also illustrates the GPS errors as they faced by user. An overview of receiver types, principal and receiver tasks gives the support to understanding the time transfer techniques of GPS. The modern receiver improvement and needs of GPS frequency and time receivers are described. The accuracies served by different time transfer techniques are analysis. The global standard for GPS to trace throughout the world by the user applications is described. GPS time propagation failure modes that cause failure of space craft, receivers and other control problems are outlined [4].

Mohinder S.Grewal and Angus P. Andrews (2001) in their research covered introduction to necessary background on linear systems, modeling and stochastic processes, detailed examples of application of linear optimal filters and predictors probability. Also, represented the kalman filter's historical background and the many more practical ways of implementation included: aspects of solving the problem in a mathematical model, oversee the estimator performance as it is concerned with model parameters, how to implement the mechanization equations in numerically stable algorithms, analyzed its appliance requirements, test the results validity, and monitored the filter performance in operation. Provide application and history of development to the general subject matter. Covered basic aspects of course in digital estimation theory and application and also describes the necessary topics in filtering theory and application [5].

Dan Simon (2001) presented the basic concepts that needed to knew the design and implementation of a Kalman filter. Introduce a Kalman filter algorithm and the use of this filter to solve a vehicle navigation problem. Kalman filtering worked as a tool to obtain the reliable estimated position of the moving vehicle. Kalman is not only theoretical but also practical attractive because it is the one who minimizes the variance in estimated error among all other filters. Gave description of kalman filter equations and algorithm simulation, further more explains the historical perspective of kalman filter, Showed vehicle position and velocity errors with the help of graphs [6].

Greg Welch and Gary Bishop (2001) provided introduction and gave description about discrete kalman filter. Algorithm of kalman filter containing time and measurement update equations was also described in details. Researchers presented the process model, filter equations and Tuning of kalman filter parameters. It was shown the selection of parameters P, Q and effects of changing the value of R on the measurements. For nonlinear process, the basic operation of an extended kalman filter was also presented [7].

Michael C. Olynik (2002) analysed the sensual characteristics of satellite clock, ionospheric and orbital errors independently. The other different errors like multipath, noise and tropospheric errors are studied together. To compute these different errors, the removal of receiver clock should be must; it is only possible if position is known. Data from different field circumstance has been used to analyse all these errors. The Orbit and satellite clock errors are investigate by comparing absolute known satellite clock and broadcast information; the results in addition of dual frequency are improved by 46-54% to 2.1 cm in easting, 2.6 cm in northing and 4.7 cm in height. To analyse the change in ionospheric error the dual frequency carrier phase data is used. In the results; the root mean square (RMS) value of change in error decreased from 5.7 to 2.6 cm in easting, 8.1 to 3.3 cm in northing, and 17.0 to 4.9 cm in height, which shows the improvement of 54-71%. And the results when single frequency data is assed with broadcast clock data and orbit, the RMS value of change in position errors over an interval of 50 second is about 3.9 in easting, 5.6 cm in northing and 10.2 cm in height. In a kinematic environment the improvement is 43-63% in all three components [8].

I. Guvenc, C.T. Abdallah, R. Jordan, O. Dedeoglu (2003); investigated the site observed issues when positioning a wireless LAN, analyzed many algorithms of pattern matching and provided a method of improving the location accuracy by Kalman filters [9].

Olivera-Reyna, Roberto, I. E. Villalon-Turubiates, Yuriy S. Shmaliy, and O. G. Manzano (2003); Differentiated three Kalman filter algorithms which showed similar estimation behavior. Very small differences appeared among them, which was impossible to see only with the statistical data [10].

Rachel Kleinbauer (2004) described algorithm included two main steps: the prediction step and correction step of standard kalman filter. Furthermore, show essential calculations of KF and extended KF and conversion of the extended KF to nonlinear systems. In the end, the program was executed taking example for calculating the orbit geostationary satellite. Also gave the application of kalman filter correcting the reference orbit for these GPS satellites from the data collecting from the GPS control stations. Explained the simplified conditions under which the general filter converted to a Kalman filter (KF). Represent general random parameter estimation vector results. Explained the block diagram of the Kalman filter and list a number of important properties of the Kalman Filter [11].

Maria Isabel Ribeiro (2004) derived the Kalman filter and the Extended Kalman filter dynamics. It was shown that the Kalman filter is a discrete time linear, optimal, time-varying system that calculates the state estimate which minimized the mean-square error. The Kalman filter dynamics followed the consecutive cycles of prediction and filtering. Derived steady state filter and the steady state gain at which kalman filter dynamics converges under additional conditions on the system dynamics. Introduce the process that contained the novel information associated with the filter transmitted using last system measurement to estimate the state. The Extended Kalman filter (EKF) is a non-optimal approach in the frame of linear filters to solve the problem [12].

Kosanam, Srikiran, and Daniel J. Simon (2004) described the robustness of kalman filter opposing measurement and process noise. An alternate robust kalman filter was proposed which dealt with uncertainities better than the standard Kalman filter. Researchers were worked on the statistics rather than assuming any bounds on the uncertainities in covariances. Some preceding results were shown for aircraft gas turbine engine, where efficiencies of fan, compressor, high and low pressure of turbine airflow and enthalpy changes were calculated when the covariance change is zero,it was observed that, the standard Kalman filter performs better than the robust Kalman filter. However, with more changes in the covariance, the robust filter gains more and more performance in comparison to the standard kalman filter [13].

Robert Bos ,1 Xavier Bombois and Paul M. J. Van den Hof. (2005), introduced the kalman filter estimation method for the system having singular values, this method was helpful for constructing a good filter, even if the case is that the first principles model is badly observable. Methodology was shown for constructing a Kalman filter without resorting to manual tuning or nonlinear optimization and various steps has been discussed for constructing an approximate

Kalman filter. It was discussed how the estimation errors get effected in the estimated auto-covariance function and methods to reduce this sensitivity were given. It has been shown that small singular values can cause poor performance of estimated Kalman filters [14].

Sophia Y. Zheng (2005) proposed the software based GPS receiver design to increase the flexibility of GPS system. The performance of acquisition and tracking of the software GPS receiver is viewed by using different threshold values and parameters. Due to flexibility of software GPS receiver's operation, it allows to track and process the weak signals. The centre attraction of receiver design is mainly on the tracking and acquisition of L1 band and C/A code of GPS signals worked in most of user applications. In this thesis author developed the acquisition and tracking algorithms to fetch the navigation data from the raw GPS signals. Both GSS 6560 simulator and MATLAB simulators are used to certify the performance of the acquisition and tracking algorithms for GPS data or realistic GPS signals. The tracking algorithm preformed on the bases of synchronizing signal (BASS) method [2].

Matthew Lashley (2006) introduced the several new tracking algorithms based on Kalman filter for software GPS receivers in alternative to traditional Delay Lock Loops (DLL) and Costas loops used to track Pseudo-Random Noise (PRN) signals and carrier signals of navigation messages broadcast by GPS satellites respectively. The Extended Kalman Filter (EKF) is used to track the PRN sequence and to estimate position of the user in the Earth-Centered Earth-Fixed (ECEF) coordinate frame. The researcher used a Spirent GPS simulator to collect the data and the collected data was used to show outperform of traditional tracking methods by the new algorithms based on Kalman filter. The result shows that vector delay lock loop (VDLL) algorithm has the ability of rapidly reacquiring of signals after a temporary blockage of satellite. In this thesis, the VDLL was also combined with an inertial measurement unit (IMU) to make algorithm able to operate in blockage condition of satellite, which made the user applicable to access the GPS application fully even in the absence of satellites. The VDLL algorithm also has the ability to operate at lower carrier to noise power levels [15].

Komaragiri, Shalini Sushmitha, and Satish M. Mahajan (2009), adapted two different approaches- kalman filter and bad data rejection technique to improve the accuracy in measuring vertical error of sag. Thus different field tests were performed by using clusters of GPS maintained at some height difference for five different days, and then raw GPS data had been processed by using kalman filter and average filter after bad data rejection technique. Comparison of results obtained from these methods has been done. This paper summarizes that kalman filter reduces error up to ±9.8% where bad data rejection and filtering technique almost reduces the error less than ±5% except in one test [16].

Sabbi Babu Rao (2009) analysed the performance of the multipath delay estimation by using the Teager-Kaiser operator technique. For all this the simulation results were computed by designing and implementation of the GPS receiver channel. So the results showed that Teager-Kaiser technique performed extremely well for the rectangular pulse with the least computing complexity [3].

Cesar Barrios and Yuichi Motai (2011) used KF to estimate the future position of the vehicle. Many small models of KF were used to cover all possible position in which an automobile can be found 3s ahead. Inaccuracies in different possible states such as constant locations, velocity, acceleration, and constant jerks dealt with comprehensive Kalman filters (KFs). The KFs can be used as the part of interacting-multiple-model (IMM) system which provides the future prediction of location of automobile. Five core steps of IMM were described [18].

Qingsheng Kong, Shenglei Xu and Sang-sun Lee (2012) proposed an important method to use the PDOP (Position Dilution of Precision) easily obtained from the GPS data in order to estimate the measurement noise covariance of the Kalman filter. Briefly gave introduction of Kalman filter and Dilution of Precision (DOP). Proposed a novel method to use DOP in Kalman filter and display the experimental results and discuss how to estimate the R parameter with the use of PDOP. Concluded that the mean of Kalman distance is closer than the fixed distance and the variance of Kalman distance is much smaller than the Original distance. From the experimental results, clears that Kalman filter uses the PDOP as the measurement noise covariance gives much better than the KF not using it [19].

Xiali Li, Shaona Yu, Yuan Lin, Min Xi (2012) realized a model that a system can switch between the first-order kalman filter and second-order kalman filter. They proposed a testing method Expectation-maximum (EM) algorithm to estimate parameters in the model. Also the performance gain of algorithm was determined by using different kalman filter models. Experiments showed that the used algorithm can trace clock offset effectively. Based on Telos B platform, sensor experiment- it was observed that sensor clock system can switch between different models. A general clock synchronization algorithm described the clock oscillator drift based on the multi-model kalman filter .Two kinds of kalman filter models were discussed (i)If the aging rate is zero, the clock model is declared as a constant velocity model (ii)If the non-zero and constant aging rate, regarded the clock model is declared as an accelerated motion model. Assuming a white noise with tiny disturbance in one set, the multi-model kalman filter method gave smaller error in clock offset tracking compared to the simple first-order or second-order methods. The multi-model algorithm was divided into two phases: learning phase and tracking phase. Thus, the multi-model kalman filter algorithm based on EM testing had a good performance than first-order and second- order filter [20].

Joao Marcos Kanieski, Rafael Cardoso, Humberto Pinheiro (2013) based on optimum theory, and considered the effects of grid voltages, measurement noise and load currents transients a control algorithm was proposed. They also addressed possible frequency deviation of the fundamental frequency. The proposed algorithms give hints for the unbalance, harmonics and displacement power factor compensation. It is also helpful for predictive controller to implement in the predictive form. Moreover, to present high performance where line impedance was unknown, design for system using control scheme was proposed [21].

Tarek Abd El-Hamied Hassen El-Damaty (2013) focuses on errors in the ionosphere and system dynamics that doesnot considered in measurement process degrades the accuracy of GPS, thus kalman filter use a single frequency I-COM GP 22 hand held receiver certainly yields better results. Linearized equations and kinematic model were also discussed in this [22].

François Auger, Mickael Hilairet, Josep M. Guerrero, Eric Monmasson, Orlowska-Kowalska and Seiichiro Katsura (2013), provides review about Kalman filtering theory and overview of designed as a conclusion about Kalman Filter’s applications and implementations in five different topics of electronics industry community namely: first is, sensor less control, diagnosis, and fault-tolerant control of ac drives; second is, storage systems and distributed generation; third is, sensor fusion techniques and robotics vision; fourth is, applications in the felid of instrumentation and signal processing; and at last but not the least, the implementation of Kalman filter on real time in the industrial control systems. Introduces the implementation issues of Kalman filter and also highlighted all latest theoretical and the experimental advantages and issues of state estimation in practical filed. Author also described the application of extended Kalman filter and Kalman filter in the newly electrical concepts like storage systems and distributed generation [23].

Hua-Ming Qian, Wei Huang, and Biao Liu (2014) described the various errors like scale factor error, the misalignment and gyros errors of the star sensors and the star sensor delay which affects the calibration in estimation of attitude. A model with star sensor delay is constructed for the uncertain attitude estimation model and thus developed robust Kalman filter for uncertain estimated system, this indicates that the uncertainties appeared not only in the estimated state but it also affects the parameters of process noise. Furthermore, simulation and analyzing of the proposed filter showing its effectiveness have been demonstrated. They also proposed the robust kalman filter which is the best among all the new fuzzy filter designs and FIR filters. It is based on minimum variance theory. On the basis of some drawn conclusions and based on the theorems, the finite-horizon robust Kalman filter summarized in few steps [24].

CHAPTER 3

GPS (GLOBAL POSITONING SYSTEM) AND DSP TECHNIQUES

3.1 GPS Introduction

The NAVSTAR Global Positioning System (GPS) was first proposed by the Department of Defence (DoD) in 1970's. The main purpose to develop the GPS system is to feed accurate measurements of position, velocity, and time for ships at sea, aircrafts, and ground combat units for U.S. military. GPS system depends upon a constellation of 24 satellites arranged asymmetrically in six orbital planes around earth with an orbital plane slanted by 55 degrees with respect to the equatorial plane. Each satellite orbits around the earth once every 12 hours, echoing the same configuration and trajectory each time [25]. With the development of the GPS, now have the ability to determine accurate position everywhere in the world as it gives continuous and worldwide positioning capacity to users using the data transmitted by satellites in the form of GPS navigation message. The GPS system accurately measures the unknown location of a user on earth by using the fundamental principle of trilateration [26]. In trilateration, the system uses the position of the orbital satellites as reference positions and calculates the position of the unknown GPS receiver by using at least four orbital satellites. GPS receiver admits defined time-pulsed radio signals from each satellite and the following simultaneous equations are evaluated.

$$(X_{sk} - X_{rj}) + (Y_{sk} - Y_{rj}) + (Z_{sk} - Z_{rj}) = (R_k - dT)^2$$
$$k=1, 2, \ldots\ldots, n \quad n>=4 \qquad (3.1)$$

Where (X_{sk}, Y_{sk}, Z_{sk}) represent the position of the k^{th}satellite and (X_{rj}, Y_{rj}, Z_{rj}) represent the position of the j^{th} unknown receiver position,R_k is the range of the k^{th}satellite and dT is the unknown receiver clock bias converted into distance [25]. The out-come of the above equation gives an approximate value of the latitude and the longitude of the GPS receiver i.e. 'x' and 'y', altitude of this is 'z' and the measurement that was taken on time 't'.

It is all depend on the estimation of range from the user to multiple orbital satellites and time delay is multiplied, the time taken by GPS signal to travel from satellites to receiver by velocity of light. Three major functions positioning, velocity measurement, and time transfer are contained by transmitted radio atomic clocks signals of the satellites in all weather conditions and anywhere on the Earth when there is an unimpeded line of sight (LOS) to four or more GPS satellites. To evaluate the user's position by using the distance, receiver needed at least four satellites [1]. To calculate its accurate parameters of position these are longitude, latitude and altitude, the GPS receiver measures the distance to all the four differently separated GPS satellites.

The system was also equipped with a less accurate, civilian component that non-military users can use. The research was performed under the patronage of the U.S. Army Aviation and Missile Research, Development, and Engineering Centre (AMRDEC) on Redstone Arsenal in Huntsville, Alabama [27].

GPS's usage now a day's is increasing sharply due to individual user applications. The service Standard Positioning Service (SPS) can be used anywhere in the world, but Precise Positioning Service (PPS) is authenticated to authorized users only. Public transport now a day's uses GPS for navigation and receiving the navigation messages through control center [2]. The GPS satellites can provide the platform for many fields like atomic clocks, computers and for military projects and various equipment used to find position. The message is broadcasted by each satellite which is received by user device to recognize the position of that satellite in space.

3.2 Segments of GPS

The whole GPS system is expressed in three main segments: first is control segment, second is space segment and last is user segment.

3.2.1 Control Segment

The control segment contains five GPS earth stations. All predication of satellite's orbit and clocking status is collected by monitoring station and is used by control segment, making sure that all information remains in acceptable limits. All monitoring responsibility of GPS performance is hold by master control station. For monitoring and tracking the satellites, the ground antennas are used. Ground antennas are also used to transmit remedial information back to all satellites [28].

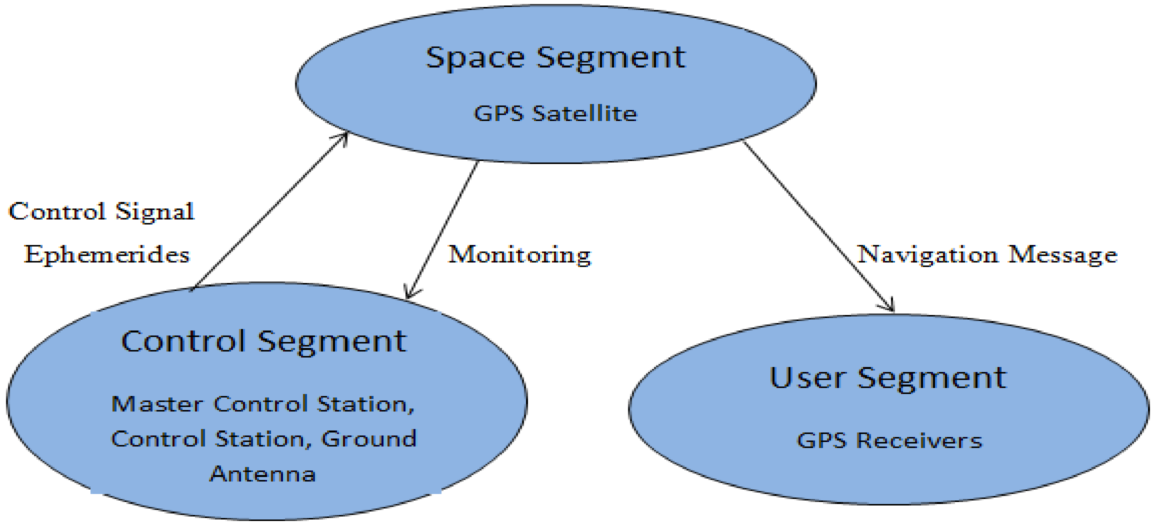


Figure 3.1 GPS Segments

The signal broadcasted by each satellite is received by four to five stations. The pseudo range parameters generated by each station for individual satellite can be used to compute in every 1.5 second and the reversed navigation message is transmitted to precise any error like the location and time of that particular satellite, since the accurate position of the particular station and its time coordinates are known. The master control station can calculates any position and clock errors for every satellite according to the information received from all the four or five monitor stations. If there is any error, master control station passes the particular instructions to all monitor station with the all information through ground antenna to deliver the appropriate accurate information back to that individual satellite [2,28]. The ephemeris data of individual satellite, position and timing errors are uploaded to each satellites once a day through the ground antennas even than if there is no error occurring.

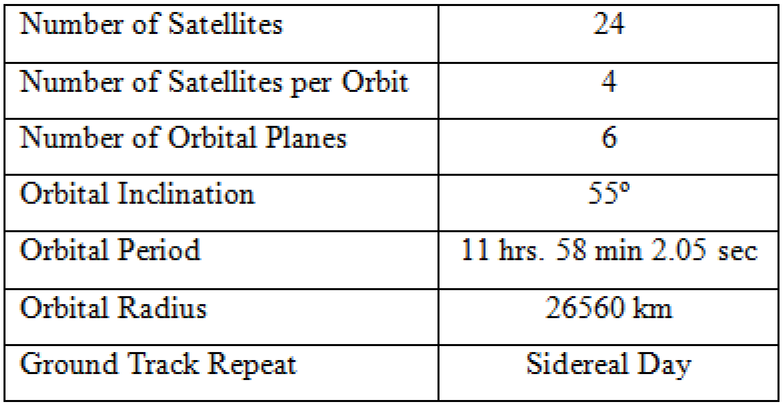
3.2.2 User Segment

The user segment subsists of the passive GPS receivers. The GPS receivers uses the signals transmitted from the all four or five satellites, together the absolute measurement of transmission delays of the signal to calculate the user velocity and position, as well as synchronize caesium clocks of satellite to that of GPS time [2]. The GPS is used in a radical range of military applications like as navigation tools for missiles to target the goal, it make the missiles a smart weapons [29]. While for civilian users, GPS technology is used in wide range of applications such as surveying as well as point-to-point navigation.

3.2.3 Space Segment

The space segment subsists of the GPS satellites and the Delta rockets that are used to launched the GPS satellites from Cape Canaveral, in Florida. An inclination angle of each orbit (the angle between the earth's equator and the actual orbit) is 55° to provide the coverage to polar region. The satellite orbit has a radius of 26,560 km. In one sidereal day, each satellite complete the orbit around the earth two times, that whole time for the earth is equal to one complete rotation of 360º. The mean sidereal day (23 hours, 56 minutes, and 4.09 seconds) is slightly shorter than the solar day (24 hours) by 3 minutes and 55.91 seconds [2]. The satellites are powered by solar cells while facing towards the sun for power and for transmission its antennas faces towards earth. Some of the characteristics of the GPS orbital satellites is in Table 3.1.

Table 3.1 Characteristics of GPS orbital Satellites



Number of Satellites	24
Number of Satellites per Orbit	4
Number of Orbital Planes	6
Orbital Inclination	55º
Orbital Period	11 hrs. 58 min 2.05 sec
Orbital Radius	26560 km
Ground Track Repeat	Sidereal Day

However, there are four satellites in each orbit but they are not equally spaced. Where two satellites are spaced by 30.0° - 32.1°, and the remaining two are 92.38°-130.98° away from the first two satellites and they are between themselves. By this spacing between satellites minimizes the effects of a satellite failure on system decline [30]. The spacing also made that sure a minimum five satellites must be in view to GPS receiver and capable of receiving signals from maximum of 12 GPS satellites. Atomic clocks are used in each satellite to broadcast signal within accurate four to three nanoseconds and are synchronized with other satellites.

3.3 Positioning Services of GPS

There are two types of services that GPS provide. These are the Precise Positioning Service (PSP) and Standard Positioning Service (SPS) as:

1. Standard Positioning Service (SPS)

The SPS provides the positioning as well as timing services. This type of service can be used by any user in all over the world. SPS is available on the L1 frequency of GPS which is modulated with a navigation data message and a coarse acquisition (C/A) code. SPS has the accuracy of 95% in predication of position around 100 meters and 156 meters in horizontally and vertically respectively. The time transfer accuracy is also 95% to UTC i.e. within 340 nanoseconds [2, 31].

2. Precise Positioning Service (PPS)

The PPS is the military positioning and is more accurate than SPS. It provides the velocity and timing service all time in worldwide. The PPS has accuracy in positioning is 95% i.e. 22 meters and 27.7 meters in horizontally and vertically respectively. The time transfer accuracy is also 95% to UTC i.e. within 200 nanoseconds [31]. The PPS service is available on both L1 and L2 frequencies of GPS system [2].

The inaccuracy of the time in the L1 frequency signal broadcast by the satellite is termed as Selective Availability (SA). SA is a slowly varying error for each satellite. It means transmitted message by satellite about positions does not give the actual positions. This inaccuracy of the position is about 50 – 150 m. Selective availability (SA) is the only largest source of C/A-code error. To remove SA error Y-code are available for GPS receivers with all knowledge about SA algorithm. SA occurs mostly in the Standard Positioning System [2, 30].

3.4 GPS Carrier Signal

The broadcast of GPS satellite takes place at two different centre frequencies. One is link 1 (L1) frequency i.e. approximately 1575.42 MHz and other frequency is the link 2 (L2) which is roughly 1227.6 MHz. The exact frequencies of L1 and L2 are shown in Equation (3.2).

$$L1 = 154 \cdot 10.23 \text{ MHz}, \quad L2 = 120 \cdot 10.23 \text{ MHz} \tag{3.2}$$

The both frequencies (L1 and L2) are multiples of 10.23 MHz frequency of master clock. The values of L1 and L2 frequencies are partially different from their mentioned values. The ionospheric effects can compensate the problem of dual frequency users [1].

The Equation (3.3), is the broadcast L1 signal by i^{th} satellite. Equation shows the composition of an quadrature and in-phase component [4].

$$S_{L1_i} = \sqrt{2P_c}\, G_i(t)D_i(t)\cos(\omega_1 t + \emptyset) + \sqrt{2P_{p,L1}}\, P_i(t)D_i(t)\sin(\omega_1 t + \emptyset) \tag{3.3}$$

where S_{L1_i} is the signal at L1 frequency, P_c and $P_{p,L1}$ is power of the in-phase and quadrature components respectively. Both these components contained a PRN sequence, sinusoidal carriers and the navigation data message. PRN sequence is also known as Gold code. The in-phase component of the L1 signal is modulated with the data message $D_i(t)$ = ±1, Coarse/Acquisition (C/A) and Gold code $G_i(t)$ = ±1 of the satellite. The quadrature component is modulated with Precision (P) Gold code $P_i(t)$ = ±1 and the same data message as in the in-phase component [30]. The each satellite has specific P code, C/A code, and data message. The power P_p of the quadrature component is 3 dB less than the power of the in-phase component, P_c [1]. For infrequent phase shift on the L1 carrier, 1540 carrier cycles per C/A code and 154 carrier cycles per $P_i(t)$ code chip are used [3]. How the L1 frequency signal is generated is shown in block diagram, figure (3.2)

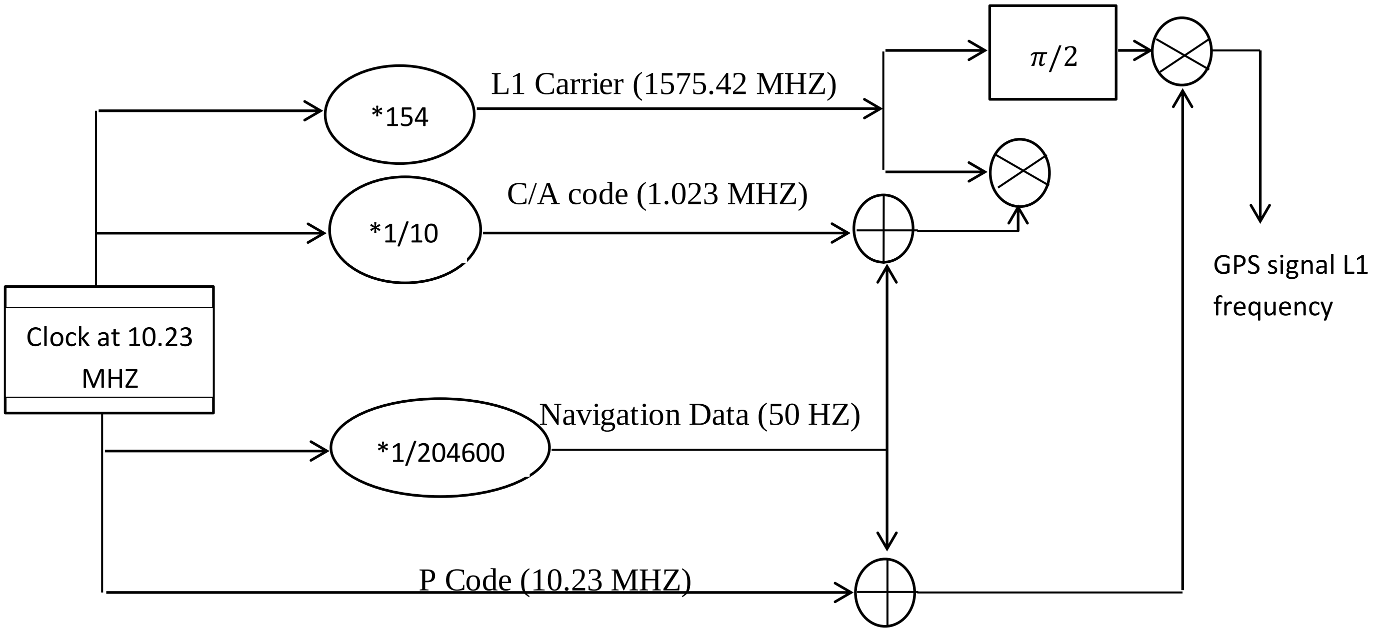


Figure 3.2: Generation of L1 Frequency Signal

Similarly L2 signal is modulated same as L1 signal with same data message, but difference is that L2 signal is modulated either by P or C/A code [15], as shown in Equation (3.4).

$$S_{L2i} = \sqrt{2P_{p,L2}}\, P_i(t)D_i(t)\cos(\omega_2 t + \emptyset) \tag{3.4}$$

Know a days, the L2 signal is modulated by P-code and 120 carrier cycles per P(Y) code chip are used, so that phase shift on the L2 carrier are comparably infrequent. Table 3.2 shows characteristics of GPS signal structure on L1 and L2. Since access to the P-code is proprietary, it was not available during the writing of this thesis. Consequently, P-code and the L2 signal will not be discussed further.

Table 3.2: Characteristics of PRN codes

Parameters	C/A Code	P Code
Chipping rate	1.023×10^6 bits per second	10.23×10^6bits per second
Chip Length	≈ 300m	≈ 30m
Repetition Rate	1 Millisecond	One week
Properties	Easy to acquire	More accurate

3.5 Navigation Data Message

The navigation data message transmitted at 50 bit-per-second (bps) by each satellite contains information about the C/A and P codes, satellite's orbit health, GPS system time, and recorded data from other satellites in its constellation. The data message has been decoded from the transmitting satellite, once the receiver has matched C/A and P codes to the code of that satellite. Thirty data bits wide word make up one word which is 600 ms (milli-second) long. Ten words create a sub-frame of 6 seconds and a page of data is created from 5 sub-frames which is 30 s (second) long [15]. Figure 3.3 shows how the navigation message is arranged. A frame constitutes by five sub-frames. The first three sub-frames of a frame contain ephemeris and clock information from the transmitting satellite and used to calculate position. Sub-frames fourth and fifth alternately provide ionosphere model correction data, almanac and health status data of satellites [32]. The information about the satellite's orbit is called satellite ephemeris data. The satellite's position is calculated by using this ephemeris data. The almanac is not as accurate as the ephemeris data in sub-frames 2 and 3, but is valid for a longer period of time [30].

The navigation data message empowers the user to calculate the accurate position of the transmitting satellite. With the help of navigation message transmitted from one satellite, the position of other satellites can also be calculated. The signal received by the GPS user device must extract the navigation data, carrier frequency and PRN code phases to calculate the user position. Theoretically, only 18 second GPS data is necessary to calculate the position. However, due to different time arrival of the sub-frames from different GPS satellite and Doppler shift, the receiver takes more time than actual theoretical value. So to calculate the position properly, the minimum data of 30 seconds is needed [30].

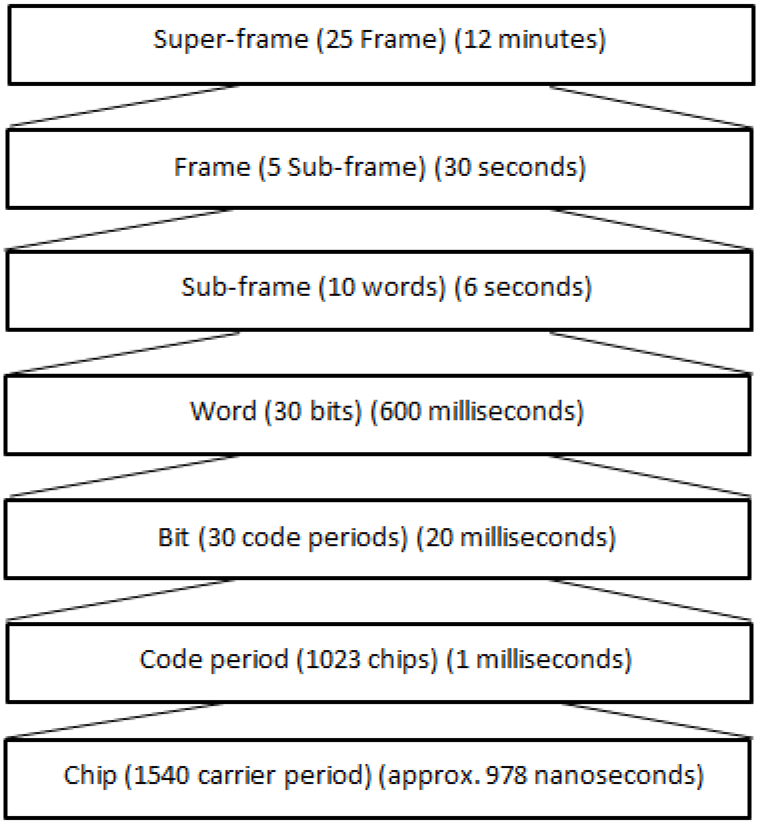


Figure 3.3: Arrangement of Navigation Message

3.6 Software GPS Receiver

In a traditional GPS receiver, the tracking and acquisition of the signals are treated through the hardware. However, for software GPS receiver, these signals are converted into digital form by using analog-to-digital converter (ADC). The software GPS receivers are more flexible due to their hardware independence. The front-end part of software receiver is not the software part, which provides all advantages of traditional GPS receivers also. Software receiver has various advantages over traditional receivers. One is due to software receivers, the nonlinear and temperature-dependency of hardware components is removed. Other advantages are it provides testing flexibility and an active simulation environment i.e. to solve different problems like jamming signals of GPS system can be removed by developing new algorithms, without modifying hardware components [2].

The software GPS receiver contains RF front-end and ADC converter mainly. Front-end of receiver is necessary to convert GPS signal into an intermediate frequency (IF). The transmitted RF signals of satellites are received by right hand circularly polarized (RHCP) antennas. Then the received RF signal passes through preamplifier, which contains filter, a low noise amplifier (LNA) and burnout protection [33]. The low noise preamplifier (LNA) is set with low noise figure of the GPS receiver. The amplified RF signal is then passes through down converter to convert signal into IF using Local oscillator (LO). At down convertor GPS signal L1 broadcasted by satellites at frequency of 1.57542 GHz is converted into 4.1304 MHz IF frequency after mixing with local oscillator's frequency [15].

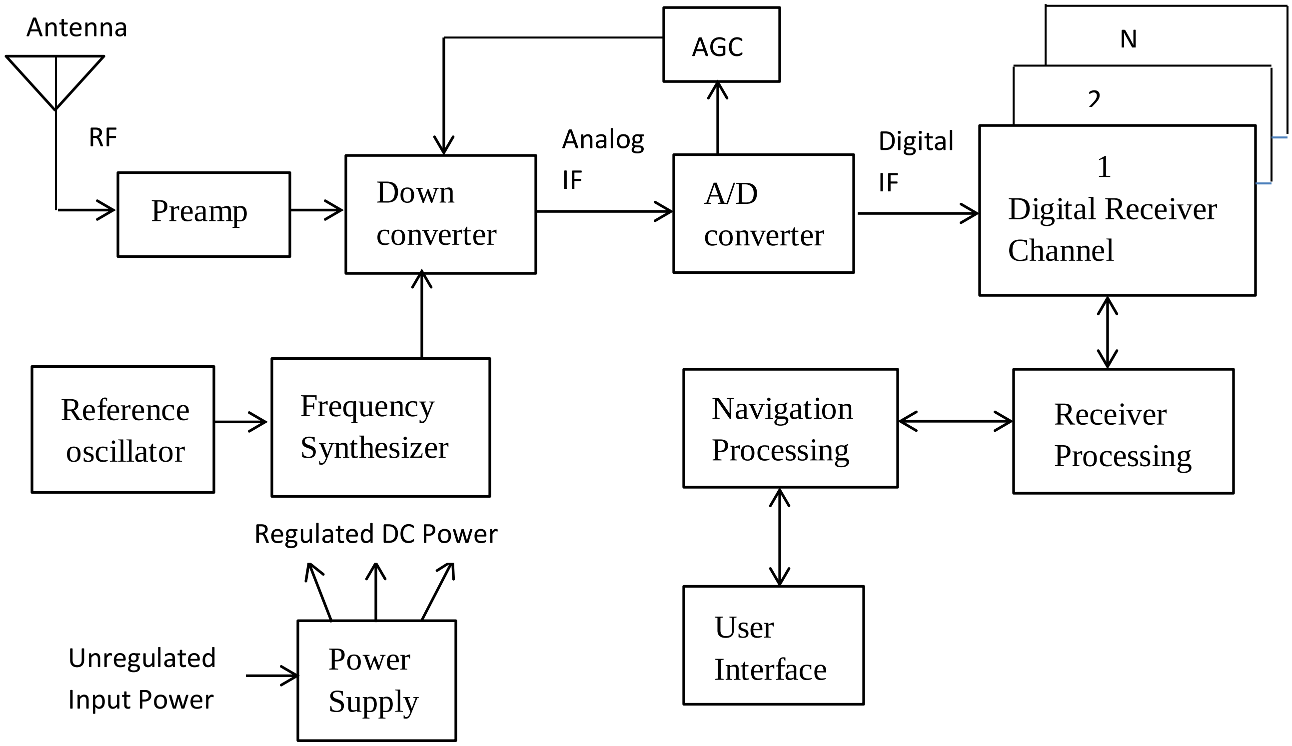


Figure 3.4: Block Diagram of GPS Receiver

The reference oscillator provides the reference frequency to the frequency synthesizer to produce inter mediate frequency (IF). The A/D conversion and automatic gain control (AGC) processes take place at this IF. Then ADC converts the analog IF into digital form. At this point digital IF is processed by different number of digital receiver channel like ASIC or FPGA [3]. Software GPS receiver does not need any demodulation of received signal, only A/D converter and signal gain are needed. So to extract the navigation information from the digital signal, the signal passes through the tracking and acquisition processes implemented in receiver software. Finally, that extracted ephemeris data is used to calculate the user position.

3.7 Errors Sources in GPS:

GPS receiver works excellent in open and clean environment without any obstructions, but they are start giving error in position when receiver is blocked to accept broadcast signals from viewed satellites. This occurs many in urban areas. As already described GPS systems needs at least four or five satellites visible to find accurate position. The main source of blocking is tall buildings, high mountains, tunnels and common foliage. The range of GPS errors is typically 100 ft. or more. The noise that produced from interference from some electronic or other thing present near the receiver can also produce an error i.e. about 1 to 10 meters. Sometimes atmospheric phenomena like clouds and rain between the receiver and satellite can be the reason for error, other objects such as buildings or mountains can also produce some error i.e. about 30 meters. The impulsive loss of GPS satellites will put negatively impact on accuracy [25, 34].

The positioning data transmitted by the orbital satellites are affected by a several types of error sources before the transmitted data is fetched into a GPS receiver's position and time solution [31]. The accuracy of GPS can be affected by a various factors i.e. noise in the transmitted signal, atmospheric conditions, satellite positions and natural barriers to the signal. Some of the GPS error sources are discussed in detail as follows:

- **Tropospheric Delays**

  Tropospheric layer of atmosphere is usually has variations in temperature, humidity and pressure and this all lead to delay in GPS signal. Both the code and carrier will have the same delays. Some models are developed to determine the tropospheric error by using receiver height and elevation angle of satellite. The delay introduced by an un-modeled receiver at lowest elevation angle is 100 nanoseconds but typically it is more i.e. 30 nanosecond [31, 8].

- **Multipath**

  In multipath, the desired satellite signal is mixed with the local reflections of signal which causes error. The multipath effect is more noticeable in case of static receivers when they are near the high reflecting surface; in this case the error is about 15 m or more [8]. The multipath error can be reduced by combining both antenna location and antenna cut-off angle as main factors. Another approach to reduce the impact of multipath on accuracy is correlate approach in GPS receivers. This approach reduced the error of one to two nanoseconds for GPS receivers for aircrafts in flight. For land-based systems, exact antenna position and local conditions can result in multipath errors maximum of 150 nanoseconds. Apparent error for land-based receivers is 30 nanosecond (ns)[31]. So the important factors to consider are antenna design, antenna position, and the materials that can absorb GPS signal to reduce such multipath interferences. It is very difficult or we can say impossible to eliminate the multipath errors completely from many applications.

- **Ephemeris Errors**

  Ephemeris errors are miscalculation of satellites broadcasted location to other neighboring satellites, due to this reason this type of error is also called Orbital errors. So ephemeris errors occur, GPS receiver does not get the correct position of satellite [35].

- **Satellite Clock Errors**

  The synchronization of satellite clock and receiver is necessary but due to inaccuracy of GPS satellite clock this type of occur. Atomic clocks are more accurate than the in-built clock of GPS satellite. So this error is very small. All ground stations and user receivers' measure same amount of satellite clock error. The satellites have atomic clocks those have an accuracy of 1 part in 10^{11}. But the GPS receivers uses crystal oscillator with an accuracy of 1 part in 10^{5}[36]. The atomic clocks are measured time against standard time in GPS control stations in all over the world. The GPS receiver clocks have to be equivalent to the satellite clocks. Therefore when the time delay is calculated, than there will be error due to clocks mismatch[31].

- **Ionospheric Delays**

  As the GPS signals has to pass through the atmospheric layer of the Earth. There is one layer called ionosphere layer, which contains free electrons and charged ions. Due to these ions the signal does not travel at the vacuum speed of light [31]. The GPS system uses average value of delay, by this partially amount of error is corrected [8]. The ionosphere layer is dense and thick layer (50 to 500 kilometers), so it slow down the GPS signals by 300 nanoseconds which create the error of 100meters [35]. The everyday change in the ionosphere layer causes the large variation in time delay. At night-time the delay in signal is minimum and is maximum at day-time because ionosphere layer is the thinner and the less dense during night and thicker (more dense) during the day. The GPS satellite signal will experience maximum delay when the signal pass through layer at lowest elevation angles w.r.t. the local horizon because signal travel large distance in ionosphere layer and it occur when the satellite is directly overhead. Use of L1 and L2 signals with the P- codes or signal squaring codeless techniques can reduce the ionospheric error and the GPS receiver calculate the time delay by computing the phase difference between the P-codes carried by the L1 and L2 frequencies. These two frequencies results in a considerable reduction in ionospheric error [31].

- **GPS Signal Noise**

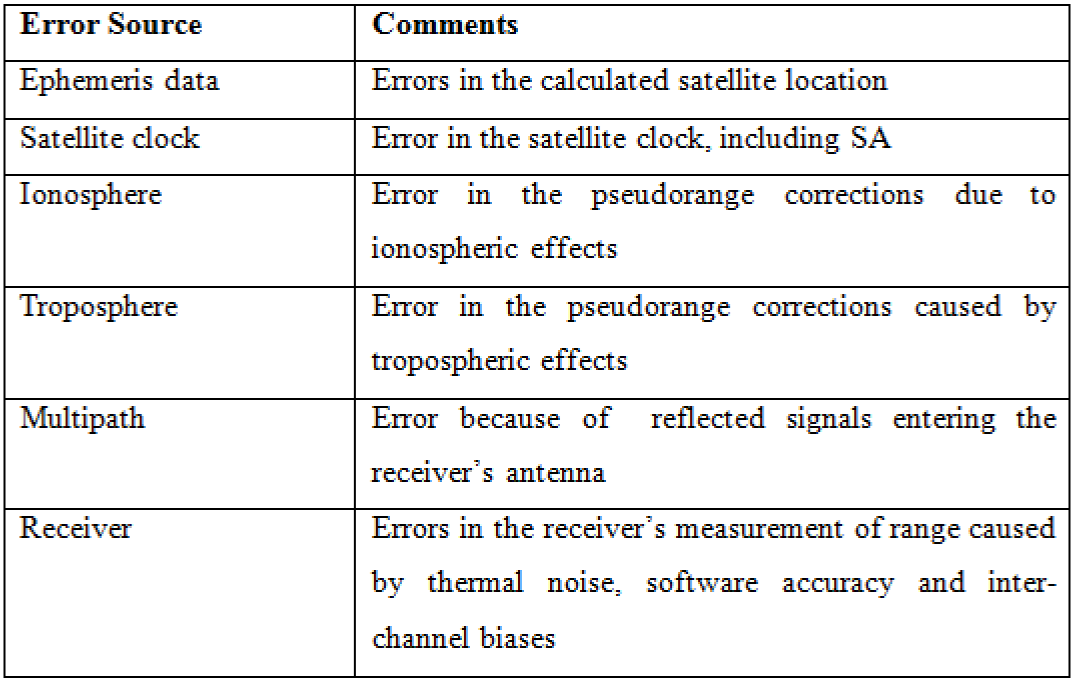
  When the GPS signals propagated from GPS Satellite to receiver, the signal become mix with noise from cosmic sources and interference with other GPS signals which causes zero bias errors in the position measurement of 3 nanoseconds [31]

- **Receiver Noise**

  Receiver noise gives the error in the receiver measurement of position due to, software accuracy, inter-channel biases and thermal noise. Receiver noise can introduce two to three nanoseconds of error in timing measurements of receiver. The error within a GPS receiver can be improved by the manufacturer. But there is error occur due to temperature change in GPS receivers [31].

There are several ways to remove these errors. One way is the comparison of a GPS calculated position with that of a known surveyed position [16]. By this, a difference of these two positions is generated which is then used as error corrector. This concept is called differential GPS(DGPS)

Table 3.3 Brief Description of GPS Inherent Error Sources



Error Source	**Comments**
Ephemeris data	Errors in the calculated satellite location
Satellite clock	Error in the satellite clock, including SA
Ionosphere	Error in the pseudorange corrections due to ionospheric effects
Troposphere	Error in the pseudorange corrections caused by tropospheric effects
Multipath	Error because of reflected signals entering the receiver's antenna
Receiver	Errors in the receiver's measurement of range caused by thermal noise, software accuracy and inter-channel biases

and it's technology is further entitled as "direct DGPS" depending on the calculation of the final result of position and "inverse DGPS" where the migrant remote station is used to find final result [34]. More recently, new recommendations have been added i.e. an additional frequency is need to be add in the GPS system to improve the accuracy of GPS applications for civilians. DGPS operation greatly compensates the errors that are occurring commonly to all local GPS receivers that in use. There are many applications of DGPS, including emergency tracking, agriculture, dispatching management and offshore exploration [25]. However, as the distance between the surveyed receiver and the base receiver increases the accuracy of DGPS decreases. Another major drawback is that the additional receiver is need and the DGPS system faces more complexity in establishing communication link between the rover and the base to transfer differential correction information.

3.8 Digital Processing Techniques

3.8.1 Kalman Filter

The term "Kalman filter" was motivated by Rudolf Emil Kalman in 1960 and 1961. The Kalman filter is based on the linear model stochastic estimation. It is a mathematical toolbox and recursive algorithm. The term recursive means, there is no need of all previous data for the estimation of sate [37]. Since the time kalman filter has been the subject of extensive research and application. Kalman Filter is one of the most important algorithms for state estimation. Kalman filter is a mathematical toolbox means it solves the problem by using mathematical equations. Its main aim is to produce results that tend to be closer to the actual values taken from observed measurement that contains noise. It is an optimal recursive filter, optimal in a sense it minimizes the estimated error covariance and is recursive as it does not require to save all the previous values to estimate the next stage, but it needs just previous value at (k-1) time instant to estimate the current value at k^{th} time instant[16][38]. Kalman filter is a learning tool.

The key features of Kalman Filter:

1. Recursive:- Estimates are updated upon receipt of each measurement. No need to save past data.
2. Kalman filter has linear model:- based on linear mean square error filtering.
3. Kalman filter creates its own error analysis.
4. Kalman filters are easily reconfigured to handle wild data points and model changes.
5. Kalman filter operates in vector/matrix format i.e. the concepts and operations are independent of number of states.

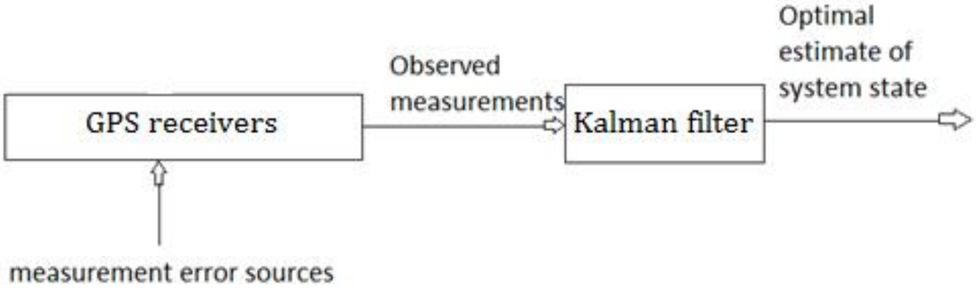


Figure 3.5: Application of Kalman filter

Inputs such as known control and measurement containing noise, biases and device inaccuracies is given to the system and this filter is a way of extracting valuable information from a noisy environment. There could be a number of various measuring devices, all having its own particular dynamics and error characteristics, that provide some information about a particular variable, and it would be required to combine their outputs in a systematic and optimal way [31].

It receives one input measurement (z_k) and returns only one output estimate $(\hat{x}_k)$. The Kalman filter works in a cycle of two distinct phases:

- The Predication
- The Correction

Time update based on the just last position also known as prediction step or prior estimated state is responsible for projecting forward the previous prior estimation value to obtain estimation of prior current state and measurement update also known as correction step is responsible to obtain posterior estimate. In measurement update phase, the current prior prediction is combined with current observation information to refine the state estimate. This improved estimate is termed as a posterior state estimate. This phase works in three steps first task is to compute kalman gain, secondly update the state estimated value and then compute the posterior estimated value of state. At completion of each cycle, the new posterior value is taken as the previous estimated prior value for estimation of current prior value in next cycle [39, 37, 11]. The procedure is repeated again and again with the state estimated at the previous time instant. It provides estimation of state error covariance recursively.

Kalman filter solve the problem by using stochastic difference equation:

$$x_k = \mathrm{A}x_{k-1} + \mathrm{B}u_K + w_k \tag{3.5}$$

$$z_k = Cx_k + v_k \tag{3.6}$$

w_k and v_k are the random variables which represents the process noise and measurement noise respectively. In this case, they are assumed to be mutually independent and zero mean white noise [3,26]. Covariance of v_k and w_k is given as:

$$\mathrm{E}[w_k {w_k}^t] = Q \tag{3.7}$$

$$\mathrm{E}[v_k {v_k}^t] = \mathrm{R} \tag{3.8}$$

Kalman filter is a minimum mean square error evaluator. The posterior state estimator error value is evaluated by: $E(x_k - \hat{x}^+{}_k)$.

3.8.2 Derivation of Kalman Filter

The priori state estimation is represented by the super minus; which gives the knowledge about the process is prior state of step *k*, and gives the measurement for our posteriori state estimation for step *k* [7]. Then the measurement of priori and posteriori estimation errors is done .The priori estimation error covariance is given by:

$$P_K = E(e_k \, {e_k}^T) \tag{3.9}$$

To drive the Kalman filter equations, the goal should be to calculate posteriori state estimation $\hat{x}_k$ as the linear combination of priori state $\hat{x}^-{}_k$. The equation 3.10 gives the difference of actual a measurement prediction $\hat{x}^-{}_k H_K$ and measurement z_k shown below in:

$$\hat{x}_k = \hat{x}^-{}_k + K(\, z_k - \hat{x}^-{}_k H_K) \tag{3.10}$$

This difference is called the residual or measurement innovation. The residual gives the knowledge of discrepancy between the actual measurement and predicted measurement. When these two are equal in value then residual will be zero or we can say these two are completely agreement with each other [7].

The variable *K* in (3.10) is n×m matrix and it is called the kalman gain. It is used to reduce the posterior error covariance (3.9). This reduction can be polished by substituting equation (3.8) into (3.9) the definition for e_k and calculating the indicated expectations, further taking derivative of the result with respect to *K* and keeping this result equal to zero, then solve the equation for *K*. One way of minimizes error covariance is given by equation (3.11) of *K*.

$$K_k = P_k^- H^T (H P_k^- H^T + R)^{-1} \tag{3.11}$$

After observing equation (3.11), we can say that the measurement error covariance R_k and priori error covariance P_k^- are approaching towards zero and the kalman gain *K* makes the residual more and less heavy respectively [7].

$$\lim_{R_k \to 0} K_k = H_k^{-1} . \tag{3.12}$$

$$\lim_{P_k^- \to 0} K_k = 0 . \tag{3.13}$$

3.8.3 Observability

Kalman filter works correctly under the necessary condition that is system under which states has to be estimated should be observable. Therefore, it is a required step to check observability of the system before applying the Kalman Filter. There may still be other problems like faulty or inaccurate mathematical Model that prevent the Kalman Filter from producing accurate state estimates. Observability for the discrete-time systems can be defined as follows:

The discrete-time system

$$x(k+1) = Ax(k) + Bu(k) \tag{3.14}$$

$$y(k) = Cx(k) + Du(k) \tag{3.15}$$

System is said to be observable if there is a finite number of input sequence u(0), . . . , u(k − 1) of time steps k, and the knowledge about the initial state of the system x(0), is given by output sequence y(0), . . . , y(k − 1).

Kalman filter works very well for estimation for estimation of past, present and even future states. In a standard Kalman filter, all the system characteristics (i.e. the system model, initial conditions, and noise characteristics) have to be specified a priori. However, if there is any uncertainty in the characteristics, the filter may not be robust enough. The basic models of kalman filter are state vector, dynamic model and observation model [3].

3.8.4 State Model of Kalman Filter

Some of the interested variables are contained in state vector. It represents the degrees of freedom and also describes the state of the dynamic system and is also responsible to represents its degrees of freedom. The variables in the state vector can be obtained from the measurable values in the state vector but they cannot be measured directly. Orientation angles, velocity, position etc. are the various elements of the state vector. There is a simple example in which a car is moving with constant velocity on single straight road and has two degree of freedom, so the distance s and the velocity s = v are sate variables [11], hence state vector is,

$$X = \begin{bmatrix} s \\ v \end{bmatrix},$$

State vector shows two different values at same time i.e. prior and posteriori values. The prior is the value that is predicted before the update and is represented by x^-. The posteriori value is correct value after update and is represent by x^+.

3.8.5 Dynamic Model

The transformation of the state vector with time is described by dynamic model [11]. Dynamic model can be expressed by the differential equations:

$$\mathrm{x}^-(t) = \frac{d}{dt}x(t) = f(x(t), m(t)) \tag{3.16}$$

In case of linear, this can be easily rewritten as:

$$\mathrm{x}^-(t) = F.x(t) + n(t) \tag{3.17}$$

F is constant and a dynamic matrix, $n(t)$ represent dynamic model which is affected with white noise and has covariance matrix '$Q(t)$'. Where '$x(t)$' is state vector. There are some systems that cannot be modeled by differential equations, but they are not discussed in this thesis.

3.8.6 Observation Model

The observational model defines the relationship between state and measurements, which depends upon the variables of state [11]. Mostly the observations are made at the discrete time steps t_i

$$l(t_i) = h(x(t_i), v(t_i)) \tag{3.18}$$

The vector form of observation model is:

$$l(t_i) = H.x(t_i) + w(t_i) \tag{3.19}$$

Here $l(t_i)$ is observation vector at time (t_i), H is the observation matrix and $w(t_i)$ is the measurement noise with the noise covariance matrix $R(t_i)$.

3.8.7 Kalman Filter Algorithm

Kalman filter is an algorithm made from mathematical models. Kalman filter is the complete statistical classifications of estimation problem [33].

The Kalman Filter is the state estimator and it produces an excellent estimate. It means that the mean value of summed value of all linear combinations of the estimation errors is minimum value. So the minimal value of sum of squared errors is given by kalman filter.

$$E\left[e_x{}^{T}(k)e_x(k)\right] = E[e_{x1}{}^{2} + e_{x2}{}^{2} + \dots\dots\dots\dots + e_{xn}{}^{2}(k)] \tag{3.20}$$

$$e_x(k) = \mathrm{x}_{est}(k) - x(k). \tag{3.21}$$

Equation 3.21 gives the estimation error. Due to this the kalman filter is also known as "least mean-square estimate". It is assumed that the model is linear, so it is not applicable for nonlinear models. It is assumed that the system is affect with noise so the state of estimation is affected with random noise called process noise and the measurements of Kalman filter contains random white noise called measurement noise. The Kalman Filter algorithm is really fruit-full for the systems model of linear state space. But, in many applications the systems has nonlinear model.

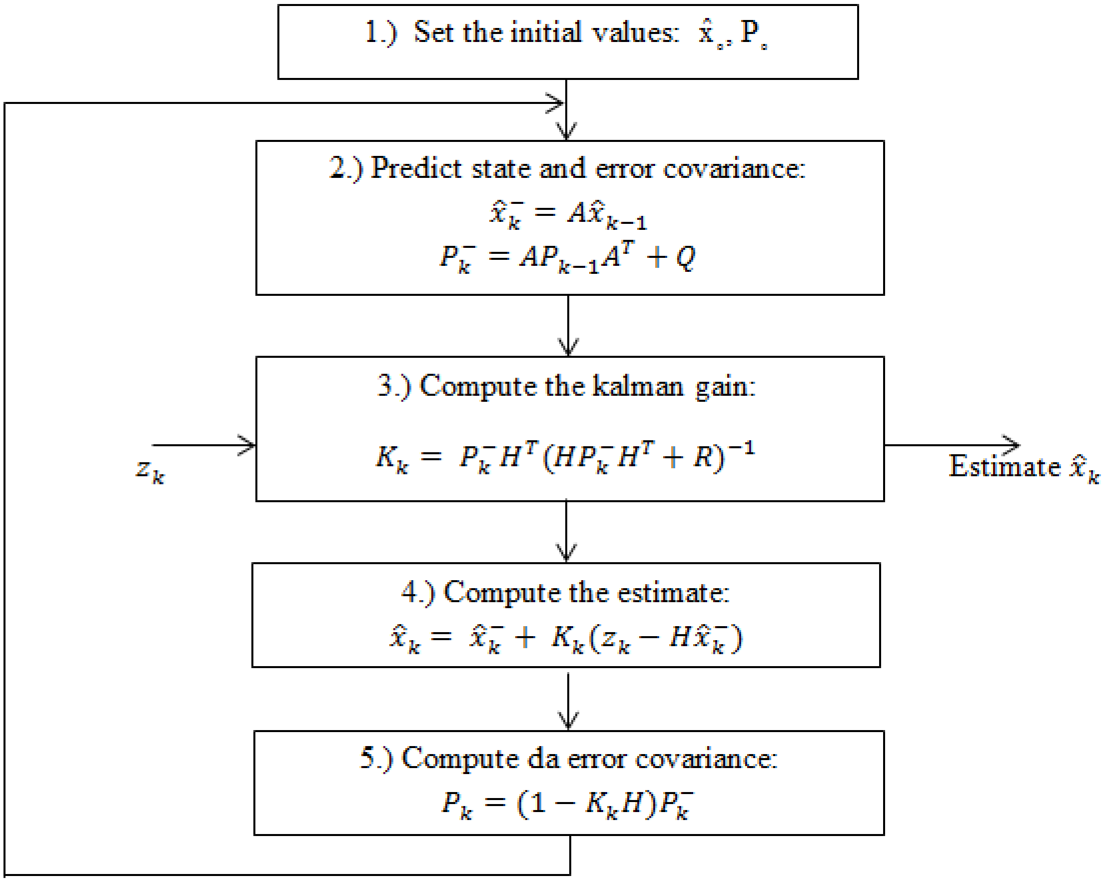


Figure 3.6: Steps of Kalman filter algorithm.

Whole schematic process for Kalman filter is laid out in a flow diagram (figure 3.7). Although it bears the name 'filter,' Kalman filter would rather considered as a computer algorithm [28]. Kalman filter algorithm has four steps described as follow:

- The first step of algorithm is for prediction. $\hat{x}_k^-$ and P_k^- are two variables which are computed in this step and will be used from step 2 to step 4. The predicted value are represented by superscript '-'.
- In Step II, the kalman gain is to be calculated in this by using the variable P_k^-, which is calculated in step 1. The values of R and H are preset values outside Kalman filter.
- In Step III, an estimated value is calculated from measurement values given as input, these are Kalman gain (K_k) and H .
- In Step IV, error covariance is calculated and the decision of use or discard the computed estimate in previous steps. Error covariance gives the indicating of how much the estimate value is accurate.
- So the cycle of predicting and correcting performed again and again to give the better estimated state. The time update represents the current state estimate and the measurement update takes near to the goaled estimate by estimating.

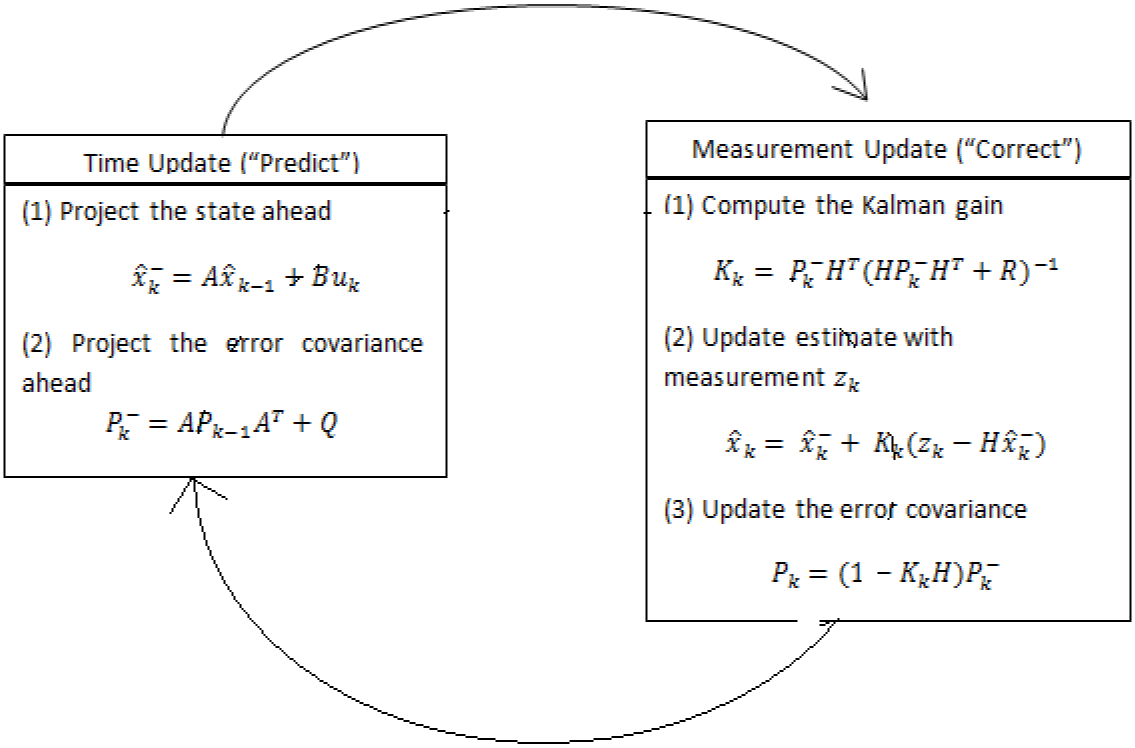


Figure 3.7 Working Cycle of Kalman Filter

Where

$\hat{x}_k^-$ = Priori estimated state at k time instant;

$\hat{x}^+_k$ = posterior estimated state at k time instant,

P^-_K = prior error covariance at k time instant,

A = Matrix that relates the state at the previous time step to the state at the current step in the absence of process noise.

B = Optional control input ‘u’ to the state x.

U = Control input;

P = Error covariance;

Q = Process noise covariance;

K = Kalman filter gain;

R = Measurement noise covariance;

H = Matrix that relates state to the measurement.

3.8.8 Estimation of Parameters

A, B and C are matrices of an appropriate dimensions. Both the Kalman gain and estimation error covariance will stabilize quickly in exponentially and then become constant. To begin with, the value of Z is taken to be equal to the actual height difference between two GPS receivers. We then simulated distinct measurements. R is the square of the standard deviation of raw GPS measurement data. The state of GPS is static in all the steps so A=1, U is taken as 0 as there is no control input [16]; Q = 0.00005 assuming to be as small as possible but non-zero. By this it gives us wide area to tune the filter [40]. The value of P is chosen such that error covariance converges. The Kalman gain will be smaller, if a posterior error covariance is low [41].

Our time update equations are:

$$\hat{x}^-_{k+1} = \hat{x}_k \tag{3.22(a)}$$

$$P^-_{K+1} = P_K + \mathrm{Q}. \tag{3.22(b)}$$

$$K_K = P^-_K (P^-_K + \mathrm{R})^{-1} \tag{3.22(c)}$$

$$\hat{x}_k = \hat{x}^-_k + \mathrm{K}\,(Z_K - \hat{x}^-_k) \tag{3.22(d)}$$

$$P_k = (1 - K_k) P^-_K \tag{3.22(e)}$$

3.9 Bad Data Identification Modification (BDIM)

The presence of bad data may be due to momentary loss of satellites, signal reflections ambient noise may degrade GPS accuracy. Thus in order to improve the accuracy it is important to remove the bad data. Bad data is recognized by identify data which differ mean value of altitude by preset tolerance value $(k * \sigma_z)$ [16]. Where σ: standard deviation values of z as it is measured by the moving window of T width. The bad data has been either replaced by the window mean. The value of k is taken to obtain proper rejection rate [17].

CHAPTER 4

EXPERIMENTAL SET UP

4.1 Introduction

In this chapter software and tools which have been used for experimental setup are mentioned. This chapter also explains the methodology used to carry out this study.

4.2 Experimental Set Up

Recent advances in GPS technology and data software has been effectively used in various areas such as military, agriculture, navigation, mapping and surveying etc. due to recent advancement in GPS technology and data software.

The following figure shows experimental basic set up.

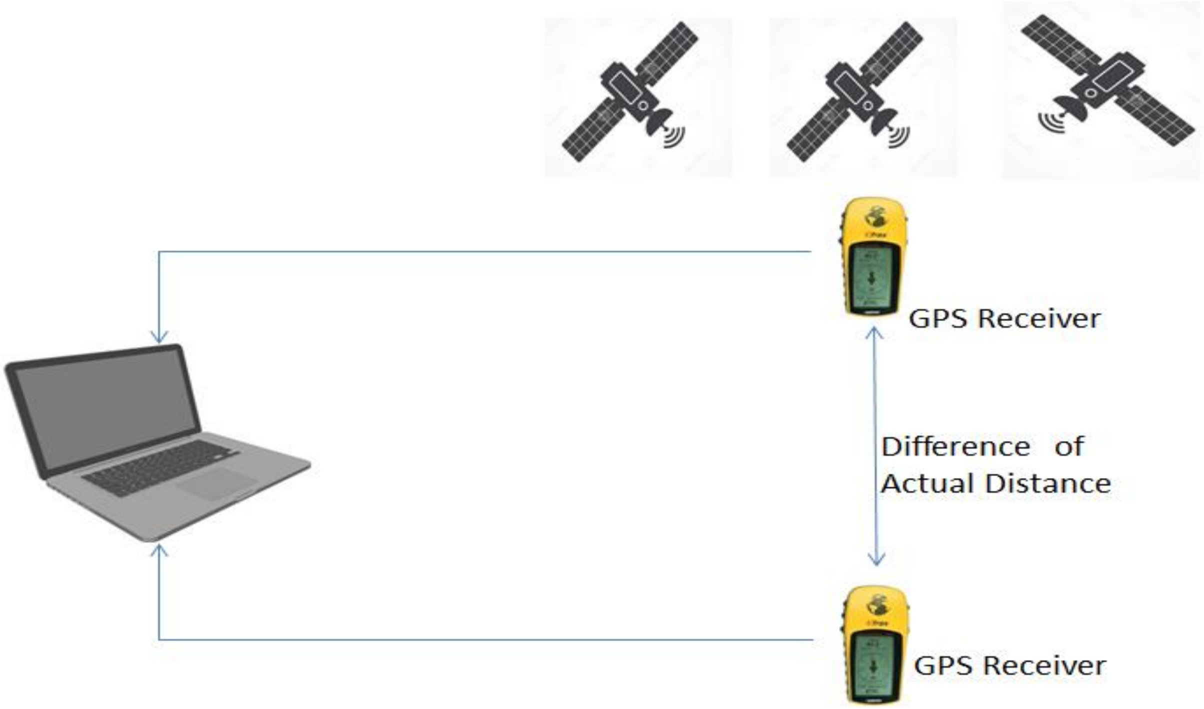


Figure 4.1: Basic experimental set up

In the basic configuration, two handheld GPS receivers are used which are connected to the laptop via Bluetooth link. The two GPS receivers are placed at different heights, one at the higher with respect to other placed at the ground plane, having some static difference. The real time data (information) is in the NMEA format. This data includes position, velocity, time calculated from GPS receiver. GPS receivers provide data at rate of one reading per second. Digital processing technique process collected data from BT359 GPS receiver at every second. The GPS height difference was calculated by taking difference of data taken from GPS receivers placed at different altitude. The error may be calculated by comparing original (actual) height with measured height using GPS. Also the actual height difference has been measured physically for estimation of error. The GPS data has been collected for approximately 250 sec. The two cases has been considered for error estimation of GPS height measurements in real time as shown in table 4.1

Table 4.1: Case studies

Cases	Location	Actual height difference
1	Girls Hostel-I	11m
2	Girls Hostel-E	8m

4.3 Logging of GPS Data

In this study to improve the accuracy of GPS attitude measurement is divided into 4 stages: GPS receivers:BT-GPS-35D829, BT-GPS-35DB80, NMEA\visual GPS logger software, Log file of raw GPS data and data processing techniques.

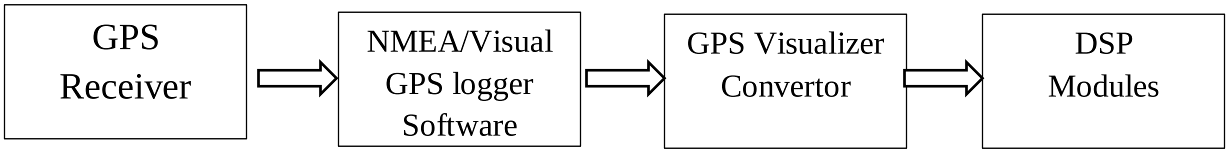


Figure 4.2: Different stages of the methodology used

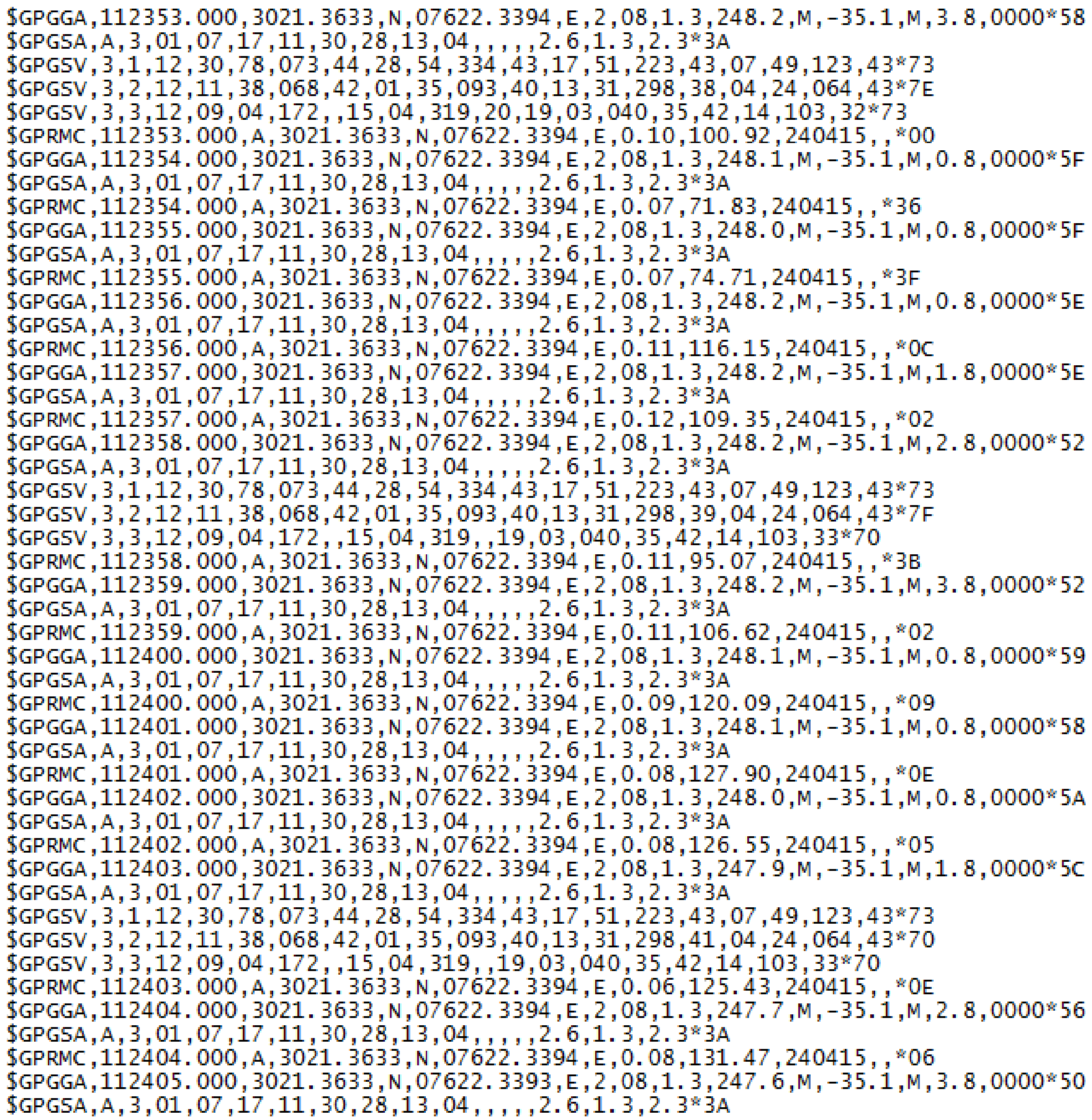
4.3.1 GPS Receiver

Two GPS receivers namely BT-GPS-35D829 and BT-GPS-35DB80 have been used in this methodology. These two GPS receivers are connected to the laptop by Bluetooth to two different ports. The BT-359 can support to different devices like Smart phone, Tablet PC and Notebook

PC with Bluetooth V2.0 for connectivity. These follows SiRF StarIII GPS standard and has built in ceramic patch antenna. The electrical characteristics of these receivers are frequency of L1 frequency 1575.42 MHz, C/A code of 1.023 MHz chip rate and 20 channel all-in-view tracking. It works on NMEA 0183 protocol. It works up to certain limits like altitude limit of 18,000 m (meter) or 60,000 feet maximum and velocity limit of 515 meters/sec maximum [31]. It is well suited to different types of applications that are used in indoor and outdoor recreation of navigation systems. These two GPS receivers are placed at different heights, one receiver at ground level another at some elevation.

4.3.2 GPS Logger Software

GPS data measurements have been collected by Visual GPS logger software. Using this software, that data is in signed character representation, which needs to be converted into human readable form so that data can be imported into MATLAB. Visual GPS logger software gives the readings at the rate of one reading per second in the form of NMEA Format (symbol representation). Most computer programs that provide real time position information understand and expect data to be in NMEA format. NMEA (National Marine Electronics Association) that includes the information in the form of position, velocity, time calculated by GPS receiver. NMEA is self-contained standard sentences, totally independent from other sentences. All lines started with two letters (for example for GPS receivers GP prefix is used). Each line of NMEA format starts with a '$' dollar sign and ends with a feed sequence and each line can’t be longer than 80 characters of visible text (plus the line terminators). The data is contained within this single line with data items separated by commas. The data itself is just ASCII text. There is a provision for a checksum at the end of each sentence which may or may not be checked by the unit that reads the data. The checksum field consists of a '*' and two hex digits representing an 8 bit exclusive OR of all characters between, but not including, the '$' and '*'[42]. There have been several changes to the standard but for GPS use the only ones that are likely to be encountered are 1.5 and 2.0 through 2.3. The current version of the standard is 3.01. NMEA file format is shown in figure 4.3.

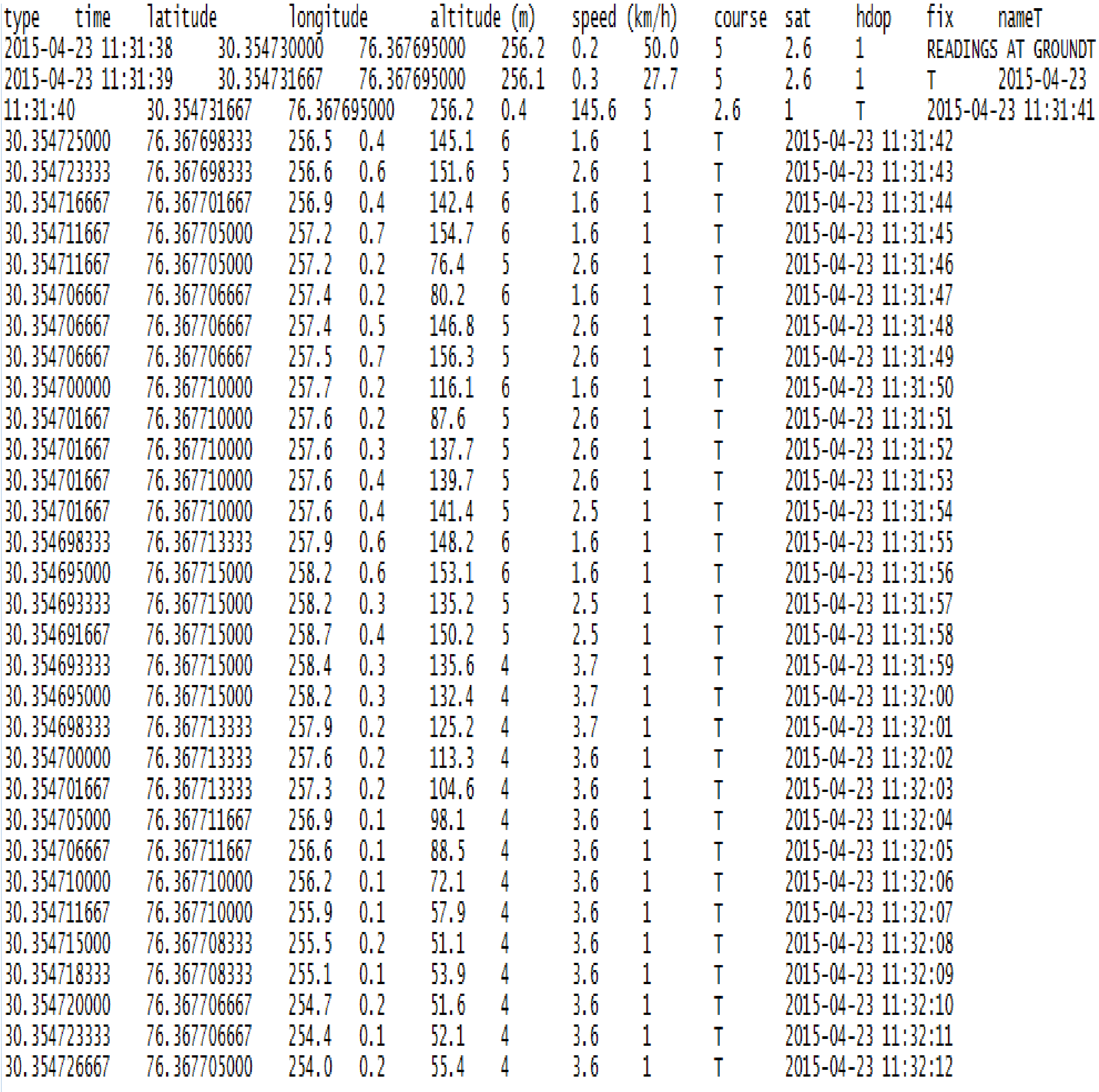


```
$GPGGA,112353.000,3021.3633,N,07622.3394,E,2,08,1.3,248.2,M,-35.1,M,3.8,0000*58
$GPGSA,A,3,01,07,17,11,30,28,13,04,,,,,2.6,1.3,2.3*3A
$GPGSV,3,1,12,30,78,073,44,28,54,334,43,17,51,223,43,07,49,123,43*73
$GPGSV,3,2,12,11,38,068,42,01,35,093,40,13,31,298,38,04,24,064,43*7E
$GPGSV,3,3,12,09,04,172,,15,04,319,20,19,03,040,35,42,14,103,32*73
$GPRMC,112353.000,A,3021.3633,N,07622.3394,E,0.10,100.92,240415,,*00
$GPGGA,112354.000,3021.3633,N,07622.3394,E,2,08,1.3,248.1,M,-35.1,M,0.8,0000*5F
$GPGSA,A,3,01,07,17,11,30,28,13,04,,,,,2.6,1.3,2.3*3A
$GPRMC,112354.000,A,3021.3633,N,07622.3394,E,0.07,71.83,240415,,*36
$GPGGA,112355.000,3021.3633,N,07622.3394,E,2,08,1.3,248.0,M,-35.1,M,0.8,0000*5F
$GPGSA,A,3,01,07,17,11,30,28,13,04,,,,,2.6,1.3,2.3*3A
$GPRMC,112355.000,A,3021.3633,N,07622.3394,E,0.07,74.71,240415,,*3F
$GPGGA,112356.000,3021.3633,N,07622.3394,E,2,08,1.3,248.2,M,-35.1,M,0.8,0000*5E
$GPGSA,A,3,01,07,17,11,30,28,13,04,,,,,2.6,1.3,2.3*3A
$GPRMC,112356.000,A,3021.3633,N,07622.3394,E,0.11,116.15,240415,,*0C
$GPGGA,112357.000,3021.3633,N,07622.3394,E,2,08,1.3,248.2,M,-35.1,M,1.8,0000*5E
$GPGSA,A,3,01,07,17,11,30,28,13,04,,,,,2.6,1.3,2.3*3A
$GPRMC,112357.000,A,3021.3633,N,07622.3394,E,0.12,109.35,240415,,*02
$GPGGA,112358.000,3021.3633,N,07622.3394,E,2,08,1.3,248.2,M,-35.1,M,2.8,0000*52
$GPGSA,A,3,01,07,17,11,30,28,13,04,,,,,2.6,1.3,2.3*3A
$GPGSV,3,1,12,30,78,073,44,28,54,334,43,17,51,223,43,07,49,123,43*73
$GPGSV,3,2,12,11,38,068,42,01,35,093,40,13,31,298,39,04,24,064,43*7F
$GPGSV,3,3,12,09,04,172,,15,04,319,,19,03,040,35,42,14,103,33*70
$GPRMC,112358.000,A,3021.3633,N,07622.3394,E,0.11,95.07,240415,,*3B
$GPGGA,112359.000,3021.3633,N,07622.3394,E,2,08,1.3,248.2,M,-35.1,M,3.8,0000*52
$GPGSA,A,3,01,07,17,11,30,28,13,04,,,,,2.6,1.3,2.3*3A
$GPRMC,112359.000,A,3021.3633,N,07622.3394,E,0.11,106.62,240415,,*02
$GPGGA,112400.000,3021.3633,N,07622.3394,E,2,08,1.3,248.1,M,-35.1,M,0.8,0000*59
$GPGSA,A,3,01,07,17,11,30,28,13,04,,,,,2.6,1.3,2.3*3A
$GPRMC,112400.000,A,3021.3633,N,07622.3394,E,0.09,120.09,240415,,*09
$GPGGA,112401.000,3021.3633,N,07622.3394,E,2,08,1.3,248.1,M,-35.1,M,0.8,0000*58
$GPGSA,A,3,01,07,17,11,30,28,13,04,,,,,2.6,1.3,2.3*3A
$GPRMC,112401.000,A,3021.3633,N,07622.3394,E,0.08,127.90,240415,,*0E
$GPGGA,112402.000,3021.3633,N,07622.3394,E,2,08,1.3,248.0,M,-35.1,M,0.8,0000*5A
$GPGSA,A,3,01,07,17,11,30,28,13,04,,,,,2.6,1.3,2.3*3A
$GPRMC,112402.000,A,3021.3633,N,07622.3394,E,0.08,126.55,240415,,*05
$GPGGA,112403.000,3021.3633,N,07622.3394,E,2,08,1.3,247.9,M,-35.1,M,1.8,0000*5C
$GPGSA,A,3,01,07,17,11,30,28,13,04,,,,,2.6,1.3,2.3*3A
$GPGSV,3,1,12,30,78,073,44,28,54,334,43,17,51,223,43,07,49,123,43*73
$GPGSV,3,2,12,11,38,068,42,01,35,093,40,13,31,298,41,04,24,064,43*70
$GPGSV,3,3,12,09,04,172,,15,04,319,,19,03,040,35,42,14,103,33*70
$GPRMC,112403.000,A,3021.3633,N,07622.3394,E,0.06,125.43,240415,,*0E
$GPGGA,112404.000,3021.3633,N,07622.3394,E,2,08,1.3,247.7,M,-35.1,M,2.8,0000*56
$GPGSA,A,3,01,07,17,11,30,28,13,04,,,,,2.6,1.3,2.3*3A
$GPRMC,112404.000,A,3021.3633,N,07622.3394,E,0.08,131.47,240415,,*06
$GPGGA,112405.000,3021.3633,N,07622.3393,E,2,08,1.3,247.6,M,-35.1,M,3.8,0000*50
$GPGSA,A,3,01,07,17,11,30,28,13,04,,,,,2.6,1.3,2.3*3A
```

Figure 4.3: NMEA Format

4.3.3 GPS Visualizer Convertor

GPS Visualizer is an online utility that creates maps and profiles from geographic data [43]. It is free and easy to use, yet powerful and extremely customizable. Input can be in the form of GPS data (tracks and waypoints), driving routes, street addresses, or simple coordinates. NMEA format is converted into readable form containing information of longitude, speed, latitude and altitude by GPS visualizer convertor. Readable file obtained is shown below:



```
type    time    latitude        longitude       altitude (m)    speed (km/h)    course  sat     hdop    fix     nameT
2015-04-23 11:31:38     30.354730000    76.367695000    256.2   0.2     50.0    5       2.6     1       READINGS AT GROUNDT
2015-04-23 11:31:39     30.354731667    76.367695000    256.1   0.3     27.7    5       2.6     1       T       2015-04-23
11:31:40        30.354731667    76.367695000    256.2   0.4     145.6   5       2.6     1       T       2015-04-23 11:31:41
30.354725000    76.367698333    256.5   0.4     145.1   6       1.6     1       T       2015-04-23 11:31:42
30.354723333    76.367698333    256.6   0.6     151.6   5       2.6     1       T       2015-04-23 11:31:43
30.354716667    76.367701667    256.9   0.4     142.4   6       1.6     1       T       2015-04-23 11:31:44
30.354711667    76.367705000    257.2   0.7     154.7   6       1.6     1       T       2015-04-23 11:31:45
30.354711667    76.367705000    257.2   0.2     76.4    5       2.6     1       T       2015-04-23 11:31:46
30.354706667    76.367706667    257.4   0.2     80.2    6       1.6     1       T       2015-04-23 11:31:47
30.354706667    76.367706667    257.4   0.5     146.8   5       2.6     1       T       2015-04-23 11:31:48
30.354706667    76.367706667    257.5   0.7     156.3   5       2.6     1       T       2015-04-23 11:31:49
30.354700000    76.367710000    257.7   0.2     116.1   6       1.6     1       T       2015-04-23 11:31:50
30.354701667    76.367710000    257.6   0.2     87.6    5       2.6     1       T       2015-04-23 11:31:51
30.354701667    76.367710000    257.6   0.3     137.7   5       2.6     1       T       2015-04-23 11:31:52
30.354701667    76.367710000    257.6   0.4     139.7   5       2.6     1       T       2015-04-23 11:31:53
30.354701667    76.367710000    257.6   0.4     141.4   5       2.5     1       T       2015-04-23 11:31:54
30.354698333    76.367713333    257.9   0.6     148.2   6       1.6     1       T       2015-04-23 11:31:55
30.354695000    76.367715000    258.2   0.6     153.1   6       1.6     1       T       2015-04-23 11:31:56
30.354693333    76.367715000    258.2   0.3     135.2   5       2.5     1       T       2015-04-23 11:31:57
30.354691667    76.367715000    258.7   0.4     150.2   5       2.5     1       T       2015-04-23 11:31:58
30.354693333    76.367715000    258.4   0.3     135.6   4       3.7     1       T       2015-04-23 11:31:59
30.354695000    76.367715000    258.2   0.3     132.4   4       3.7     1       T       2015-04-23 11:32:00
30.354698333    76.367713333    257.9   0.2     125.2   4       3.7     1       T       2015-04-23 11:32:01
30.354700000    76.367713333    257.6   0.2     113.3   4       3.6     1       T       2015-04-23 11:32:02
30.354701667    76.367713333    257.3   0.2     104.6   4       3.6     1       T       2015-04-23 11:32:03
30.354705000    76.367711667    256.9   0.1     98.1    4       3.6     1       T       2015-04-23 11:32:04
30.354706667    76.367711667    256.6   0.1     88.5    4       3.6     1       T       2015-04-23 11:32:05
30.354710000    76.367710000    256.2   0.1     72.1    4       3.6     1       T       2015-04-23 11:32:06
30.354711667    76.367710000    255.9   0.1     57.9    4       3.6     1       T       2015-04-23 11:32:07
30.354715000    76.367708333    255.5   0.2     51.1    4       3.6     1       T       2015-04-23 11:32:08
30.354718333    76.367708333    255.1   0.1     53.9    4       3.6     1       T       2015-04-23 11:32:09
30.354720000    76.367706667    254.7   0.2     51.6    4       3.6     1       T       2015-04-23 11:32:10
30.354723333    76.367706667    254.4   0.1     52.1    4       3.6     1       T       2015-04-23 11:32:11
30.354726667    76.367705000    254.0   0.2     55.4    4       3.6     1       T       2015-04-23 11:32:12
```

Figure 4.4: Readable File form NMEA format

4.3.4 Data Processing Techniques

In the module, combination of DSP techniques such as kalman filter and BDIM after kalman filter has been used given in figure 4.4. The algorithm programming for both Kalman filter and BDIM is done in the MATLAB to estimation the GPS error in raw GPS height difference.

:

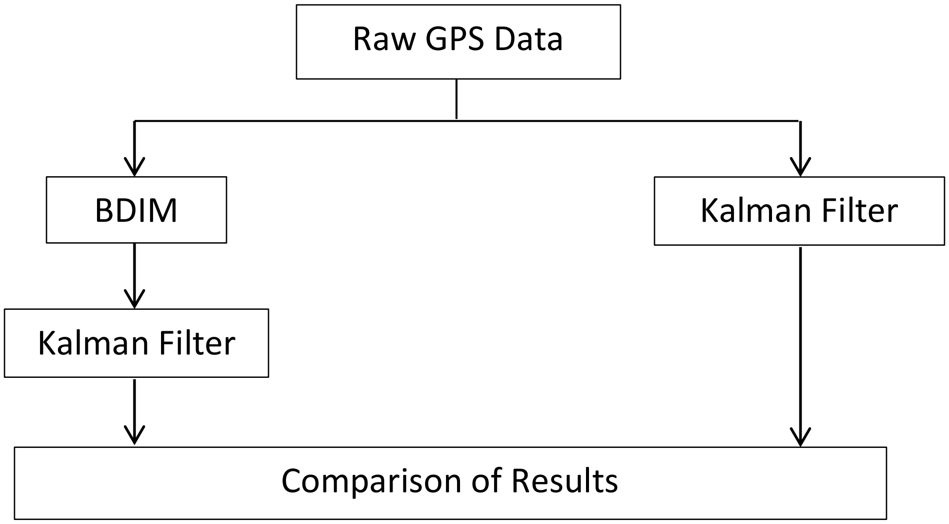


Figure 4.5: DSP techniques used to process GPS Raw data

The implementation of this methodology is done to get the result for GPS accuracy in the next chapter 5 of this thesis.

CHAPTER 5

RESULTS AND DISCUSSION

5.1 Introduction

Various cases are considered for error estimation in raw GPS height difference in the chapter. The output of DSP techniques: Kalman filter and Kalman filter after BDIM has been presented in the chapter.

5.2 Observed Measurements

5.2.1 GPS Altitude Measurements

The following figures 5.1 shows observed GPS height measurements at ground level and at elevation of 11m for case 1.

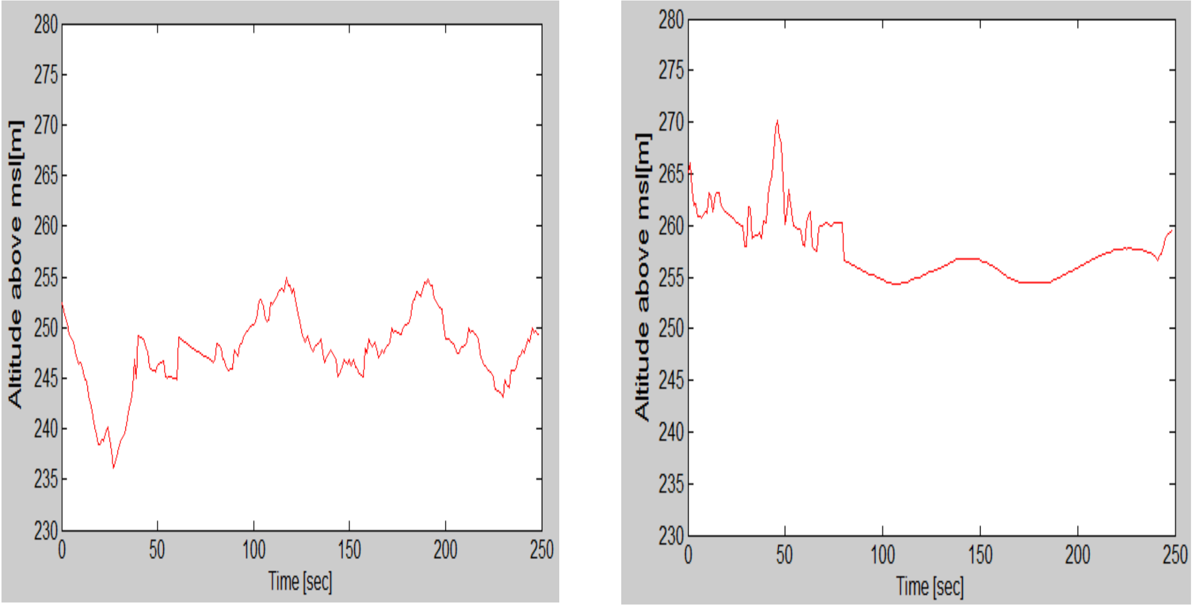


Figure 5.1: Raw GPS measurement at ground level and at elevation of 11m for case 1.

The following figure 5.2 show observed GPS height difference measurements when GPS receiver is placed at ground level and at elevation of 8m respectively for case 2.

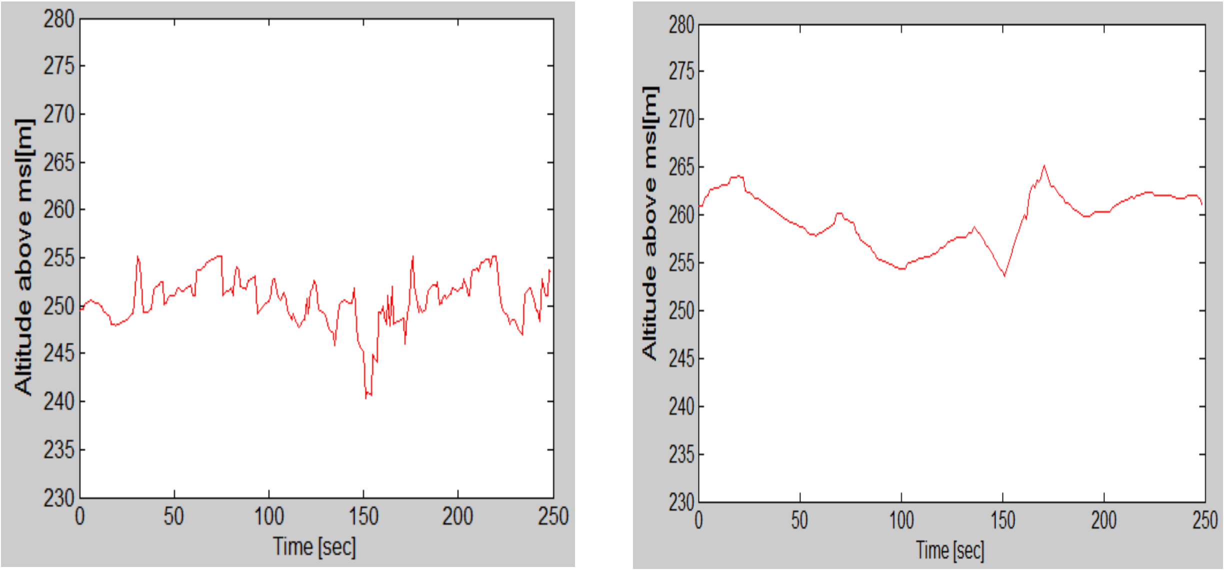


Figure 5.2: Raw GPS measurement at ground level at elevation of 8m for case 2

5.2.2 Observed GPS Height Difference

The observed GPS height difference and actual height are depicted in figure 5.3 for case 1. It has been observed that the GPS height difference is not closer to actual height due to some inherent errors.

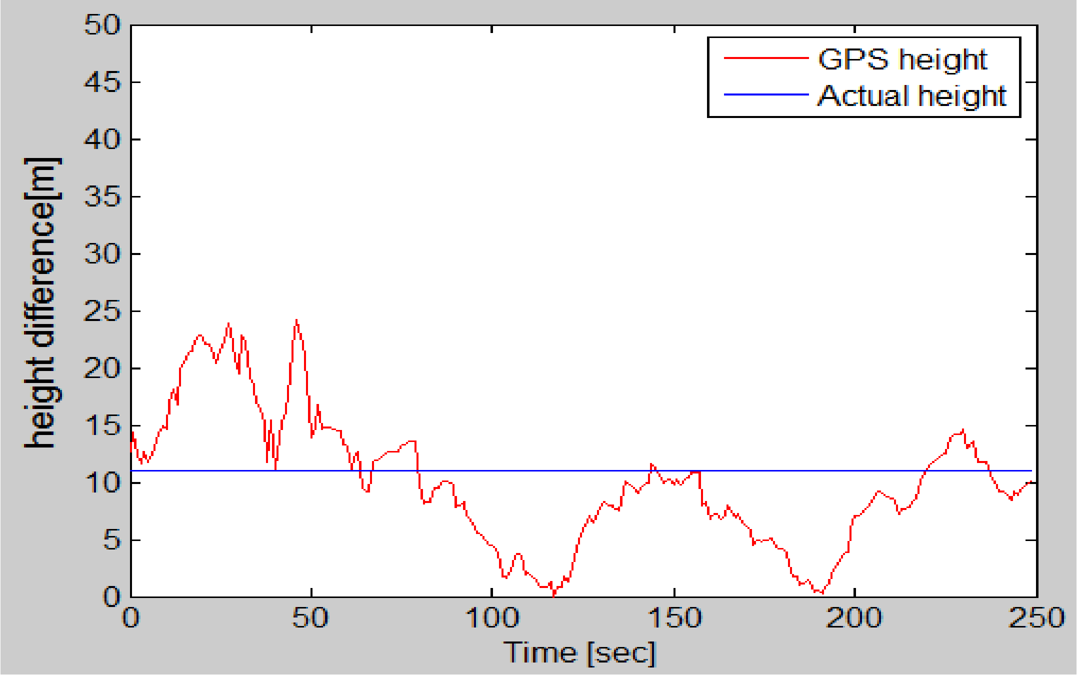


Figure 5.3 : Observed GPS height difference for case 1

In figure 5.4, GPS height difference and actual height has been shown for case 2. It has been observed that the GPS height difference is not closer to actual height.

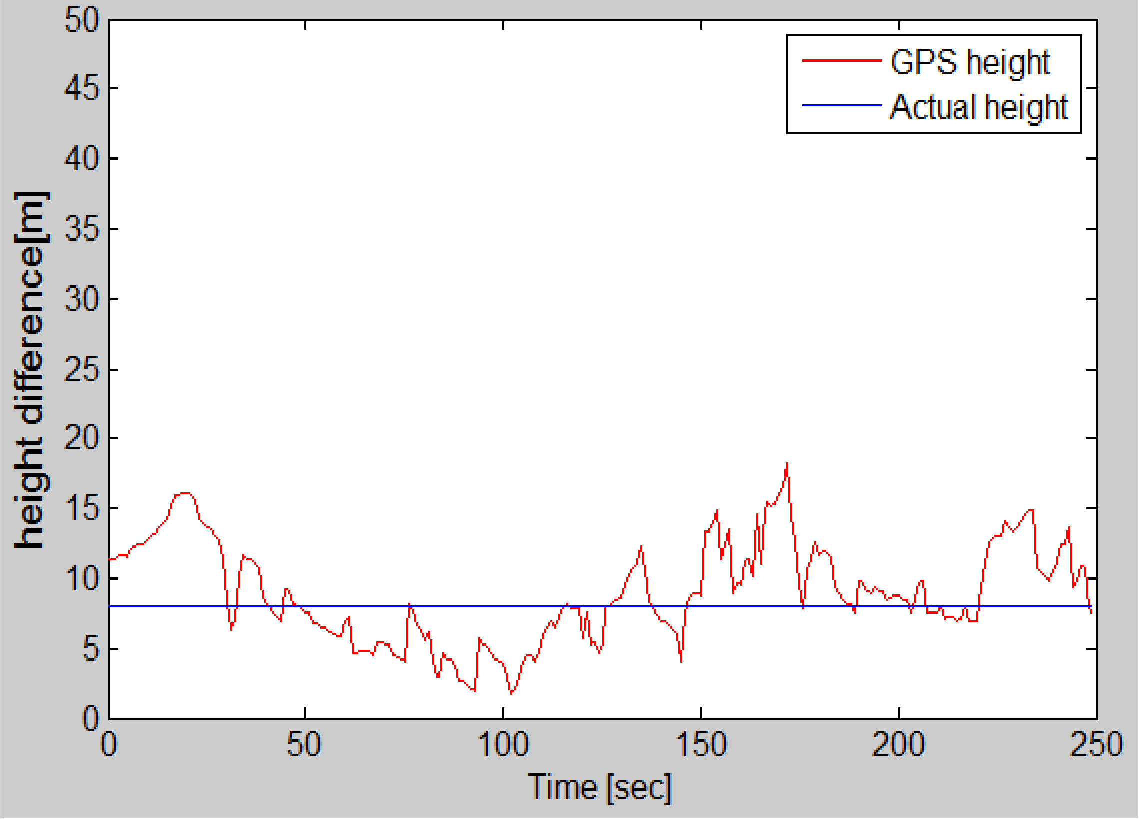


Figure 5.4: Observed GPS height difference for case 2.

5.3 Processing of GPS Height Difference

In the observed GPS height difference measurements as shown in above Figures 5.3 and 5.4, error has been experienced with respect to its actual measured height. The error in observed GPS height difference has been reduced with various combinations of DSP techniques such as BDIM, Kalman filter after BDIM.

5.3.1 Using Kalman Filter

The Figure 4.7 shows effect of Kalman filter on raw GPS height difference. The processed GPS height difference resulting from Kalman filter is seen to be more close to the actual height difference.

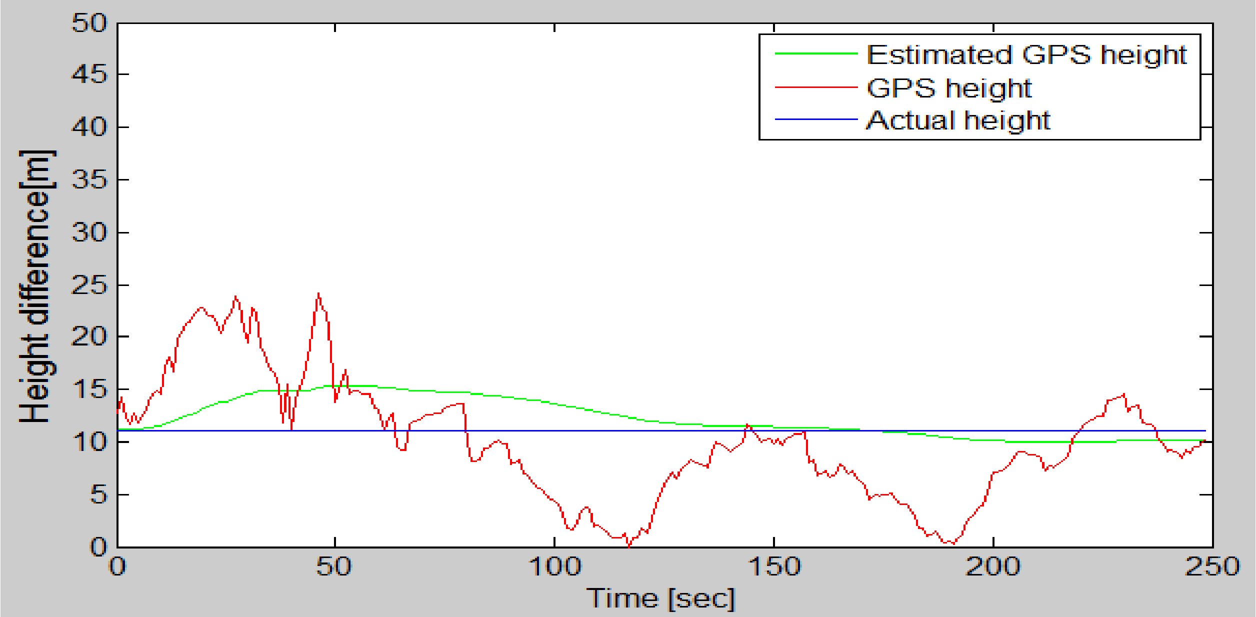


Figure 5.5: Estimation of GPS measurements using Kalman filter for case 1.

In the following figure 5.6 GPS height has been compared with the estimated GPS measurements obtained using Kalman filter for case 2. It is found that error in estimated GPS height difference has been reduced as estimated GPS height difference is more close to actual height than that of measured GPS height.

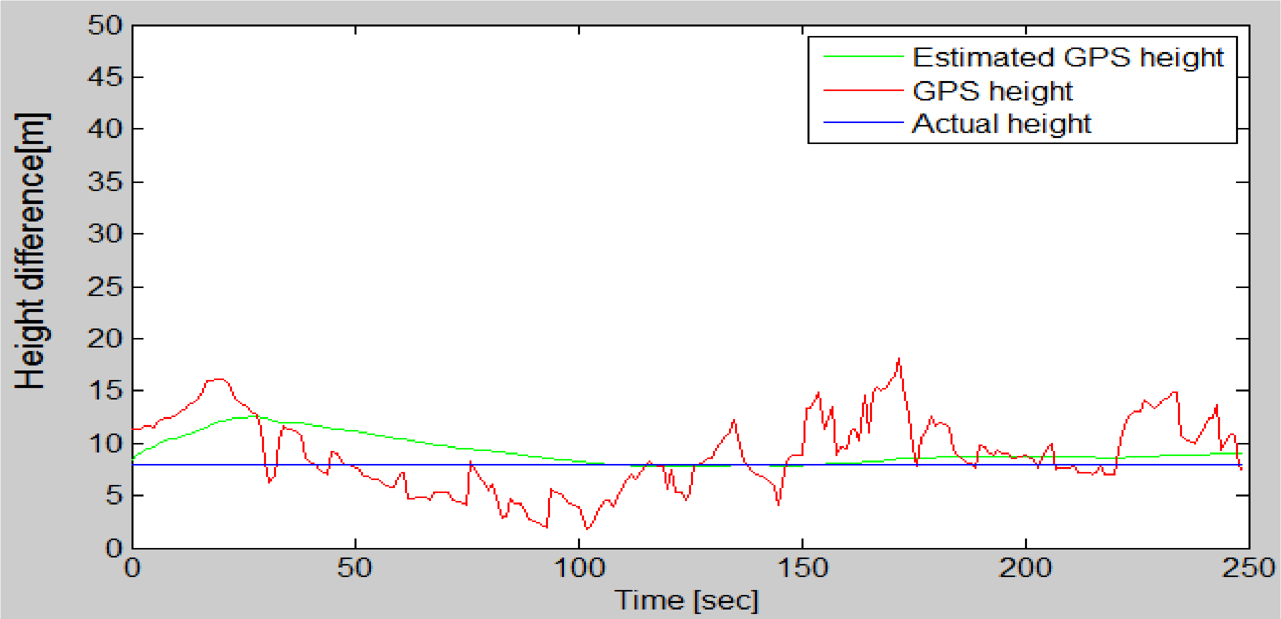


Figure 5.6: Estimation of GPS measurements using Kalman filter for case 2

5.3.2 Using Kalman Filter after BDIM Technique

The Figure 5.7 and 5.8 depicts raw GPS measured height difference and processed GPS height difference using Kalman filter after BDIM technique. It is observed that error in estimated GPS height difference measurements has been further more reduced, as output of BDIM technique has been processed by Kalman filter. Thus comes very closer to the actual altitude.

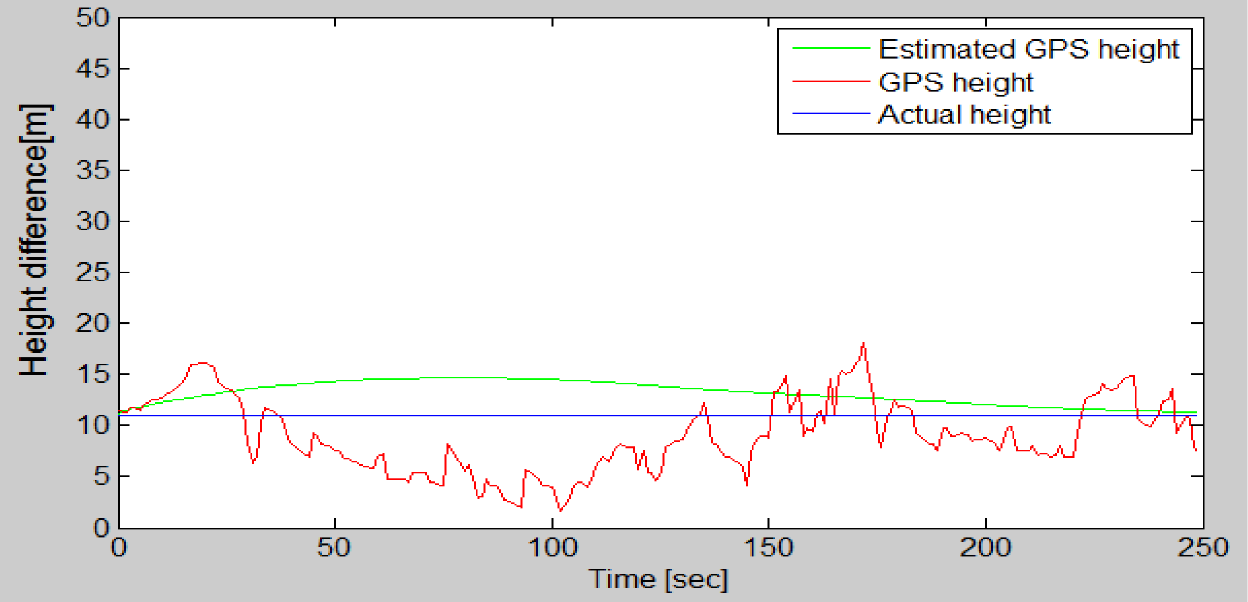


Figure 5.7: Processing of GPS height using Kalman filter after BDIM for case 1

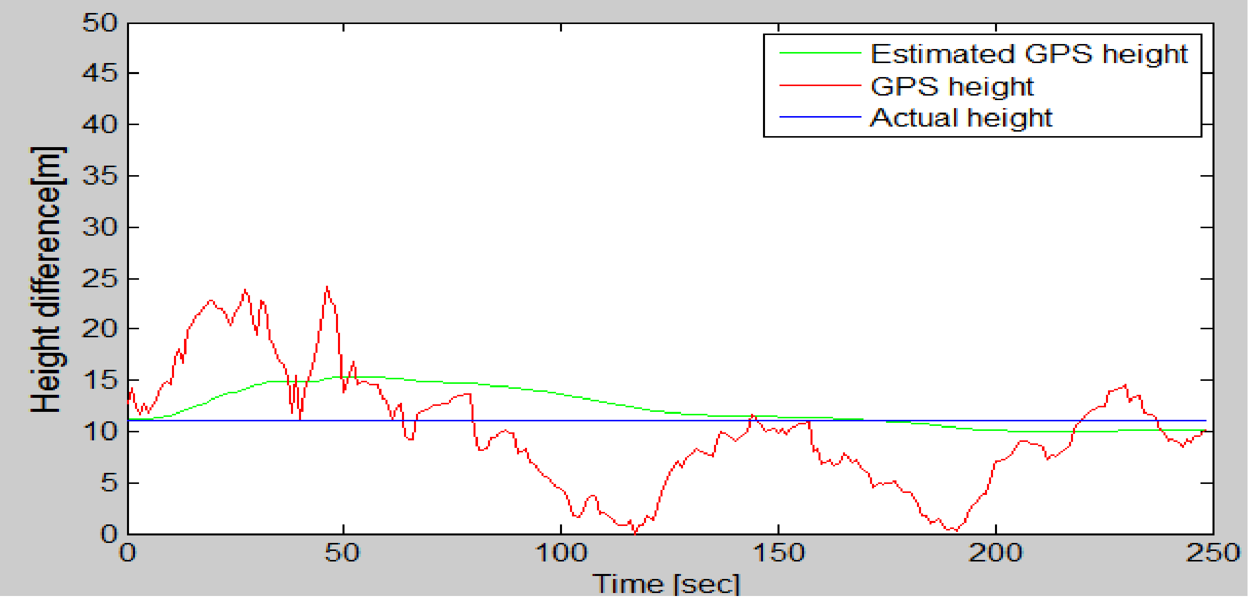


Figure 5.8: Processing of GPS height using Kalman filter after BDIM for case 2

5.4 Error Analysis

The table gives maximum absolute error achieved using Kalman filter and Kalman filter after BDIM technique, for cases under studies.

Table 5.1: Absolute error analysis

Cases	Actual height difference(m)	Maximum absolute error in measuring GPS height difference (m)	Maximum absolute error in measuring GPS height difference using Kalman filter (m)	Maximum absolute error in measuring GPS height difference using Kalman filter after BDIM (m)
1	11	13.1000	4.3316	3.6848
2	8	9.3	3.2493	2.4231

Therefore, Kalman filter after BDIM further reduce errors in processed GPS measurements. Resulting from Kalman filter and thus gives better accuracy of observed GPS measurements.

CHAPTER 6

CONCLUSION AND FUTURE SCOPE

6.1 Conclusion

The conclusion is observed in the present work are summarized as below:

1. An experimental set up has been made using:

-GPS receiver BT 359

-Laptop

2. Two case studies has been done for processing of observed GPS height difference. Also actual height has been measured physically.

3. The accuracy of observed GPS height difference has been improved using combination of DSP techniques such as:

-Kalman filter

-Kalman filter after BDIM

4. It can be concluded that kalman filter after BDIM combination of DSP techniques is best combination for error reduction in observed GPS height difference

6.2 Future Scope

The challenges remained in the work are given as:

1. Continuous power supply to GPS receiver may be used

2. The accuracy of GPS receiver may be further improved using other accurate DSP techniques

3. The experimental set up can be used for overhead conductor sag in power distribution lines.

[1] J. J. Spilker, B. W. Parkinson, GPS Signal Structure and Theoretical Performance, “Global Positioning System: Theory and Applications (Progress in Astronautics and Aeronautics”, *American Institute of Aeronautics and Astronautics, Washington* 1996

[2] S. Y. Zheng, “Signal Acquisition and Tracking for a Software GPS Receiver”, PhD diss., Virginia Polytechnic Institute and State University, 2005

[3] S. B. Rao, “Design and Implementation of a GPS receiver channel And Multipath Delay Estimation using Teager-Kaiser operator”, PhD diss., Indian Institute of Science Bangalore, INDIA, 2009

[4] P. H. Dana, “Global Positioning System(GPS) Time Dissemination for Real Time applications, Real Time Systems”, vol. 12, pp. 9-40, 1997

[5] Mohinder, S. Grewal, A. P. Andrews “Kalman Filtering: Theory and Practice using Matlab”, John Wileys and Sons, Second Edition, 2001

[6] D. Simon “Kalman Filtering Embedded Systems Programming”, Embedded.com article, June 2001

[7] G. Welch and G. Bishop, "An introduction to the Kalman filter" *Proceedings of the Siggraph Course, Los Angeles* (2001)

[8] M. C. Olynik, “Temporal Characteristics of GPS Error Sources and Their Impact on Relative Positioning”, UCGE Reports Number 20162, July 2002.

[9] I. Guvenc, C.T. Abdallah, O.R. Jordan, **“**Enhancements to RSS Based Indoor Tracking Systems Using Kalman Filters” *International Signal Processing Conference (ISPC) and Global Signal Processing Expo (GSPx), Dallas, TX.*, 2003

[10] O Reyna, Roberto, I. E. Villalon-Turubiates, Y. S. Shmaliy, and O. G. Manzano, “GPS based design of the local clock control system based on the optimally unbiased moving average

filter", In *Advanced Optoelectronics and Lasers, Proceedings of CAOL 2003. First International Conference on*. vol. 2, pp. 278-281. IEEE, 2003

[11] R. Kleinbauer, "Kalman Filtering Implementation with Matlab", 2004

[12] Ribeiro, M. Isabel, "Kalman and Extended Kalman Filters: Concept, Derivation and Properties", Institute for Systems and Robotics, vol. 43, 2004

[13] Kosanam, Srikiran, and D. J. Simon, "Kalman filtering with uncertain noise covariances", 375, 2004

[14] R. Bos, X. Bombois and P. M. J. Van den Hof "Designing a Kalman Filter When No Noise Covariance Information is available" 2005

[15] Matthew, Lashley, "Kalman Filter Based Tracking Algorithms for Software GPS Receivers", PhD diss., 2006

[16] Komaragiri, S. Sushmitha, and S. M. Mahajan, "A sag monitoring device based on a cluster of code based GPS receivers", *In Power & Energy Society General Meeting, PES'09. IEEE,* pp. 1-7, 2009

[18] C. Barrios and Y. Motai, *Member, IEEE,* "Improving Estimation of Vehicle's Trajectory Using the Latest Global Positioning System with Kalman Filtering", *IEEE TRANSACTIONS ON INSTRUMENTATION AND MEASUREMENT,* vol. 60, December 2011

[19] Q. Kong, S. Xu and S. Lee, "Using PDOP to Estimate Kalman Filter's Measurement Noise Covariance for GPS Positioning", *International Conference on Traffic and Transportation Engineering (ICTTE 2012) IPCSIT,* vol. 26, Singapore, 2012

[20] X. Li, S. Yu, Y. Lin, M. Xi, "A Multi-model Kalman Filter Clock Synchronization Algorithm based on Hypothesis Testing in Wireless Sensor Networks", *2nd International Conference on Electronic & Mechanical Engineering and Information Technology (EMEIT-*2012, Paris, France, 2012

[21] J. M. Kanieski, R. Cardoso, H. Pinheiro, *Member IEEE,* and H. A. Gründling, "Kalman Filter-Based Control System for Power Quality Conditioning Devices", *IEEE TRANSACTIONS ON INDUSTRIAL ELECTRONICS,* vol. 60, November 2013

[22] Dr. T. A. E. H. H. El-Damaty, "The Role of Kalman filter in improving the accuracy of GPS Kinematic Technique", International journal of civil engineering and technology ,vol. 4, issue 2, pp. 49-57, 2013

[23] F. Auger, M. Hilairet, J. M. Guerrero, E. Monmasson, O. Kowalska and S. Katsura "Industrial Applications of the Kalman Filter: A Review", International journal of civil engineering and technology , vol. 4, Issue 2, pp. 49-57, 2013

[24] H. M. Qian, W. Huang, and B. Liu, "Finite-Horizon Robust Kalman Filter for Uncertain Attitude Estimation System with Star Sensor Measurement Delays", *Hindawi Publishing Corporation Abstract and Applied Analysis,* vol. 2014, Article ID 494060, 2014

[25] J. G. McNeff, *"*The Global Positioning System*", IEEE Transactions on Microwave Theory and Techniques,* vol. 50, pp. 646, 2002

[26] L. Heng, J. J. Makela, A. D. Domınguez-Garca, R. B. Bobba, W. H. Sanders, and G. X. Gao, "Reliable GPS-Based Timing for Power Systems"

[27] M. Fujii, R. Ogawara, H. Hatano and Y. Watanabe, "A Study on Position Tracking System for Pedestrian Navigation using Location and Sensor Information", *13th International Conference on ITS Telecommunications (ITST),* 2013

[28] P. Misra, P. Enge, "Global Positioning System: Signals, Measurements, and Performance", *Ganga-Jamuna Press,* 2001

[29*] Spirent Communications Limited, SimGEN USER MENUAL,* Issue 1-08, January 2004

[30] J. B. Tsui, "Fundamentals of Global Positioning System Receivers: A Software Approach", *Wiley-Interscience*, 2000

[32] US Dept. of Defense "NAVSTAR GPS Space Segment/Navigation User Interfaces", *Interface Control Document No. ICD-GPS-200C,* US air force, 2006

[33] Dierendonck, A. J. V. GPS receivers. In Parkinson, B. W., editor, "Global Positioning System: Theory and Applications", *Progress in Astronautics and Aeronautics, chapter 8. American Institute of Aeronautics and Astronautics*, vol. 1, *Washington, DC.*1996

[34] M. Singareddy, "Sag Measurement using Differential Global Positioning System", *Ms Thesis; Tennessee Tech University*, August 2007

[35] T. Pratt, C. Bostain, J. Allnutt, "Satellite communication, Singapore: John Wiley & Sons", 2005

[36] Parkinson, W. Bradford and J. J. J. Spiler, "Global Positioning System: Theory and Applications", vol. 1, Washington, D.C.: *American Institute of Aeronautics and Astronautics, Inc.*, 1996

[37] G. Welch and G. Bishop, "An Introduction to Kalman Filter", *University of North Carolina, Chapel Hill, NC, US* , 2006

[39] Wu, J.Feng, Y.Hu, Z. He, W. Jing, H. Lv, J. Li, "The study of GPS Time Transfer Based on Extended Kalman Filter" In *European Frequency and Time Forum & International Frequency Control Symposium (EFTF/IFC)*, pp. 819-822, 2013

APPENDIX A

Give some selected specifications of GPS Receiver

DEVICE	MODEL	SPECIFICATION
GPS Receiver	Global Sat BT-359	(*)
Bluetooth Device	Orchid Bluetooth 66528	• Compliant with Bluetooth V1.1,V1.2 and V2.0 • Class 2 operations • Fully Bluetooth Version 2.0 qualified • Powered by PC USB interface • Full speed USB interface, compliant with USB 1.1 • LED indication • Built-in NTENNA • Frequency band: 2.4GHz unlicensed ISM band • Maximum date rate: 2.1m • Sensitivity: -89Dbm AT 0.1%BER • 20m-100m operation range • System requirements: PC or notebook with USB port • Windows 9X/ME/2000/XP Size:51.0 x 16.0 x 8.0 mm

(*) Appendix B (Specifications for GPS Receiver BT359)

APPENDIX B

SYSTEM SPECIFICATIONS

ELECTRICAL CHARACTERISTICS	
GPS standard	SiRF Star Ⅲ
GPS Antenna	Built-in ceramic patch antenna
Bluetooth standard	Bluetooth V2.0
Operation range	10 meters (33 feet)
Bluetooth Default PIN	0000
Operation time	Up to 11 hrs
Charge time	4~5 hrs
Auto Shut-Off	When no active Bluetooth connection has been detected within 10 minutes
Battery Charging	Mini

POWER BUTTON	
Power On	Pressing the Power button for approximately 1 second will cause the unit to turn ON
Power Off	Pressing the Power button for approximately 1 second will cause the unit to turn OFF
Perform reset	Pressing the ON-OFF button for approximately 5 seconds will cause the unit to reset itself.

STATUS LED	
GPS status	Flashing -GPS position is fixed Steady – GPS position is not fixed

Power status	Solid Red – Battery Low Solid Amber – Battery is being charged
Bluetooth status	Flashing (Slow) – Not connected to a Bluetooth device Flashing (Fast) – Connected to a Bluetooth device

TEMPERATURE	
Operating	-10°C ~ 60°C (14°F ~ 140°F)
Storage	-20°C ~ 70°C (-4°F ~ 158°F)
Humidity	Operational up to 95% non-condensing

POWER	
DC supplies	4.5V~5.5V / 0.5A

BATTERY	
Battery Cell Type	Lithium –ion Rechargeable Battery

MECHANICAL	
Dimension	82.0 mm x 41.0 mm x 13.4 mm

ELECTRICAL CHARACTERISTICS	
GPS Chipset	SiRF Star III
Frequency	L1, 1575.42 MHz
C/A Code	1.023 MHz chip rate
Channels	20 channel all-in-view tracking

ACCURACY	
Position	Horizontal 10 meters, 2D RMS1-5 meters 2D RMS, WAAS corrected

Velocity	0.1m/sec
Time	1 micro-second synchronized to GPS time

AQUISATION RATE	
Hot start	1 sec average
Warm start	38 sec average
Cold start	42 sec average
Reacquisition	0.1 sec. average

PROTOCOL	
GPS Protocol	Default: NMEA 0183 (Secondary: SiRF binary)
GPS Output format	GGA(1sec), GSA(1sec), GSV(5sec), RMC(1sec), GLL, VTG is optional

DYNAMIC CONDITION	
Acceleration Limit	Less than 4g
Altitude Limit	18,000 meters (60,000 feet) max.
Velocity Limit.	515 meters/sec. (1,000 knots) max
Jerk Limit	20 m/sec**3

DYNAMIC CONDITION	
Acceleration Limit	Less than 4g
Altitude Limit	18,000 meters (60,000 feet) max.
Velocity Limit.	515 meters/sec. (1,000 knots) max
Jerk Limit	20 m/sec**3

BLUETOOTH SPECIFICATIONS

ELECTRICAL SPECIFICATION	
Bluetooth Chipset	CSR BC4
Frequency	2402MHz to 2480MHz
Standard Bluetooth	V2.0
Operation Range	10 meters (33 feet)
Bluetooth Profile	SPP (Serial Port Profile)
Output Power	0 dBm (class II)