

**Dermatoglyphics: Processing fingerprints for the recognition of innate
multiple intelligences in an individual**

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

MASTER OF ENGINEERING

in

Electronic Instrumentation & Control Engineering

Submitted by

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2015

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DECLARATION


I hereby certify that the work which is being presented in the thesis titled “**Dermatoglyphics: Processing fingerprints for the recognition of innate multiple intelligences in an individual**” in partial fulfilment of the requirements for the award of degree of **Master of Engineering** in Electronics instrumentation and Control engineering, submitted in Department of Electrical and Instrumentation Engineering of Thapar University, Patiala, is an authentic record of my own work carried out under the supervision of **Dr Mandeep Singh**, Associate Professor, EIED, Thapar University, Patiala.

The matter presented in this thesis has not been submitted to any other degree of this or any other university.



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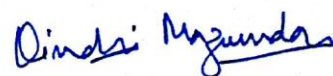

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ACKNOWLEDGEMENT

First of all, I would like to express my regards to **Dr Mandeep Singh**, Associate Professor, Electrical and Instrumentation Engineering Department, Thapar University Patiala for his patient guidance and support throughout the period of my stay. I am truly very fortunate to have the opportunity to work with him. I found this guidance to be extremely valuable.

I am also thankful to our Head of Department, **Dr R Agarwal** as well as PG coordinator, **Mr Nirbhow Jap Singh**, Assistant Professor, Electrical and Instrumentation Engineering Department. I would like to thank the entire faculty and staff of Electrical and Instrumentation Engineering Department and my friends who devoted their valuable time and help 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 like to express my sincerest gratitude to my parents **Sh Kunal Majumdar** and **Smt Nibedita Majumdar** for their years of unyielding love and encouragement. They have always wanted the best for me and supported me through thick and thin. I admire their determination and sacrifice.



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List of abbreviations

1. VARK/VAK : Visual, Aural, Read-Write and Kinaesthetic (sensory modalities)
2. CMOS : Complementary metal oxide semiconductor
3. PASS : Planning, Attention-Arousal, Simultaneous and Successive (*theory of intelligence*)
4. IQ : Intelligent Quotient
5. EQ : Emotional Quotient
6. SQ : Spiritual Quotient
7. AQ : Adversity Quotient
8. DISC : Dominant/Influential/Steady/Compliant
9. MI : Multiple Intelligence
10. EGF : Epidermal Growth Factor
11. NGF : Nervous Growth Factor
12. FM : Fourier Mellin
13. FFT : Fast Fourier Transform
14. DFT : Discrete Fourier Transform
15. STFT : Short Time Fourier Transform
16. POC : Phase Only Correlation
17. ROC : Region of Convergence
18. LT: Left Thumb
19. LI: Left Index
20. LM: Left Middle
21. LR: Left Ring
22. LL: Left Little
23. RT: Right Thumb
24. RI: Right Index
25. RM: Right Middle
26. RR: Right Ring
27. RL: Right Little
28. TFRC : Total Finger Ridge Count

ABSTRACT

From time immemorial, human beings have craved upon the idea of knowing the unknown. Quite surprising though, getting to know the future that has not even occurred, has been bestowed greater importance than what we all have already been born with. Fingerprints are the mirrors to our inborn talents and potentials, knacks and likings. If not recognised duly and well in time, they may remain shadowed all through a person's life. What follows next is a life full of resentments and frustrations of underperformance at work or dissatisfaction of occupation. In this study, fingerprints of 18 individuals of Thapar University were acquired. Out of them, 12 subjects are recognized in the field of fine arts. The patterns were preprocessed for enhancement. The affine transformations were registered in the acquired images using Fourier Mellin transform, which registered 5 out of 6 similar dermal patterns. On the other hand, all the different patterns when correlated with each other, showed mismatch for perfect image registration. The Phase Only Correlation has shown a 85 percent pattern matching on 58 patterns. This algorithm was designed for a two class classifier of two dermal patterns, the loop and whorl. This study reveals that people having imitative and creative artistic intelligence have whorls and ulnar loops as the most occurring dermal patterns.

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Chapter 1

Introduction

Humans have always been intrigued by the skin carvings and ridges, which quite fascinatingly, follows some or other pattern. Skin ridges and carvings exclusively include fingerprints, palm prints, prints on the sole of foot. No one knows where these patterns have got their exquisite shapes. Speaking of fingerprints, around ten patterns have been identified and classified so far. The largest fingerprint database available, is created by Integrated Automated Fingerprint Identification System (IAFIS) which accounts for over a hundred million fingerprints. It is maintained by the Federal Bureau of Investigation (FBI). According to developmental biologists, prints are prenatal. Developed in mothers' womb during 13th to 18th week of pregnancy, they are largely influenced genetically [1]. According to medical science, the ridge growth takes place in synchronisation with Neocortex. The Neocortex, which is a learning system, is primarily brain's centre of intelligence. Its structural makeup has much to contribute towards an individual's ability to perceive, learn and react to an input. Intelligence is as much effected from environment as much it is present since the brain development of foetus. It deals with how the brain operates distinctly in males and females under same situation, emotions affecting the acuity, not leaving behind the immense impact our genetic makeup and environment makes over the individualistic and socio-cognitive ability.

The dynamic structure of Neocortex changes dramatically over a lifetime [2]. Quite interestingly, fingerprints, which develop complementary to cortex, do not alter. Though, studies have claimed to notice variations in palm prints of passive hand of a person over course of time [3]. If neurobiologists claim such a link between fingerprint ridges and cerebral cortex, intelligence is bound to reflect from fingerprint patterns. Dermatoglyphics is the science that analytically studies finger ridges or carvings.

There has been quite an upheaval regarding determining learning abilities and personality type of an individual by looking at her dermal ridges, especially fingerprints. Intelligence quotient has a deep effect on people. Most of it is preconditioned. On the contrary, according to psychologist Howard Gardener there are nine different types of intelligences [4]. On an average, each human being portrays three or four different types, one prominent than other. Dermatoglyphics focusses on analysing the intelligences that a person is born with by simply looking at dermal ridge patterns on fingers. The bilateral symmetry of cerebrum ^[5] reflects

upon the functionality of similarly symmetric limbs. The left part of brain controls motor and sensory mechanism and so does the right part of brain with left half of body. The major role played by Neocortex in learning and memorizing a situation and registering consequent changes in the environment, lead a human being to an intellectually conscious being. She can counter events, reflect upon changes and variations, learn from experiences and develop measures or tools in response to events that may be favourable or fatal for survival. The unique levels of intelligence displayed by different individuals depends upon the unique pattern of grooves or sulci developed in prenatal stage. According to developmental biology, Neocortex development goes hand in hand with other groove dermal developments [6].

Chapter 2

Literature survey

For the anthropological studies, based on biological markers like dermatoglyphical marks on the tribes of east Africa like subjects from Kenya and Tanzania ^[7], a detailed study of subjects' palmar and digital prints was done. Ridge patterns consisting of loops, arches, whorls were counted and classified among the different races and the genders. Two other important palmar parameters were analysed: TFRC (Total Finger Ridge Count) and AtD angle, the angle between the a-triradius (under the index finger), the axial triradius (near the wrist), and the d-triradius (under the little finger). Comparative study based on sexes to analyse pattern intensity index was also done along with a-b ridge counts. The study also concludes that palmar patterns do not exhibit sexual dimorphism and may therefore not differentiate population groups.

Dermatoglyphics is the study of dermal ridges of hand, foot. Studies conducted on selected school students of Nigeria ^[8], have shown that they are formed alongside CNS development and are affected if CNS is affected. Most studied dermal ridge configurations are fingerprint patterns, ridge count, pattern intensity etc. human intelligence is controlled by polymorphic genes which are going to be studied in the two tribes of Nigeria. Heritability index of human intelligence ranges from 0.45 to 0.85. if a person has chromosomal disorder then, mutation affects the dermal ridges. 210 students were surveyed for finding an association between fingerprints and their IQ. The fingerprints were scanned using Secugen fingerprint analyser and ridge counts, ANOVA, chi – square tests were performed keeping in consideration the parameters of sexes, tribes, area of native. Independent sample of t- test at 95% level of confidence using SPSS statistical package was also done.

In this study ^[9], dermatoglyphical patterns have been linked to dental structures and their malocclusions. The study has been based on the proven fact that embryological development of orthodontic structures and these dermal patterns and formations occur during the same period of development of foetus. The study compares the palmar and plantar patterns of normal subjects with respect to persons with abnormal occlusions. The procedure includes classification into four groups of class 1 ideal, class 1 malocclusion, class 2 and class 3 respectively. The measurement parameters were the usual TFRC, a-b ridge count and the angle ‘‘AtD’’ (angle formed by connecting lines from digital triradius ‘a’ to the axial triradius

and from this triradius to digital triradius 'd'). The data was entered and analysed using ANOVA (analysis of variance) test and t- test. The findings show that there was not anything particular found in each class with respect to any certain pattern of fingerprints occurring in a certain dental case. Also the percentage frequency of digit patterns was calculated.

Till date it had been hypothetically considered that prenatal environment contributed to the development of sexual orientation in females. This was studied in this paper ^[10], wherein the dermatoglyphics analysis of finger ridge count of two groups of female monozygotic twins where the study group was discordant in sexual orientation and which was analysed with respect to a control group which was concordant for sexual orientation. The findings say that the TFRC calculated using Wilcoxon matched pair statistics, portrayed that lesbian twins showed consistent trend for lower TFRC than their heterosexual co-twins. Hence prenatal environmental differences are correlated with differences in sexual orientation and that second trimester prenatal environment is likely to contribute to the etiology of this trait.

According to studies in genetics ^[11], there is a correlation between total finger ridge count and the twin or sibling factor. The total finger ridge count, TFRC is inversely proportional to the amount of genetic material in a person's cell and thus in its DNA. The TFRC correlation between identical twins was found to be 0.95 and that between dizygotic twins or siblings to be 0.50. Also, according to the gender and hence the amount of testosterone hormone, the total ridge count varied. Males were found to have higher TFRC than females. Also it was proved by the fact that patients of Turners syndrome, having a single X chromosome, had higher ridge count than normal peoples' ridge counts, irrespective of their genders. It was concluded that higher ridge count represents rapid cell division during the peak of embryonic development that is during 8th to 16th week of gestation ^[12]. If any variations were caused they were due to the amount of sex hormones. Systemic asymmetry of hands showed that right hand had higher number of ridges than the left hand due to larger rapid cell division on one side of body.

The directional asymmetry ^[13] showcases the natural presence of heart or liver on either side of midline. If there are some exceptional variations from the bilateral symmetry, the person lacks the buffering ability to avoid the variation causing environmental influences. It depends on heterozygosity of genetic makeup. Heterozygosity is the presence of dissimilar pair of genes for any hereditary characteristics. Zygosity refers to the degree of similarity of alleles for a trait in an organism. It leads to the conclusion that phenotypic expression and

fluctuating asymmetry are related. For twins, having fluctuating asymmetry, the study was carried out on both twins being schizophrenic, neither of them being schizophrenic and either one of them being a concordant to them. Zygoty was not found to have any direct effect on ridge counts or fluctuating symmetry. Males however, displayed higher number of ridges. For a subject, the pair of fingers from both hands, were tested for similarity in ridge patterns. Each pattern type, was thus checked to have the occurrence similar fingerprint patterns.

Overlaying of two or more images in image processing is called IMAGE REGISTRATION^[14]. The translated, rotated and scaled images uses registration method that uses Fourier domain approach to match images. As per information in frequency domain, Fourier methods are unique because they search for optimal match. The Fourier shift property forms the basis of this method and assures that the phase of cross-power spectrum and phase difference between images are equal. On taking the inverse we will get an impulse function bearing a nonnegative value where displacement is needed to register the two images optimally. The necessary theory which is required to match images which are translated, rotated and scaled with respect to each other using Fourier properties. Some of the implementation issues like Cartesian to polar conversion, High pass filtering and logarithmic conversion, image transform, Fourier spectra computation and other are considered. From the various implementation strategies it can be concluded that matching algorithm can work up to a scale change of 1.8 having a corresponding amount of translation in log polar domain of 28. The performance is tested on different sets of images. It was observed that transformation parameter values and real parameter values were equal, which were obtained manually by actual matching. Also three FFT computations are required and three IFFT's. Main advantage of the proposed algorithm that, irrespective of rotation, translation and scale it takes fixed time in computing the matching parameters for fixed size of images.

Fingertip conditions that varies on environment or personal cause, sometimes influences the human identification by fingerprints. So using phase spectra, these paper proposes a new fingerprint matching algorithm using Phase Only Correlation (POC) function^[15].

Feature based method cannot be used to identify fingerprints of many due to special skin conditions as it is difficult to extract feature points sometimes by image processing. So the paper proposes the POC technique to high accuracy image registration tasks. Accuracy in matching of POC function makes it have the most remarkable property. Kronecker's delta function is obtained by POC algorithm between two identical images. Sharp peak is obtained when the two images are similar proving to exhibit higher discrimination capability as

compared to other functions. POC function is not influenced by the change in brightness or the shift caused to it. Also the function proves to be highly robust against noise. In band limited POC function, to improve the matching performance, the basic idea is to remove the higher frequency components that have meaningless information. Sum of the highest P peaks are employed as matching scores. Due to large variability in fingerprint impressions of the same finger, matching becomes difficult. All the variabilities are normalized by the band limited POC function. Hence, the proposed technique is efficient to verify very low quality fingerprints and can also be applied to other biometric technologies.

Poor quality fingerprints lead to generation of spurious and false minutiae ^[16]. Since fingerprinting is somewhat touch prints, any extra smudge may create a new false minutiae. A minutiae is a certain ridge pattern. Several ridge patterns have already been registered universally. While acquiring raw data, great care should be taken in order to avoid any human error. The regularity of ridges is of crucial nature because it helps in estimating the ridge frequency and instantaneous orientation. We will later on find that the gradient is calculated by it. The next phase includes a robust enhancement technique being applied on the acquired data. It should be such that any minutiae does not remain undetected or any non-minutiae element gets detected as one. Such techniques include, histogram equalization of the input image, mean and variance normalization as well as Weiner filtering for noise removal. The reference of work done by Hong et al gives an insight into use of anisotropic filters. Their speciality lies in the fact that a ridge, at some angle to zero line, gets multiplied by two unit vectors, one parallel and another perpendicular to the ridge. As a result, the nature of ridge orientation can be estimated. The normalization reduces each pixel to the global mean and variance without altering the ridge structure. The contrast gets better. Any wide variation in the pixel intensity gets scaled in between 0 and 1. Ridge estimation is done by first calculating the gradient and then applying morphological operations for segmenting the image into recoverable and non-recoverable parts. For the filtering purpose, set of Gabor filters have been applied which calculate the possible ridge orientations. The set of filters can have angle ranging over 0 and 360. Since ridges appear in equal width, the ridges are perfectly suitable for periodic estimation function. In contrast, Fourier domain filtering neglects the fact that ridges might lose their constant frequency at times. Here, the pre-computed filter bank of Fourier transform fail. Gabor filters, on other hand are much tuned to the requirements. The elementary kernel of filter can be rotated in any angle possible to estimate the ridge orientation. The proposed short time Fourier analysis does not need

localised block processing, different algorithms or the orientation image. While masking the image locally, in order to filter in the valid ridges, energy image $E(x, y)$ of the original image is checked for highest energy containing areas in Fourier spectra. Fingerprint region is then classified from background areas by thresholding. Otsu thresholding automatically determines the optimum threshold for binarization. The STFT improves the ridge structure even in areas of high ridge curvature which is an important aspect of coherence. Also, the intrinsic images like ridge orientation, ridge frequency are well addressed by STFT. Enhancement technique fully utilised the information from orientation, frequency, angular coherence. A good amount of recognition rate has been enhanced.

Fingerprint recognition remains as one of the most prominent biometric identification methods. The quality of the fingerprint image is the most significant factor in a reliable matching process. Any pre- processing algorithm ^[17] should aim to enhance the quality of the existing features without creating false features. In this paper we describe a regional average thresholding (RAT) scheme for 256 grey scale images. The algorithm thresholds by moving a small, fixed size window on 256 colour grey scale image and uses a novel averaging scheme. Images after thresholding, are then operated by a median filtering (3x3 mask or 5x5 mask) algorithm which eliminates any random noise contained in the already threshold applied image. The filtered image is finally operated on by a ridge following thinning algorithm. We compare the results of using this algorithm on median filtered and non- filtered images.

Facial expressions are the most appropriate information source about an individual's emotions require for Effective Human Computer Intelligence Interaction (EHCI) ^[18]. Noise is either of additive or multiplicative in nature. Automatic identification of facial expressions is of great use in the fields of medicine, robotics etc. FACS or Facial Action Coding System codes the facial expressions where movements on the face are described by a set of action units. The research has been classified into three stages wherein the first one is image pre-processing. The facial features were extracted for statistical analysis. While talking of feature extraction, the input needs to be noise free. Speckle type noises were removed using Weiner filter. The author has applied the optimisation technique called the Mutation based Bacterial Foraging Optimization technique. This method removes the errors due to differences in filtered image and the noisy image. It is more of a correctional process. ANN is necessary to train the neurons for emotions. To understand, how the human emotions are being understood by the machine, some algorithm and classifier based on weights need to be given to neurons

corresponding to several human face expressions. The back propagation neural network applied at input to hidden layer gives the output which back calculates the errors in the previous phases. As the iterations pass by, the synaptic weights are updated and subsequently reduced as the error narrows down and the solution converges. The next method that was applied was radial basis function. It is much faster than the previous one. It can be concluded that Wiener filter could not remove the speckle noise which was finally dealt with BOFA.

An automatic verification ^[19] depends heavily on quality of fingerprint image. The acquired sample is then enhanced. Adaptive oriented low pass filter is used to enhance image quality. A method should be such that image does not look good but simplifies the process of further processing of the image. Here, we apply subsequent minutiae detection method. The method includes a gray level image with narrow valley and ridges. A minutiae primarily consists of ridge ends and bifurcation points which are more important to study. Minutiae detection has become significant because due to problems of low quality acquisition device, skin pigmentation, impression conditions as well as ridge configurations. These all are ridge structures that are not always well detected. Till date, Gabor filter, contextual or directional filter, band pass filter and directional Fourier transform filters. These all filters have performed low pass filtering along ridge orientation. The band pass filter is used along orientation at 90 degrees to ridge orientation whereas the low pass filters are used along the direction of ridge orientation. The positive outcomes include clearer ridge formations and higher contrast of ridges and valleys. The shortcomings included oriented BPF form spurious ridge configurations. Performance of BPF strongly depends on ridge frequency but calculating ridge frequency is a tedious task. Linked parallel ridges give rise to spurious minutiae where BPF is applicable. Spurious minutiae have location, ridge configurations which are detected. And hence true minutiae are detected. Extraction of minutiae includes skeletonization. Ridge pixel value of one are made single pixel width. Increase the contrast of ridge by having maximum and minimum values on ridge skeleton as one and zero only. To enhance contrast, sharpening is not always required. To process image important features like ridge orientation, ridge frequency are detected using adaptive oriented low pass filter. If length of filter is too long along 90 degree of orientation, at some point two parallel ridges may get linked by the filter. If filter length is small, it will not be able to join broken lines. Requirement of a good low pass filter are long enough length. Cut off frequency should be low enough, which means the physical spatial sense. It should be able to detect small breaks in the ridges. It should be able to bring about constant valued ridge of desired length and

intensity. If the length of filter is long enough for the ridge and it is oriented along the ridge. The reference window used is hamming window.

Fingerprint matching techniques are: Correlation based matching, minutiae based matching and Pattern based matching. Most common method is minutiae based matching. It is popular and most widely used. It is the analysis of some unique points on fingerprint called minutiae points ^[20]. Detection and representation of minutiae points are called minutiae sets. Major minutiae points used for matching are ridge ends and bifurcation points. For fingerprint recognition, two images need be analysed. They are test and template. Parts of recognition mechanism are: verification system and identification system. Former one verifies authenticity of one person from one to one matching. On the other hand, later one does one-to-many matching. Algorithm includes introduction of fingerprint image as input. Then matching score or total number of ridge end points and bifurcation points are calculated. After acquisition of fingerprints, it is converted into binary form. We apply thinning process on binary image. Hence total minutiae are calculated. If total number of minutiae points in two images are same it is proved that both image are same. If they are not equal, it is related to two distinguished people. In pre-processing stage, binarization is executed by thresholding process. Image thinning is the process of decreasing the thickness of all ridges into ridge of only one pixel thickness. Thinning does not convert original pixel location and angle of direction of minutiae points. So true calculation points remain intact. For the process of minutiae extraction, first point searching is done. Minutiae points are found on basis of ridge end points. Ridges are disconnected at arbitrary points. Then ridges are associated with bifurcation points. Next comes substructure creation. This is done to classify between a ridge end and a bifurcation point. Ridge pattern is formed by a matrix. If the template or window matrix is having a central element and only one neighbour. If matched to original, then it is a ridge end. If there is central element of matrix and two neighbours in two directions, then it is a bifurcation point.

Subject is component inspection of electronic assembly image ^[21]. Template is the image of PCB with incorrectly assembled devices. Standard image is image of standard or correct PCB. Processing time of machine algorithm is minimized. Memory size of image should be minimized. 7 percent memory is used to sort out any issue of difference between standard and

template images. Features distinguished by automatic optical inspection machine. Polarity of image, missing enhancement and wrong alignment are the methods. Several hundred thousand images required to inspect one PCB. Template matching methods for compressed image are discrete cosine transform, colour filter array and multi scale compression. Application of DWT is to match template for component inspection on PCB, let us suppose a capacitor. DWT does compression, filtering as well as machine vision. Compression standard used is JPEG 2000. It is superior to previous methods. It does not lose the original image data at spatial domain. Template matching method are comparing new method with existing ones. Comparison is carried out on basis of full matching method, coarse to fine matching method and also DCT template matching method. Method proposed in this paper has been to better processing time and achieve inspection accuracy. Full matching method includes input image where pixel to pixel matching is done to determine differences for all pixel values. Other method is coarse to fine method which diversifies the image into parts of low and high resolution. This is done by detection thresholding. The DCT template matching method deliberates on transition method used according to compressed jpeg image. Pixels irregularly spread in image concentrated on low frequencies. The proposed method is discrete wavelet transform. Input image inspection is compressed to compare with original template image. Its benefit is to achieve very small storage space. It also increases fast processing. The features inculcated by DWT are high compression ratio and low computation in time. It also increases memory efficiency.

The major application Fourier Mellin transform is to enhance the images it may be object oriented video coding or content based retrieval as well as digital image watermarking. The last one requires to precise the shape of objects in some and geometrical transformations that act globally on objects. Global features are invariant to some geometrical transformations. The two dimensional study includes plane closed contours and gray level objects which are widely studied. The analytical Fourier Mellin transform is to study the similarity transformations which is based on direct product of rotation and scale groups. Ganthier et al ^[22] worked on Fourier transform in case of two and three dimensional motion groups which is semi direct product of translation and rotation groups. The standard FM transform includes global transform. It is applied on all pixel in the same way. It needs to be textured image. The need of centre of coordinates is because the centre is independent of translation. Translation

invariant positioning procedures are autocorrelation function and modulus of Fourier transform.

3.1 Human behaviour and cognitive response towards surroundings

3.1.1 Learning styles

Learning styles of a person relates to her ability to approach something playfully or plan fully. The preferred learning style of a person can be – auditory, kinaesthetic or visual. On the contrary, intelligence is the analytical and computational ability of corresponding mental system. Difference in perception styles leads to two linguistically intelligent people to choose contrasting careers, one going for law or journalism whereas other taking up poetry. Human cannot visualize intelligence. They need to compute numerical, language, presentation of thought, speech, social relations as well as spatial relations. One feels the urge to initiate a thought or action, in reflection to what others have projected upon him/her. According to Barbe et al ^{[23][24]}, there are three primary learning modalities. A person can have more than one, naturally or imbibed over the course of time. They may also get altered with age. These are as follows

Visual – Picture, Shape, Sculpture, Paintings

Kinaesthetic – Gestures, Body Movement, Object Manipulation, Positioning

Auditory – Listening, Rhythms, Tone, Chants

Neil Fleming's VARK/VAK model ^[25] adds another class which is Read / write preference learners. If students are made to focus their efforts according to these models of learning, they can do better. It is not of more importance what a student is learning, but it makes difference how smartly one learns. Explaining what visually stimulating learning is, we simply take the case of a child sitting in the classroom and grasping each and every thing he/she can see. Whether it be how the teacher's eyes widen while telling something interesting and curious, the movement of lips, gestures and body language. Such is the dependence of a person on his/her learning style, that they prefer to place themselves somewhere where there is no obstruction between them and their preferred medium of information transfer. For example, in this case, the student will prefer to sit in the first bench so that his sensitive visual receptors get no diversion even from his fellow classmates. On the other hand, a person stimulated by auditory inputs learns when imparted lectures, discussions, speeches or talks. Such is their competence that listening to components of speech such as pitch, tone or voice modulation, the individual can make out the deeper meanings that

underlie the talked content. Through proper psycho-analytical and personality tests, the student must be classified under one of the categories. The last one is the doer. He/she learns better when they perform or implement the idea or theory into some experimental or practical model. They learn better when it involves some sort of activity or task. It must involve lots of gestures, hand and body movement and touching of materials. They are the people who can be trained best by hands-on training or workshop programmes. Sitting for long hours at same place can make the session mundane for them.

The various methods by which an average individual learns a new job, concept or task is by visual input, auditory knowledge or by doing them himself and learning in the process. The final one is kinaesthetic type of learning mechanism. The children who are prone to use visual means of information like displays, graphs, charts for better understanding of a concept are the ones gifted with visual learning style. They do better in their studies when taught using slides and overhead slide presentations or even textbooks. They differ from their counterparts who have a knack for group studies or learning from auditory inputs. Such people speak out the lessons loudly and memorize them by listening through the whole session. It has also been observed that such students have an inherent knack in music and can study better when some soft instrumental music is played. There is yet another class of learners, who are better off doing some activity rather than understand it by simply reading or writing. Psychological experts have found that these kind of learners indulge in some physical activity while concentrating on academic lessons. It maybe roaming around in a place, bouncing balls etc. They are also found to take keen interest in activities involving acting, sports etc.

3.1.2 Personality types – DISC profile

According to dermatoglyphics studies, a person can be categorised to having one of the following personality characteristics and behavioural tendencies which may be dominant, steady, complaint or influential ^[26]. For example, a person with a loop on his left thumb is of steady nature whereas one with a whorl is a complaint or dominant one, depending on the type of pattern. The four major personality types include Dominant, Influential/Inspiring, Steady/Sufficient and Compliant/Cautious. The personality types can be well understood if they are measured in terms of their social and professional behaviour. The dominant class of personality types are of outgoing nature with an attitude which is task oriented. On the other hand, inspiring/influential class is somewhat outgoing but of people oriented nature. The steady or supportive kind are reserved but people oriented, while the compliant/cautious lot is more of reserved but task oriented nature. A people oriented person loves working in team, is much

social and interactive in his/her behaviour towards others. On contrary, a task oriented person focusses completely on getting his job done with ultimate precision, right on time. An outgoing person does not keep himself confined to boundaries of his inner self when it comes to accomplishing a task, while a reserved kind of person is more of self-dependent in his professional or personal pursuits.

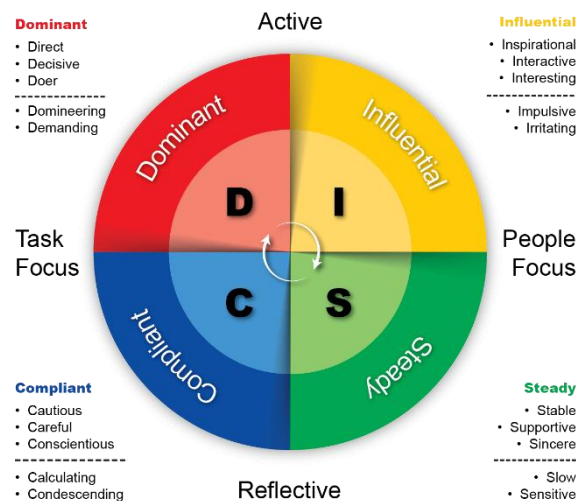


Fig 3.1. Dominant-Influential-Steady-Compliant personality profile

A person on general can be classified into one of the above mentioned personality types. Although, it may happen that he/she is a mix of any two, both natures getting expressed at different situations. A person can either be dominant, influential, and compliant or steady in nature, in a social or accomplishing a task in a professional environment, as illustrated in figure 3.1. The behavioural tendencies can be primarily be of four types. A person can either be outgoing, reserved, task oriented or people oriented.

3.1.3 Preferred acquisition style:

The modes of acquisition of knowledge ^[27], regarding a fact or happening from the surrounding are called the preferred acquiring styles. They may vary from self-cognitive, those who learn by reading, writing and teaching themselves, creating a way of their own; Affective learners, reverse thinking or contrarian as well as reflective learners. They have been proved to be quite scientific and relevant. For instance, people with naturally acceptable auditory efficiency are prone to verbal interactions either with fellow students or the educator. They become good orators, speakers, counsellors who are comfortable interacting with fellow individuals. On the other hand, kinaesthetic learners have the tendency to act upon a task for better understanding and learning. It is observed that the various learning

styles can be well off correlated with above mentioned preferred styles of information acquisition.

The self-cognitive style are very much dependent on themselves, when it comes to conceptualising a thing. Sometimes it becomes tough to make such subjects understand a prospect from an angle that is more widely accepted. They tend to learn from the mistakes they make over the course of experiencing something. Highly self-motivated, they believe in their own believes and acquired knowledge. Not much verbal when it comes to answering to others, they are goal oriented and find inspiration from their own achievements. They hold high self-esteem and are amongst those few people for whom personal space and decision making is more significant than accepting others' opinions. The affective type of learner are the ones who are affected and inspired from matters around them. It may range from learning something from media to getting motivated from inspirational biographies. They thrive upon others, to be guided or tutored upon, although it all may take place in an indirect fashion ^[28]. They conceptualise an idea all by themselves, but only after an example of its unmodified version has been experienced by them. Next comes the class of reflective learners. They have high potential of accumulating knowledge, especially when imparted on a one to one format. They can absorb all they have been taught but understand only when the teachings have been repeated ^[29]. They are highly driven by the recognition they get or the failures they encounter. Highly philosophical and conscious about the life, these kind of people reflect deeply upon day-to-day activities. The last category of acquiring styles is that of critical or reverse thinking contrarian type learners. They can be coached when given a challenge, they do not accept others' ideologies and tend to go against the tide. They are the ones who learn by reflecting upon the reverse reasoning of what they have been imparted to.

3.1.4 Innate quotients of intelligence

Intelligence is a metaphysical aspect. It might be understood or evaluated based on certain characteristics, qualities, or attributions. It is more of a phenomenon than an element. Intelligence includes various capabilities of a person to comprehend ideas, to think, learn, reason, strategize, memorize, create etc. it can never be bound up to the limits of training and academic education. An individual's instinctive ability to react to a situation with a particular action reflects upon his/her cognitive makeup. Addressing a situation requires a complex mix of various potentials that may be innate or acquired over period of time. However, the conscious or subconscious appliance of knowledge and skills to act upon a situation showcases his/her profound quotients of intelligence. So far, five major types of quotients of

conscious are discovered. They are Intelligence Quotient (IQ), Emotional Quotient (EQ), Creative Quotient (CQ), Adversity Quotient (AQ) and Spiritual Quotient (SQ). IQ is the ability to reason, think and adjust to changing environment. It includes the logical mathematical and linguistic intelligence types. Emotional quotient is the ability to think abstractly and understand others' emotions and manage emotional understanding to work better as a team. The emotional quotient of intelligence ^[30] affects the logical as well as linguistic intelligences. Creative quotient of intelligence is the ability to imagine new things, not experienced before. It is unique ability to create new things and bring down ideas to reality. It covers the musical and spatial intelligences. The interesting thing about the adversity quotient of intelligence is that it deals with the varying degree of competence a person shows while dealing with an adverse situation effectively and endure it for long term benefit. This quotient is important to determine the fact that who will stand to the situation and who will give up. Although it has been found that humans can learn to endure and face situations of crisis with mental perseverance.

3.2 Human brain

3.2.1 Left and right brain bias

The human brain is made up of two morphologically symmetrical cerebral hemispheres. Though, functionality of both vary. In terms of behaviour of a person, the logical – computational abilities are handled by the left hemisphere whereas the aspects of human life that deal with emotions, passion, creation, intuition, are all controlled by the neural circuitry of right hemisphere. Apart from it, there are lobes into which a brain can be segmented according to functions ^[31].

On the basis of classification into lobes, the brain can be studied as composed of frontal lobe, superior and inferior, parietal lobe, temporal and occipital lobes.

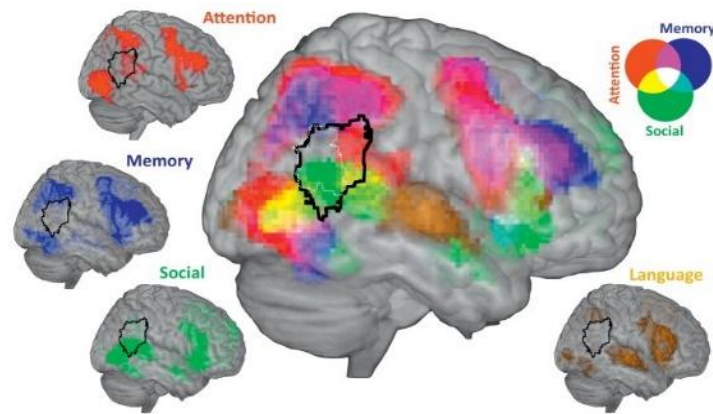


Fig 3.2. Brain functional localisation (courtesy: Trends in Cognitivescience)

Before studying the lobes, we must know what left and right halves of brain are responsible for, as far as human abilities and behaviour are concerned. The left hemisphere corresponds to academic expressions, which includes logical mathematical, computational as well as linguistic abilities. To look into something deeply, with proper perception and comprehension, deriving conclusions and logical verdicts, compare with past and present experiences, form strategies and sequential plan of actions, and practical and cautious planning of methodologies. On the other hand, people with pronounced right brain expression have the natural tendency to look at matters on a bigger holistic note. They are very random and subjective in thinking capabilities. They rely on emotional expressions easily, while behaving, and believe and appreciate objects with similar nature. They are found to possess defined spatial perception. Adventurous and carefree in nature, such people are impulsive and spontaneous in nature and take risks. Mild in nature, they see possibilities when things go out of way. Not much planned like their counterparts, they base their actions on intuition, feelings, fantasies and are very proficient at synthesizing concepts and ideas.

The superior frontal lobe deals with ability of a person to judge, have foresight on matters and affect motor organs for voluntary movement. Beyond the superior frontal lobe, lies the inferior frontal lobe which governs the bodily movements or kinaesthetic of humans. The control and coordination of basic physiological functions can be well off understood by studying lobes and their functions. But conceptualising intelligence and giftedness is altogether, a different approach.

3.2.2 Brain lobes functionality

The cerebral cortex can be divided into four sections, which are known as lobes. The Frontal lobe, Parietal lobe, Occipital lobe and Temporal lobe have been associated with different

functions ranging from reasoning, linguistic, mental, visual and auditory perception. Figure 3.2 gives a comprehensive illustration on the facts.

i) The Frontal Lobe (mainly used for Thinking and Imagination)

It is located at the front of the brain and is associated with reasoning, problem solving, Logical thinking, and computational processing, rational thinking etc. It has also been found that all the language related perceptions and tasks are coordinated from the frontal lobe. The tasks related to spatial intelligence are also coordinated from here. It may include visuo-spatial imagination, and conceptualization of some idea. At the back of the frontal lobe, near the central sulcus, lies the motor cortex. This area of the brain receives information from various lobes of the brain and utilizes this information to carry out body movements.

ii) The Prefrontal lobe (corresponds to Mental Ability)

The anterior (front) portion of the frontal lobe is called the prefrontal cortex. It is very important for the "higher cognitive functions" which comes under the metaphysical domain. This aspect of one's personality has a major contribution towards her overall persona. The prefrontal lobe has been found to coordinate this higher level consciousness. However, it assists an individual in planning, management, communication, coordinating, controlling our behaviour and emotions. It also regulates our creative ability, leadership qualities, intuition and visualization.

iii) The Occipital Lobe (primarily used for Visual Perception)

It is located at the back portion of the brain and is associated with interpreting visual stimuli and information. The primary visual cortex, which receives and interprets information from the retinas of the eyes, is located in the occipital lobe ^[32]. The left part controls Visual Identification, observation and reading comprehension and the right part controls visual and image appreciation ability.

iv) The Parietal Lobe (governing Kinaesthetic Ability)

It is located in the middle section of the brain and is associated with processing tactile sensory information such as pressure, touch, and pain. A portion of the brain known as the somatosensory cortex is located in this lobe and is essential to the processing of the body's senses. It is responsible for Movement differentiation, Physical Movements, Operation understanding, Bodily mobility, rhythmic movement, muscle coordination & Physical appreciation.

v) The Temporal Lobe (governing Auditory Perception)

It is located on the bottom section of the brain. This lobe is also the location of the primary auditory cortex, which is important for interpreting sounds and the language we hear. The

hippocampus is also located in the temporal lobe, which is why this portion of the brain is also heavily associated with the formation of memories. The left part controls Phonics differentiation, Language understanding & Sound Identification ability and the right part controls auditory and music appreciation ability.

3.2.3 Intelligence and giftedness... explained!

Getting to know how people perceive what actually intelligence is, different answers are bound to surf. As much as it varies from one culture to another, so does it from what different members in the same culture value the most. On an average, intellect or giftedness can be defined as above average level of intelligence in one or more behaviours.

An intelligence refers to complex bio-psychological potential of human beings to process certain kinds of information or data or input from the nature around him in a way of his own. It henceforth, involves different processes that are carried out by dedicated neural network and connectivity. It is of no doubt that different intelligences have their own characteristic neural processes. They may have been incorporated from his/her home environment, peer group, social circle or various daily experiences that came across. The mind adapts to function in a way it has decided on its own and which suits the optimal requirements of the person.

From evolutionary point of view, it is evident that each kind of learning ability or intelligence was not as self-content as it seems. Once a capacity emerged, on how to deal with contents of predictable world, there is nothing that forces it to remain as original it was, during conception. A human mind has the ability to compute. Whether it be a language or number or social relation or the spatial relations. It becomes far easy going had it been his/her inherent domain capability.

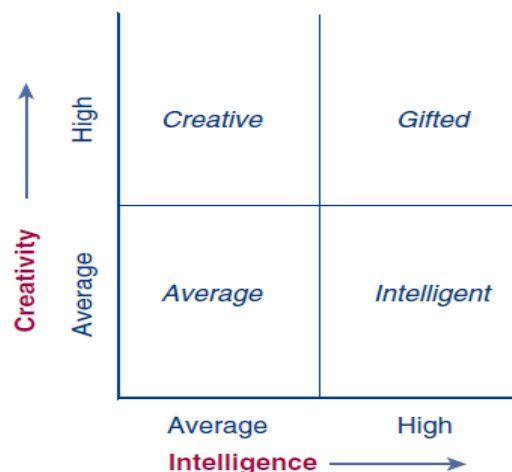


Fig 3.3: Creativity vs Intelligence chart

3.2.4 Role of genetic makeup

If natural inborn talent or giftedness is to be studied, then we need to focus on an individual's genetic makeup ^[33]. Researchers study identical twins to distinguish between the level of intellect contributed from gene and the remaining, which arises due to environment factors. This is necessary because some intellectual traits of humans are found to express fully when conventional style academics are imparted to the subject. To discriminate between the intellects shown by average and above average people, marker genes are selected which are found to contribute whatsoever, to intellectual capabilities. Although, such participation of genes in intelligence is very minor. But studying genes can be a task of controversy because these trait expressing genes characterise differently when provoked in different environments. Hence, great deal of indifference and variability can be observed. It is also to be noted that genes express differently in various socio economic conditions.

3.2.5 Is brain structure related to intelligence?

Over the years of strenuous study, developmental biologist have pondered over the idea of relating how the structure of brain relates to how we behave, perceive, invent etc. It cannot completely be ruled out that such a relation exists. Analysing section of brain that processes sophisticated information, it is found that cortex and its development has major role to play. This part of brain continues growing differently according to various environment and genetic factors, up to the age of 22 – 24 years. Majority of neurons are bundled in here and as they grow in number, thicker does the cortex get. But brain has its own way of dealing with redundant neurons. The ones not in use for prolonged periods get removed and cortex becomes thinner. This development already takes place when the subject is in his/her teens. Scores of studies and researches have shown that greater volume of grey matter have been found in and around both frontal and parietal lobes, contrary to earlier theories that only accounted for frontal lobes. The Parieto-Frontal Fit (P-Fit) theory ^[30] exclaims that high intelligence is related to higher processing power of information with speed. Such activity takes place in regions associated with attention, memory as well as complex cognitive functions like language and processing of sensory information.

3.3 Multiple intelligences

Human intelligence is the ability to learn, conceptualize, and derive meaning from pre-perceived consciousness from society or self and then applying reason or logic. Other cognitive abilities that may follow include ability to solve a problem, make decisions, retain in memory and using some set protocols of communication. Humans are exclusively known

to communicate in verbal language. To think and reflect upon, makes the man a creation unique in its own terms. Robert Stenberg provided a formal definition as “*your skill in achieving whatever it is you want to attain in your life within your sociocultural context by capitalizing on your strengths and compensating for, or correcting, your weaknesses*”. Path breaking research was done by Harvard professor Dr Howard Gardener. He claimed that conventional idea of evaluating a person based on his intelligence quotient, which according to him, was based only on logical-computational and linguistic ability and to some extent, assess spatial intelligence, was not enough to quantify the skills of a person in a holistic way [31]. According to him, intelligence was something defined as, “*a biopsychological potential to process information that can be activated in a cultural setting to solve problems or create products that are of value in a culture*”. Though never peer reviewed, Gardener’s claim remains debatable till date. He was criticized for being biased politically so as to appreciate the inherent uniqueness in every individual. Still, his works provide a new dimension altogether. Dermatoglyphic experts could relate themselves most. When talking of multiple intelligences, mutually exclusive but effective personality types come under the scanner. Other well-established theories of intelligence including psychometric approaches of Robert Stenberg’s Triarchic theory of intelligence, A. R. Luria’s PASS theory of intelligence and Piaget’s theory of cognitive development have been strictly kept off the pages due to their insensitivity towards the matter of relevance. The theory of multiple intelligences focusses primarily on seven types of intelligence, namely – logical – mathematical, linguistic, spatial, bodily – kinaesthetic, interpersonal, intrapersonal and musical. Later on, two more abstract kinds were included. These were natural and existential kinds of intelligences. It is anticipated that every individual has all these intelligences to some extent, but the difference lies in the pattern of how strong or weak is the understanding of them. Howard described them as follows

3.3.1 **Visual/Spatial**

Ability to perceive and mentally manipulate a form or object, and to perceive and create tension, balance and composition in a visual or spatial display [37]. They showcase a strong knack to create visual-spatial representations of the world and to transfer those representations either mentally or concretely. They have the ability to think in three dimensions. Core capacities include mental imagery, spatial reasoning, image manipulation, graphic and artistic skills and an active imagination.

Sailors, pilots, sculptors, painters and architects all exhibit spatial intelligences. Young adults with these kind of intelligence maybe fascinated by mazes or jigsaw puzzles or spend free time drawing or day dreaming.

Learning visually and organizing ideas spatially. Seeing concepts in action in order to understand them. The ability to "see" things in one's mind in planning to create a product or solve a problem.

3.3.2 **Verbal/Linguistic**

Ability to use language to excite, please, convince, stimulate or convey information. Involves not only ease in producing language, but also sensitivity to the nuances, order and rhythm of words ^[37]. It is the capability to use language to express what is on the mind and to understand other people. Any kind of writer, orator, speaker, lawyer or other person for whom language is an important stock in trade has great linguistic intelligence. It is the most widely shared human competence and is evident in poets, novelists, journalists and effective public speakers.

Young adults with this kind of intelligence enjoy writing, reading, telling stories and doing crossword puzzles.

Learning is through the spoken and written word. This intelligence was always valued in the traditional classroom and in traditional assessments of intelligence and achievement.

3.3.3 **Mathematical/Logical**

Ability to calculate, quantify, consider propositions and hypotheses, explore patterns, categories, carry out complete mathematical operations and relationships by manipulating objects or symbols, and also to experiment in a controlled, orderly way ^{[37][38]}. Ability to reason either deductively or inductively and to recognize and manipulate abstract patterns and relationships. Thus it enables the person to perceive relationships and connections and to use abstract, symbolic thought, sequential reasoning skills as well as inductive and deductive thinking patterns. This type of intelligence is usually well developed in mathematicians, scientists, detectives. Young adults with lots of logical intelligence are interested in patterns, categories and relationships. They are drawn to arithmetic problems, strategy games and experiments.

Learning is through reasoning and problem solving. Also highly valued in the traditional classroom, where students were asked to adapt to logically sequenced delivery of instruction.

3.3.4 **Bodily/Kinaesthetic**

Ability to use fine and gross motor skills in sports, the performing arts, or arts and crafts production. Body smart, as they are called, these kind of people are able to manipulate

objects and use a variety of physical skills. This intelligence also involves a sense of timing and the perfection of skills through mind-body union. Bodily Intelligence involves using the body to solve problems, to create products, and to convey ideas and emotions ^{[37][39]}.

Athletes, dancers, surgeons and craftspeople exhibit well developed bodily kinaesthetic intelligences.

Learning through interaction with one's environment. This intelligence is not the domain of "overly active" learners. It promotes understanding through concrete experience.

3.3.5 Musical/Rhythmic

Ability to enjoy, perform or compose a musical piece pertains to above average musical intelligence ^{[37][38]}. Includes sensitivity to pitch, rhythm of sounds, as well as responsiveness to the emotional implications of these elements. It is the ability and knack to discern pitch, rhythm, timbre and tone. This intelligence enables us to recognise, create, reproduce and reflect on music, as demonstrated by composers, conductors, musicians, vocalist and sensitive listeners. Interestingly, there is often an affective connection between music and the emotions; and mathematical and musical intelligence may share common thinking processes. Young adults with this kind of intelligence are quite aware of the sounds that others miss.

Learning is through patterns, rhythms and music. This includes not only auditory learning, but the identification of patterns through all the senses.

3.3.6 Intrapersonal

Ability to gain access to understand one's inner feelings, dreams and ideas. Personal knowledge turned inward to the self. This form of intellect entails the ability to understand one's own emotions, goals and intentions. It is the kind of intelligence of a person that deals with sensitivity and capacity to tackle deep questions about human existence, such as the meaning of life, why one is born in this world, what is the purpose of one's existence, why do we die and how did we get in here. They have the capacity to understand oneself and one's thoughts and feelings and to use such knowledge in planning and giving direction to one's life. Intra- personal intelligence involves not only an appreciation of self but also the human condition.

Such young adults maybe shy. They are aware of their own feelings and are self – motivated. Learning is through feelings, values and attitudes. This is a decidedly affective component of learning through which students place value on what they learn and take ownership for their learning.

3.3.7 Interpersonal

Ability to understand other people, to notice their goals, motivations, intentions and to work effectively with them ^[40]. Empathize with others, observe and understand others' moods, feelings, temperament. It is the ability to understand and interact effectively with others. It involves effective verbal and non-verbal communication, the ability to note distinction among others, sensitivity to moods and temperaments of others, ability to entertain the people's perspectives.

Teachers, social workers, actors, politicians – all exhibit interpersonal intelligence. Young adults with this kind of intelligence are leaders among their peers, are good at communicating and seem to understand others' feelings and motives.

Learning is through interaction with others. Not the domain of children who are simply "talkative" or "overly social." This intelligence promotes collaboration and working cooperatively with others.

3.3.8 Naturalist

Ability to recognise flora and fauna, communion with the natural world and its phenomena. This kind of talent designates the human ability to discriminate among living things as well as sensitivity to other features of the natural world like clouds, rocks configurations. This ability was clearly of value in our evolutionary life when we were hunters, gatherers and farmers and it continues to be a central in such roles as botanists and chef. Involves the full range of knowing what occurs in and through our encounters with the natural world including our recognition, appreciation, and understanding of the natural environment ^[41]. It is also speculated that much of our consumer society exploits the naturalist intelligences which can be mobilized in the discrimination among cars, sneakers and kinds of makeup and the like.

Learning is through classification, categories and hierarchies. The naturalist intelligence picks up on subtle differences in meaning. It is not simply the study of nature; it can be used in all areas of study.

3.3.9 Existential

Learning by seeing the "big picture": "Why are we here?" "What is my role in the world?" "What is my place in my family, school and community?" This intelligence seeks connections to real world understandings and applications of new learning ^{[38][42]}.

3.3.10 Pedagogical

Intelligence that allows human beings to convey knowledge and skills to others. Assessing humans based on IQ is like having a general purpose computer. If the system performs well, it implies a higher IQ, a normal IQ for average and low IQ for poor performances respectively. But the concept of MI, on contrary, relates to having several relatively

independent computer systems. A person with high/low linguistic ability may or may not have musical ability. And the beauty lies in the fact that one cannot be predicted from other. Processing of information corresponding to different intelligences might prove to be similar for many people but some of them are more customized. The genetic makeup as well as experiences from environment contributes to the uniqueness and exclusivity. Even among identical twins, the experiences in utero are different, though the genetic profile is same. From an educational point of view, it can be stated that some students learn best by building something, some learn from reading or listening to others' perception of the matter. Some may even learn when the story has been acted out. We live in a preconditioned way, where every intelligence type pertains to certain contents of the world. Rarely does it come to be noticed, this notion can be contravened. For example, the neural processes that evolved for recognising and distinguishing species in nature is nowadays used in recognizing commercial products in sociocultural platforms. It signifies that evolutionary natural intelligence can be well off applied in cultural perspectives of modern man. Unless validated models of neural processes occurring while a certain intelligence is in use, one cannot firmly claim that multiple intelligences are mutually exclusive in functionality.

3.4 Brain Functionality under Arts training

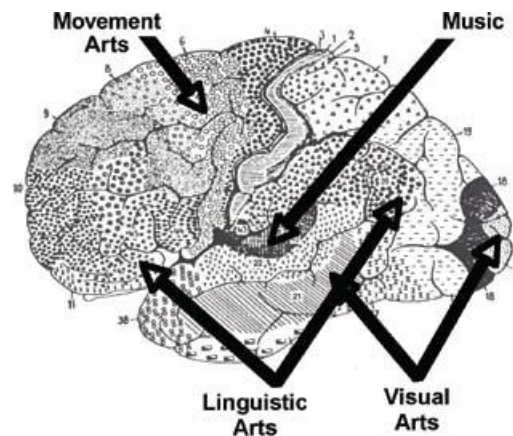


Fig 3.4: Functional localization for brain activity in during art training and performance

Recent studies in focussed training programs for human brain have shown that long term, dedicated practice of any art form can immensely contribute to enhancement of cognition. The association attention related neural pathways have with focussed art training and practice have strong scientific foundation. Brain is highly flexible. Whatever we do in our daily lives leave profound impression on neural circuitry. Along with attention, other cognitive traits like better learning and memory are also enhanced. However, increment in intelligent quotient

cannot be directly related to arts training, because IQ includes many variables and leave others, which directly or indirectly gets affected from art education. The infamous “Mozart Effect” was testified scientifically in 1993 in a paper ^[43] that was published in *Nature*. According to it, college students who were trained in music had enhanced spatial intelligence. The spatial intelligence is also significant for performing tasks pertaining to logical and mathematical intelligence. Different aspects of arts have underlying governing locations within human brain, as illustrated in figure 3.4, become highly active when under repeated use. The enhancement of attention network ^[44] occurs in the following neural networks. The first one being the alerting network, second one being orienting network and the last one being executing network. The first one facilitates the brain to get in a state of alertness and focus. The second network enables it to concentrate on the particular diversion recently occurred. It becomes the primary object of focus and complete attention. The last network is the executing one, which does the actual affective function. Subjects try to overcome the inhibitory thought processes that may hamper the learning in the focussed direction, and act in the direction of achieving the desired ^[45].

3.5 Fingers and dermal prints

3.5.1 Fingerprints

Fingerprints are the mirror to a human being’s individuality. The complete information regarding his genotypic makeup is claimed to be reflected in works of established researchers. It is no coincidence that epidermal ridges on skin of our limbs form certain patterns, mostly of which are curvilinear. Some resemblance can be found in sulci or cortical grooves in brain hemispheres. It is also evident that various limb terminals are actually nerve endings to special brain lobe locations. The terminal organ skin is highly sensitive. Till date, researchers have widely used fingerprint minutiae as points of reference to establish any uniqueness. In this paper, ridges and furrows have been studied and linked with localised brain functionality, learning style and socio-cognitive behaviour. They develop during the 13th to 18th week of gestation. The anatomy of fingerprints and their growth is well illustrated in this image.

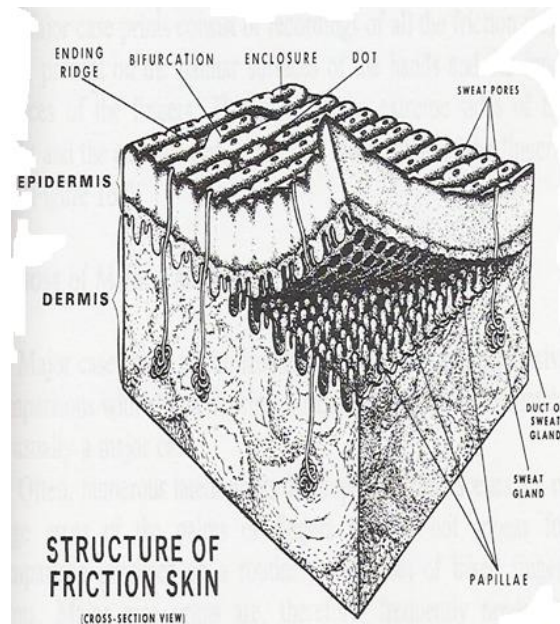


Fig 3.5: Cross sectional structure of friction skin

The skin is composed of three anatomical layers of dermal tissue cells ^[46]. These are epidermis, dermis and hypodermis. The ridges surface or volar cells, as they are primarily called, have morphology that suits their functionality. Between the epidermis and dermis, there exists a layer of dermal papillae. This layer forms the patterned ridges. Each of the ridges have pores on them, which secrete sweat and cause the finger pads to leave invisible to eyes, latent fingerprints.

The ridge patterns have been broadly classified into five types, namely, arch, tented arch, whorl, ulnar and radial loop. A person can have any of the above in any of the fingers. Still, majority of fingerprints found in population survey shows that 70 percent of the prints are loops, 20 – 25 percent being whorls whereas only 5 to 10 percent count as arch or tented arch patterns. Studies conducted have proven that chance, heredity as well as genetic makeup of a person all contribute to the type and occurrence of a pattern in a finger. Some studies done on twins have concluded that monozygotic or identical twins have similar but not identical patterns. Though the studies use a vast expansive data of minutiae points, here we have restricted ourselves to the core of patterns. Most of the prints have equally spaced ridges.

3.5.2 Fingerprint acquisition techniques

Fingerprints can readily tell about the kind of personality a person may have, his/her preferred learning style as well as mode of easy, naturally acceptable learning. Fingerprints can be acquired either physically or using some electronic equipment that captures the print ^[47]. The physical means of acquisition include fingerprints that are plastic, latent or even

visible in nature. The plastic fingerprints are gathered by taking the impression on soft material like butter or soap. The latent fingerprints are so far, the most effective ones [48]. They are generated due moisture and oil secretion from sweat glands present beneath the skin. Since they are usually invisible to the naked eye, hence insufficient to be used for pattern recognition, unless developed. The process may include coloured powder sprinkled on them or chemical treatment. The chemicals used are iodine, ninhydrin or silver nitrate. The patterns may also be acquired by digital scanner. It uses advanced CMOS sensor technology to deliver high quality fingerprint images. Scanning is usually done at a resolution of 500 dpi on a scanning window of around 16 mm by 24 mm. The images are 8 bit 256 grayscale. The fingerprints can be either a loop, a whorl or an arch. A loop is defined by a pattern where ridges start from a side, rise towards the centre and return back to the side where they started from. Loops usually have one delta and can either open towards the thumb or the little finger. They are the most frequently occurring ridge patterns, occurring in around 60 percent of fingerprints. A whorl is the next most frequently occurring type of ridge pattern. A whorl is characterised by two deltas and one central circular core. The core may have different patterns. It may be spiral, concentric circles, vertically compressed circles or even of the shape of eye of a peacock feather. The ridges start from one end, rise and circle towards the centre and go down towards the other end. Each pattern characterises a different kind of cortical fold around the specific brain lobe the finger is associated with. Hence, the phenotypic makeup gets altered from man to man, finger to finger. Other studies have primarily focussed on minutiae points which are specific ridge sections that are somewhat present in almost every fingerprint. At least 12 minutiae points are needed to validate a person's identity. There are around nine types of such recognised minutiae points. They are, namely, bifurcation, trifurcation, dot/ island, spur/hook, bridge, delta, pore, crossover, lake etc.

3.5.3 Connection of fingerprints with brain

i) Origin of Epidermal Growth Factor (EGF) and Neural Growth Factor (NGF)

The key to the fact that fingerprint patterns are related to brain's cortical folds is held by embryogenesis. Embryogenesis is the study of development of a single cell into a complete complex organism. All life forms initiate from a single cell, which is called the embryo. It is the latter stage of zygote, which is the result of fusion of the male and the female gamete cells sperm and ovum, respectively. This unicellular entity develops into a formation that consists of three distinct layers of cells. These layers are formed in similar manner with little

differentiation. They are namely, Ectoderm, the outer layer, Mesoderm, the middle and Endoderm, the inner one.

It has been found through years of toiling research that there are several neuro-physiological processes and interactions that occur amongst these layers of cells, which further differentiate into various organs having distinguished biochemical processes along with different morphology. Hence, it is queer to relate something like neuronal activity to that completely exclusive, skin or epidermal growth ^[49]. Path breaking research was done by Dr Rita Levi-Montalcini and Dr Stanley Cohen in the field of Physiology supported biochemistry that won them the Nobel in 1986. Their work has been summarized under for further reference.

The fact has been massively supported by the work by of Canadian neurobiologist Wilder Penfield ^{[50] [51]} who established the functional connection between fingerprints and various locations of human brain.

ii) Evidence for relation between brain and fingerprints

The neural tube defect, also famously known as Anencephaly is the absence of the prime brain portions, skull as well as scalp. It occurs due to failure in complete and proper development of cephalic end of neural tube. A foetus born with such deformity usually has no forebrain. The forebrain is the largest portion of a mammalian brain and governs all thinking abilities and organ coordination functions. It has been observed that such babies are devoid of any fingerprint ridges too.

Several medical conditions have also been correlated to fingerprints and there pattern occurrence. Such conditions need be congenital defects. They are Down's syndrome, Klinefelter's Syndrome, Cerebral Palsy, Schizophrenia, congenital diabetes and cardiac diseases etc.

In the path breaking neuro-embryology research undertaken by Dr Stanley Cohen, under the supervision of Dr Rita Levi Montalcini ^{[52] [53]}. They studied nerve growth activity around the periphery of a grafted tumour tissues on healthy chick embryos. It was also found that this nerve growth factor, when extracted from snake venom and purified, was thousand times more potent in developing growth nerves when extracted from snake venom rather than extracted from tumour. Next, the epidermal growth factor was studied for assessing metabolic effects of EGF. It stimulates the growth of fibroblasts in human tissues. It was found in human urine. After purifying it, they injected it into mice. The results were astonishing. The mice foetus opened eyelid earlier than normal. It is commonly called as human-EGF. The

functional loci of both EGF and NGF are related and regulated by amino acid sequence of transforming protein.

iii) Connection of brain locations to fingers

Advanced studies in genetics and developmental biology ^[54] have claimed that the different lobes of human brain are physiologically connected to different fingers of both the hands. The functional coordination governed by the left half of cerebral hemisphere is related to the fingers of right hand and vice versa. Hence, the convergent left half of brain is connected to the fingers of right hand, the thumb is coordinated by the superior frontal lobe, index finger is connected to the inferior frontal lobe, middle finger with parietal lobe, ring finger with the temporal lobe and little finger with the hind part of brain, which is the occipital lobe. Similarly, the left half of brain is connected to the same lobes of brain. Every lobe area is responsible some or the other sensation of surrounding. However, there occurs slight difference between the functions of right and left halves of brain. Figure 3.6 duly explains the above mentioned theory.

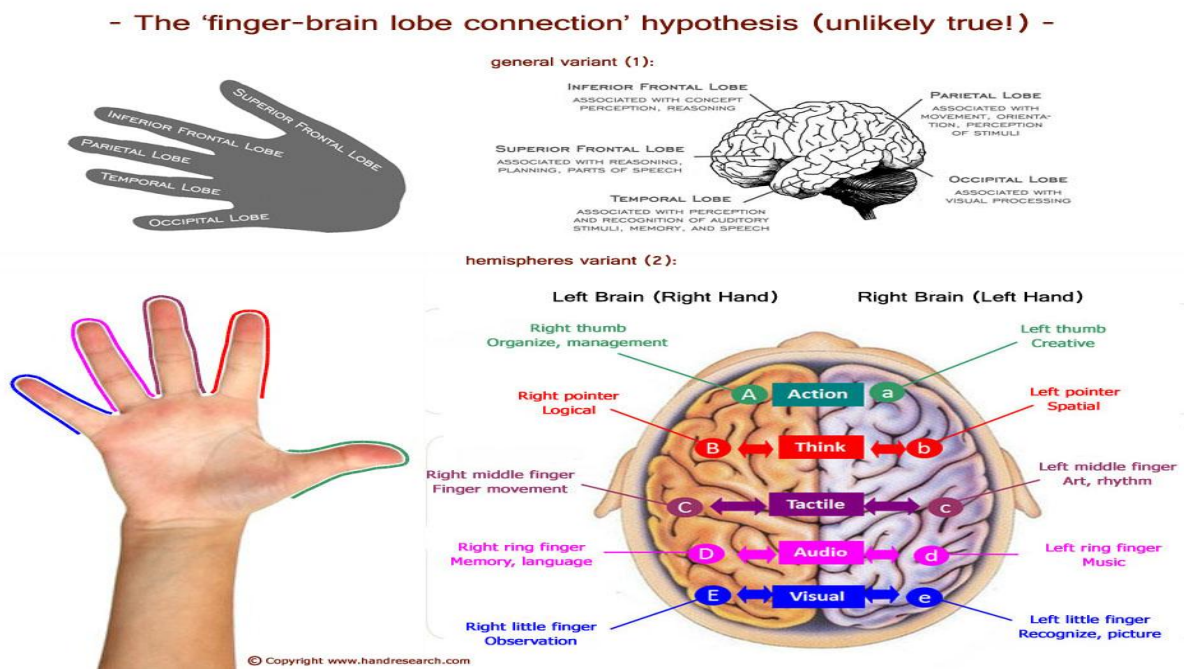


Fig 3.6: Finger-brain lobe connectivity theory ^[15]

3.6 Fingerprints and behaviour

Human behaviour is fuzzy in nature. It cannot be discrete like some conventional mathematical model. It may be understood by an example. When a group of people are assigned a project, the task may be executed on a conservative or liberal note as per the

requirements. But whenever the same job is assigned to each person individually, the way of approaching the situation may be very distinct from one another. Their thought process would be majorly effected by certain beliefs or principles of their own rather than competing beliefs from others. Personality and behaviour are so vague and imprecise. They are manipulated, torn by conscious ego, sub-conscious superego as well as the unconscious id. While experiencing a lifetime with certain aspects of life, one tends to pick up things that other people do not. Fingerprints are blueprints to one's self ^[55]. They can tell how perception, emotions, cognition, motivation and finally, the action of a person towards a situation are directed. A person may be very restricted and demands logic while accepting someone else's notion regarding a subject matter, but then at the same time, he/she might feel too unwise to share his/her ideas with others. Such a person is consciously an independent thinker, but then his intrapersonal intelligence restricts him to his own boundaries.

A person has loads of unused intelligence that he/she may be unknown of. It is a matter of utter importance that they be made acknowledged of their hidden talents and potentials in order to help them lead a more fulfilling life. Some people are born to create music like no one else can, while others do much better than others when they involve their physical beings into some act. This may either be playing some sports or acting on stage, they cannot yield high when forced into office works or engineering solutions. A person is what he is born with, and what is better than to recognise his/her innate talent and nourish this prospect. With professional guidance and grooming, an average individual can become someone no one ever imagined of.

It is very important for parents, teachers and other acquaintances of a person to understand that no one is too highly abled than their own wards. Also, no one is born with similar capabilities as others. But each and every person has his/her own talents, some in conventional and some in unconventional fields of life. This uniqueness balances the society and there is huge need to understand this difference.

3. 6.1 Arch



Fig 3.7: Arch pattern

Arches account for only 5 – 10 percent of the total fingerprints that are found in any random sample space. People with arches on any finger have showcased settled, rigid or and practical approach towards the corresponding brain functionality tasks. Since they are organised and stubborn in what and how they intend to execute the particular task, these people work in sequential steps. However, this leads them to shadow their emotional quotient in the concerned prospect. People with arch pattern prefer simple lifestyle without much ambition of fast life with money making pursuits ^[55] ^[56]. They prove skilful in doing anything that they are trained in. Although, brand names and money does matter to them. They have the capability to improvise efficiently, using anything in surrounding. They do not plan much ahead in time and tend to live in the moment. This is the very reason, they easily get into trouble. Because they cannot visualize consequence of events. Not very open-minded though, they love socializing with people. A knack towards traditional music has also been observed among people with arch patterns.

However, documentation on specific brain functionalities corresponding to thumb, index, middle as well as ring fingers are available. According to it, if arch is present on left thumb which is responsible for creative intelligence, then the person is insecure in interpersonal relationships, keeps correspondences transparent. The individual has been found to have high priority for discipline and punctuality. Apart from it, excellent skills in profession along with infinite learning ability have been observed on him/her. On the other hand, arches on right thumb indicates patience and firmness for organisation and managerial aspects in personal as well as professional life. If arches are present on the index fingers, then the individual shall have practical approach in cases requiring spatial as well as logical intelligence. The middle finger of left hand depicts the fine art and rhythm perception whereas the right one deals with finger movement and brain coordination. People having arch pattern on their middle fingers have an intellectual pursuit for the simple tasks they prefer to perform, related to performing or creating sophisticated art forms. However, the brain function related to ring fingers on

either hands are quite contradictory from elemental perspective. The left ring finger represents part of brain responsible for understanding and creating music. Quite surprisingly, the right ring finger is connected to areas of lobe governing memory and linguistic abilities of an individual. Such people have great craftsmanship in particular music form they pursue in career. They have shown an inherent knack towards artistic aspects of simple art forms like dance. However, no documentation is available for the presence and importance of arch on little finger.



Fig 3.8: Arch with Loop

If an arch is present such that there is an adjoining loop to it, in any of the above mentioned fingers, it indicates higher intellect in creativity of abstract domains like medicine or science. They have also displayed sharper memories.

3. 6.2 Tented arch

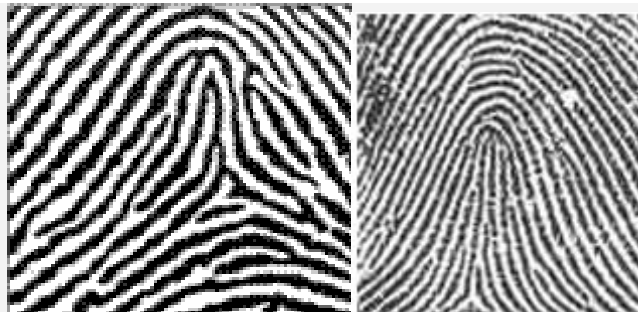


Fig 3.9: Tented Arch

Tented arch is a pattern that is characterised by a straight upright ridge at the core of a simple arch pattern. People having tented arches have all the general arch characteristics. But such individuals show inconsistency in their performance in tasks related to the specific related intelligence. They lack steadiness and end up displaying nervous behaviour. Such people come under the effect of easy emotional manipulation by others. Although, they have been found to have a special liking and attachment to musical tunes notes. It comes naturally to them.

People with tented arches can easily adapt to new environment and circumstances. They do not face trouble while changing jobs and places. They always wish to keep people happy and

satisfied. They have strong faith in themselves and what they choose to do. Hence, they are not easily manipulated. It takes scores of logic and effort to convince them of anything outside their own thought process. They strictly abide by rules and restrictions. Although, they do not tend to take much interest in art work of others, they themselves follow artistic trends.

Individuals having tented arch patterns want stability in their lives, when it comes to relationships and career. They are emotionally dependent upon close family relatives. Though not very introvert, they love spending time with themselves, reading books and novels, going to movies. They despise taking risks in life and crave for stability in personal as well as professional life. Hence, they are a good fit for administrative jobs.

3. 6.3 Loop

Loops are the most commonly occurring features on an individual's fingerprints as well as in an arbitrary sample space of several fingerprints ^[57]. They are characterised by ridges that start flowing from a side of the fingertip, loop around the centre of finger pad, and loop back to the same direction where they started from. These loops can either run towards or away from the thumb. Due to respective location of arm bones - Radia and Ulna, any loop opening away from thumb is an ulnar loop, and the one opening towards the thumb is a radial loop. They account for about 60 – 65 percent of total occurring patterns in whole worlds' population ^[58]. Hence, analysing them is very crucial. Primarily of easy going nature, such individuals have easiness of expressing themselves and are better at communication skills. They have ability to fare well in almost every aspect. They can maintain a balance between serious as well as humorous sides of matters. They fare better at jobs that require change of place and environment because of their adaptable nature. It has been observed that people having loops on their right thumb are caring and compassionate for others. Much of humanitarian natured. They have better memory of visual-spatial objects. On the other hand, loops on the left thumb indicates outstanding performers with respect to perception, imagination. They think and express straightforwardly and have little or no patience for long sessions of conversation or teaching. They usually fall victim to the existing education system. They feel bound to ask questions to their faculty which sometimes, may go out of course. If an individual has loops on all his fingers, that person has ability to survive most of the unfavourable conditions ^[59]. Although, such people hate to be cornered aside and can revolt back if not given prior importance. If there are six or more number of loops in a subject's hands, this signifies easy going affectionate nature, who can easily understand and

respond to others' mood changes. They are adaptable and show emotional plasticity or relaxation.

i) Ulnar loop



Fig 3.10: Ulnar Loop (Opens toward the little finger)

Ulnar loops correspond to sulci folds giving people ability to extract ideas from others, manipulate it their way and publish. They have the potential to observe loopholes in others and inculcate that quality into themselves. They are open to broad ideas, are mild in nature and take active participation in any conversation.

ii) Radial loop



Fig 3.11: Radial Loop (radius toward the thumb)

People with radial loops on their finger tips are enthusiastic in their pursuit towards goals. They have ability to improvise a great deal. They can readily idealise and conceptualise. If the pattern is present on index finger, the person is more of individualistic than in crowd. He/she lives and learns better on his/her own rather than in crowd. This supports the fact that they are unable to adapt to new environment, people and situations. Unlike their ulnar partners, who are very much flexible in their perspective, people having radial loops find it hard to accept others' ideas. Also, they are not much planned about their course of action. Although, what makes them stand out in a crowd is their ability to lead others. Most of them have been found to be self-indulged. They easily get bored of doing or pursuing same trade

over a longer period of time. They like change of profession. They are more of adventurous kind of person and always feel the urge to satisfy their inner need of newness and change. Though, stability is not much of an issue.

3. 6.4 Whorl



Fig 3.12: Composite Whorl

Whorls signify intensity of character and intelligence. Higher the number of whorls, stronger is the trait in the person. Also, whorl pattern combined with denser ridge counts between delta and core denote higher levels of understanding of corresponding cognitive abilities and human behaviour ^[59]. Such people with above average perception of things tend to repel monotonous day-to-day office jobs and occupations that require labour without creativity. This kind of person loves jobs that involve dynamism, research, creation and not just some mundane administrative job. They are easy on taking up new challenges everyday which involves involvement of new team members, execution of ideas, non-conventional methods of prosecution of methodology etc. Such people are more oriented towards technical careers. They have been found to excel in fields of engineering or architecture. If this person has other types of patterns, preferably loops on ring and middle fingers, a taste in artistic trends have been shown by them. Having a steady practical approach towards life, they do not tend to take life too easily. They remain productive in careers they aim for. People with number of whorls have also been found to be good orators ^[60]. Their speech is most of time, politically correct. All whorl patterns distinguish from each other, person to person in the sense that more complex the pattern is, more complex is the behaviour of the person. Hence, tender care needs to be taken of individuals having such patterns.



Fig 3.13: Target/Concentric Whorl

i) **Spiral whorl**



Fig 3.14: Spiral Whorl

A spiral whorl is characterised circular patterns that are in spiral shape at core. This pattern does have two deltas at both corners. They have vibrant surging kind of personality with fantastic grasping ability. They can easily understand the concepts and whatever knowledge is imparted. But they easily get affected by emotional manipulation of others. When they decide upon one goal in life, they are very determined towards achieving it. They put utmost efforts into it. They have displayed strong sense of self consciousness and immense will power to win a competitive situation. Spiral whorl individuals are self-motivated and self-driven towards their ideas and passion. Parents must act accordingly and utilise this innate quality in them.

ii) **Concentric Whorl**



Fig 3.15: Concentric Whorl

The concentric whorl pattern is characterised by having concentric circles of ridge formations. It is one of the whorl patterns having strong expression of corresponding intellectual trait. Having sharp minds, such subjects show discipline towards achieving goals set early in their lives. Such subjects are conscious about their image amongst others in the social environment. They have a decent nature although, they are quite aggressive towards acquiring what they aim for. It can be somewhat said, that their self-conscious nature leads them to work tremendously hard in that direction ^[60]. If this pattern is present on left thumb, then the person is very strict towards others. One has to request or beg for mercy from him/her. Such an individual lacks compassion and humanity. On the other hand, this pattern on right thumb shows that the subject is very precise about what wants in his professional life and works towards achieving it. They are not easily manipulated by others and remain very individualistic while pursuing their dream. They highly seek independence of thought and speech and are very straightforward when it comes to putting one's own thought amongst others. Since they do not tend to think twice before being vocal about what they think or perceive of others, they easily hurt people in the due course of action.

iii) Elongated whorl

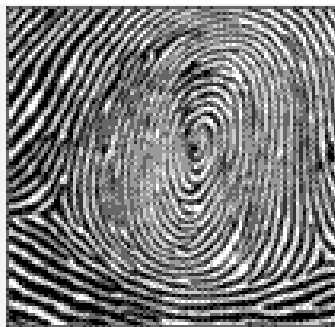


Fig 3.16: Elongated Whorl

Elongated whorl pattern is characterised by a long oval whorl flanked by two triradii on either sides. All other features of a whorl are also present in this type of pattern. They are highly focussed towards achieving the goal that they set for themselves. They take up goals too seriously and are quite aggressive and obstinate towards achieving them. Although they are of very decent nature, they are quite sincere towards their outlook towards others. They usually love doing multiple tasks all at one time, plan tasks in systematic manner and execute them well within time. They have immense ability to grasp goals and work towards the

required direction. They have high emotional quotient hence, they get easily manipulated emotionally. Unfortunately, sometimes this leads them into indecision, where they are stuck up in between logical and emotional sides of matters. They are good at managerial skills where they love analysing and recruiting multidisciplinary aspects. They depend upon the art of deduction. Their ability to analyse a situation without getting biased or overly stated, make them prosper in careers related to judiciary. Their logical analytical skills are also well above average and hence they are good with numbers and calculations ^[59]. However, they have a manipulative side to them ^[59]. It is their inability to cope up maturely with past experiences of emotional nature. They are quite vulnerable to their emotional lives. They keep all good and worse memories and can hardly let go of sensitive issues. They can become easily affected by churning past memories again and again. On the outside, they despise getting second to anyone. Overly ambitious, competitive and hardworking are some of the positive traits that a person with elongated whorl carries with himself regarding the particular intelligence associated with the finger on which this print is present ^[60]. However, researches have also found that if a spiral whorl is present, elongated in oval shape, the person develops some distinct behaviours other than those mentioned above. He/she becomes quite inadaptive of changing situations. Obstinacy might become a part of the personality.

iv) Imploding Whorl

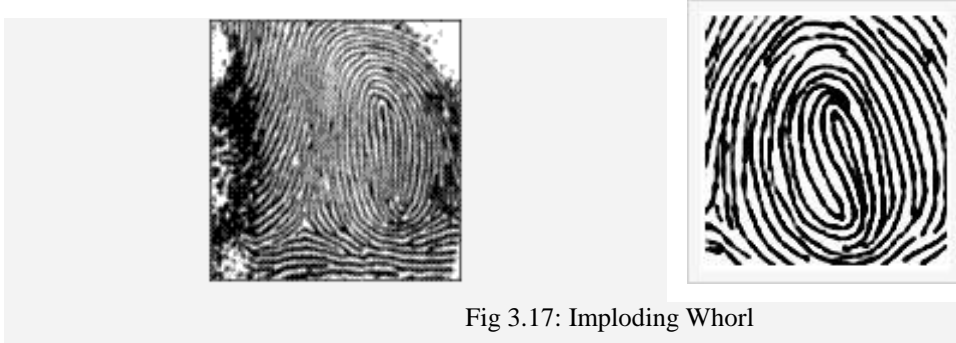


Fig 3.17: Imploding Whorl

It is one of the rare fingerprint patterns. It seems like a Tai-Chi pattern at the centre or the core, surrounded by multiple circular layers of ridges. Since the symbol has two symmetric but oppositely oriented formations, the subjects having imploding whorls showcase dual mindedness. Although they are efficient enough to finish off two different tasks, simultaneously. They are much of individualistic, seldom mingle with others in order to execute some task or plan. But they undergo tough ordeal while deciding upon something. Hence, they are not much suitable for jobs that need quick decision making, like executive and administrative occupations. Although, adding another feather to the cap, people having

imploding whorls are systemic thinkers. They can form systemic strategies. However, they are too worldly and materialistic. They seldom get affected by emotional ordeals of others. They do not hold idealism as one of their life path priorities. Hence, they are rarely the ones, who value morals and deep understanding and appreciation of life. They have also been found to lack open mindedness. They hardly keep into consideration other people's thoughts into their own course of action. On the other hand, they are highly self-conscious. They are not much of sentimental and lead life in a much practical, objective way.

v) **Composite whorl / Double loop:**

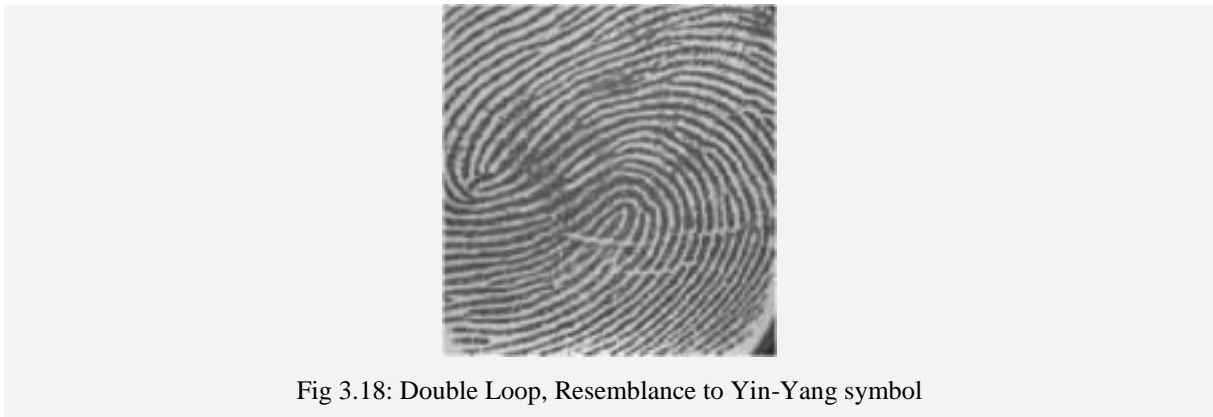


Fig 3.18: Double Loop, Resemblance to Yin-Yang symbol

Composite whorl or double loop is one of the rare fingerprint patterns ^[59]. It is either present on thumb or at most, the index finger. About 10-15 percent people have composite whorl pattern. Often resembling like the sign of Yin-Yang, this pattern derives characteristics of dual mindedness. People with such patterns on their finger tips are usually good at counselling others, facilitating their growth and achieving settlement. They have natural capability to judge fairly without any bias. Adding to unusual traits of such individuals, it has been observed that they have natural connection with abstract and spiritual dimensions. It may happen that some of them are “star people”. They subconsciously choose careers that involve objectivity and judiciary. It has been studied and found that they possess deeper conscious and feel the connections of life after death with events. Psychic readers claim such people have their third eye opened wider than average. Although such individuals may or may not perform conventional rituals but they do have deep interest in spirituality. It may surpass the common social meaning and understanding of religion. They readily accept other cultures and races and may even end up having multicultural relationship. They have this understanding of prioritising things above materialistic success. For them, hollistic spiritual well being and inner conscious holds a higher place, showing a true realization of universe.

However , such individuals do have some cons to their characteristics. Being dual minded, they



Fig 3.19: The Chi symbol

sometimes procrastinate important decisions and events in their life. They easily get into self doubts and end up being in a state of indecision. However, such traits have been readily linked to schizophrenia and split personality disorder by experts, but jumping to conclusion would prove to be a negative verdict. Composite whorls are patterns associated with higher psychic abilities and one should take intense care in handling subjects with such personalities ^[59]. That is not all, such people are eager to gain knowledge on everything they can lay their hands on. They are good at communication with others but reveal personal expressions to only chosen few. They have very systematic and patterned thinking and tend to be very practical and objective when it comes to maintaining interpersonal correspondences. They overindulge themselves by thinking way too much and sometimes, lose grip on planned course of action at the end. If this pattern is found on thumb, such a person is deemed to be a good judge of personal matters with ability to set goal for himself ^{[61] [62]}. This pattern's presence on index finger signifies ability to fairly judge other people. Since middle finger denotes firmness in decision making related to career. If the pattern is present on little finger, it will represent bisexual orientation.

vi) Peacock's eye whorl :



Fig 3.20: Peacock Whorl

It is again, one of the rare whorl patterns that contains a peacock's eye shaped loop contained inside a whorl. The core consists of more than one spirals which are lined by a straight line at one of the corners. It somewhat looks like the pattern on a peacock's tail feathers. This pattern should be having one triradius on either the left or right side. Some psychic readers consider this pattern to bring good luck upon the bearer. Along with having a discerning eye for matters requiring judgement, people with peacock eye whorl pattern have high degree of observational skills. They surpass others while in a competitive situation where there requires survival skills. They express themselves better, superiorly than others. Although it cannot be claimed that they are dominant beings. However, they have been found to possess outstanding leadership qualities. Hence, they are somewhat influential ^[60]. They have high perception of things around them. Some of other characteristic features include very sharp mind, hunger to gain knowledge, highly creative ability, especially in artworks. It is rare to have peacock's eye whorl in any other finger than ring and little fingers. These fingers are known for memory power as well as linguistic abilities and observational abilities in left hand respectively. On the other hand, ring finger represents musical perception and creation as well as little finger denotes pictorial perception as well as pattern recognition skills. Another skill of people having peacock's eye whorl is that they have effective convincing powers. They become good counsellors ^[61]. They are highly selective and maintain aesthetics in whatever they pursue.

Target centric ulnar peacock's eye (if print is of left hand) – Such a print signifies high perception than others, which indirectly denotes high intelligence. Such people also have good leadership skills. They have artistic bent of mind. They are highly focussed towards their aim in life. However, they are quite stubborn about their perspective and rarely consider other's advice or suggestions.

Spiral ulnar peacock's eye (if print is of left hand) – Such pattern signifies highly artistic abilities. They are more of passionate being, enthusiastic about what they do. They have commendable observational skills. They are mainly right brain biased person. Their creative intuitive abilities are highly enhanced.

Target centric radial peacock's eye (if print is of left hand) – Quite stubborn about what and how they think, people having peacock's eye whorl on fingers of their right hand, are highly competitive. For them nothing comes before life's goal on professional side. However, they hate to listen to others and take their suggestions. They are very self-driven.

Spiral radial peacock's eye (if print is on left hand) – Such people stand out in a crowd when it comes to deciding upon life's career choices. They feel bound to travel the path less

travelled. They seldom follow trends in whatever they pursue. It is also the reason why they are highly creative and passionate. They are born to not within the conventional system of living. Their perception of matters of general interest also differs hugely from others.

vii) Accidental whorl/ Variant

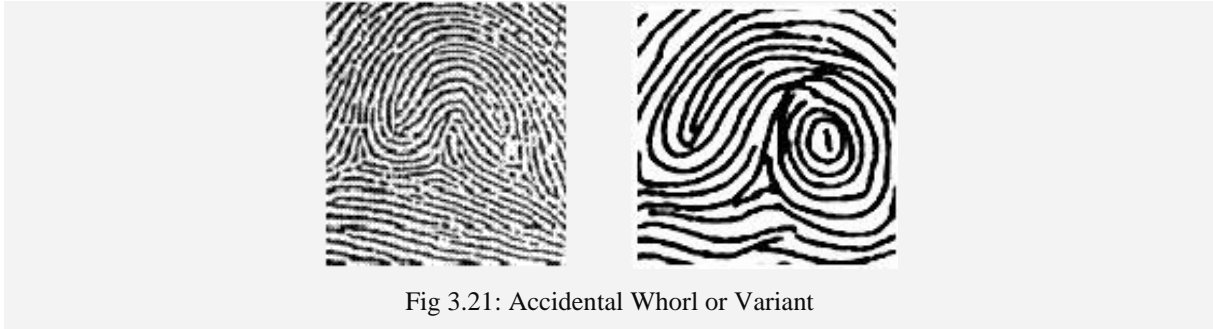


Fig 3.21: Accidental Whorl or Variant

When a pattern cannot distinctly be able to categorise into any of above pattern types, consists a mix of two or more above discussed patterns like fusion of concentric whorl and inverted loop etc., it is claimed to be a variant pattern. They do not contain any plain arch or loop, be radial or ulnar. They do not include any conventional pattern. People with accidental patterns are different from others. They like to express themselves in ways different from others. Sometimes they may hurt others in the process. But they do so out of no deliberation. However, this may create misunderstandings. Parents and teachers need to have more patience mingling with such individuals.

3.7 How the combination of patterns affect?

It is a matter of immense concern that what combination of patterns does an individual carry, as his/her blueprint to behaviour. If the whorl patterns are denoted by O, and arches are represented by W, due to the circular and wavy nature of the patterns, respectively. Although there can be 3^5 combinations of fingerprint patterns, loosely based upon all whorls categorised as one, both loops as a single category and both arch and tented arch patterns grouped into one category of arches, assuming that patterns under single category correspond to more or less similar kind of behaviour among humans ^[63].

i) Shape: OOOOO (all whorls)

A person having whorls on all his/her fingers is confident in nature. Such an individual has a strong character and influential personality. But it has been observed that they have high temperament. It can be very well concluded from such observation that with time and coming

opportunities, this person has the potential to mend his life and fate dramatically. Although, it can be suggested that, incurring patience and calmness in his attitude shall prove beneficial.

ii) Shape: WWWW (all waves)

Considering the fact that each pattern design is related to neocortical fold makeup and neural circuitry, an individual possessing such a combination is straightforward in social interactions. He/she is most likely to be honest in his pursuit. Although, they have been observed to be very sensitive towards arts and crafts that includes creation. This suggests that such people should pursue such passion and knack for fine arts as career. They are quite introvert and shy in nature. They find it tough to mingle easily with others, rarely expressing themselves. They also are unable to conduct tasks that involve supervision and management of team under their leadership.

iii) Shape: OWWO

Individuals having such a combination of prints on their fingers succeed in their professional life. They tend to get into jobs that are highly valued for and well-acknowledged. However, they should be careful to not get into any kind of hustle because they tend to take things for granted. They tend to keep an air around themselves which may offend colleagues. They easily attract jealousy from people and their pride may let them get betrayed. People of such nature are counselled to treat their counterparts with respect. They must avoid getting into petty issues.

iv) Shape: OWWOW

People with this combination of fingerprint patterns need to put lots of efforts into their professional matters. They are observed to get recognition for their hard work at the prime of their ages. They certainly will have struggling initial years into their jobs. But they must keep patience because they gain wealth with age.

v) Shape: OWOWW

These people tend to easily get judgemental about others. As a result they can find it hard to accept others as they are and perceive things in a narrow minded way. They must learn to be humble and generous. This negative attitude can interfere in the way of holistic well-being of their personal as well as professional lives. It will also mean being considerate to others

which will indirectly help them to scale the ladder of success, especially if they are involved in executive and administrative careers.

vi) Shape: WOOOO

A persona having arches on his/her thumb and remaining all whorls is a very sharp and clear headed person. They can attain success in life only when they work towards the aim, rather than leaving it all upon fate. They have respect of their associates who will support his/her pursuits. It may be because of the fact that a person having such fingerprint patterns is a kind, compassionate humanitarian being.

vii) Shape: OOOOW

People with such a sequence of fingerprint patterns are very soft hearted. They easily get attached to elderly. They are kind and caring. Hence, they prove good associates to old aged people. However, they have trouble trusting people easily which may come in between their paths of success. Still they have been found to make a decent, well-acknowledged living for themselves. They need to get out of their shell and be little less conservative.

viii) Shape: OOOWW

Individuals with such pattern sequence need to be cautious of their behaviour of jumping to conclusions too early. They also need to control their temperament and check that they do not easily loose temper. This behaviour might land them up in trouble. This is the only challenge they face towards making big of themselves. They are of high potential and must channelize their energy tactfully, by approaching a situation in a calm manner.

ix) Shape: OWWWW

Subjects with whorl only on thumb and arches on remaining all fingers are of good and firm character. They need to put huge effort towards their professional growth. However, they are suggested to keep patience as their efforts will turn into success only after a certain age.

x) Shape: WOWWW

These individuals have one special characteristic. They are quite remarkable at social skills. They do not hesitate taking risks in situations that involve their career. They are confident by themselves and face challenges knowingly. However, not every situation is as yielding as the

fortunate ones. Hence, it is advised to such subjects that they try taking lesser risks as they mature in life. They should consider options that are more stable.

xi) Shape: WWOWW

People having this kind of pattern sequence are little different than their same age counterparts. For them life holds deeper meanings and greater visions. Such people are great visionary but can often loose grip on reality. They are not much of practical and hence may invite trouble for themselves, leading a dreamy life. They need to realize that this great potential that they have been endowed with, also hands them great responsibility towards others.

xii) Shape: WWWOW

People having arches on all four fingers except on ring finger which has a whorl are a huge success at academic fields. Usually, they are of high intellect and easily make themselves renowned as scholars. They lead a smooth decent living and earn moderately handsome amount of wealth. They have the potential to hugely succeed from their academic intellect.

xiii) Shape: WWWWO

These people have the stars to inherit property from some senior member of his/her family or closed acquaintances. They too can make profitable career for themselves and succeed in life. However, their only stone in the path is their impatient nature. This might lead them into many unwanted hustles both in professional and personal lives. They need to train themselves to be little less impatient with people and situations around themselves so that they can obtain better results.

xiv) Shape: OOWWW

Such people are arrogant and proud. They may appear tough at outside, dealing with people around them. To understand them deeply, needs great patience and perseverance. It has been observed that deep inside, they are kind hearted beings. They do not find it easy to mingle with other people and they need to put effort in that direction. Also, this snob nature may land them up in some trouble as their relatives may make the most of this particular weakness of theirs.

xv) Shape: WOWWO

Such individuals are very responsible and thoughtful about their own lives from a young age. They know what they want to do further in their lives. On an average, they lead peaceful contented lives. They are deep thinkers and do not take anything very lightly.

xvi) Shape: WOWOO

People with this combination of fingerprint patterns are very outgoing and extrovert in nature. They have high interpersonal intelligence and are much carefree when it comes to enjoying life with same aged people. As they reach the prime of their ages, they crave for emotional dependency on others as their whole emotional make up is based upon people from very young age. They need to make a stable career for themselves so that they need not get vulnerable at very old age.

xvii) Shape: WOWOW

They usually are rebellious in nature, when it comes to ideology or thought on how to pursue something. They go the way which is most unconventional. Also, they are obstinate in nature and very hard to talk into something. However, their high confidence in themselves, coupled with good amount of confidence. Although, it is a matter of bigger concern that things such a person want from life, mostly turn out to be vague and abstract.

xviii) Shape: WWOWO

Such an individual needs to be much patient with his life because it has been observed that he/she shall have alternate events of success and failures in life. Although, it can all can be overcome by using more of other abilities with steadiness and patience. This will pay off and the person matures enough to handle issues tactfully.

xix) Shape: WWOOO

This combination of fingerprint patterns appearing in mentioned sequence represents a very kind hearted, compassionate person. He/she has above average interpersonal intelligence and is jovial around people. They must get into business that includes marketing, counselling, PR etc. because they are one of the few having charismatic personalities. They need to focus and work towards their aim in life. This will reap them huge success.

xx) Shape: OWWOO

Another class of print patterns is the above mentioned one. People having this combination reach summit of career in the mid of their lives. However, they need to work hard during initial years to enjoy the perks later in life.

xxi) Shape: WWOOW

The people having this combination of patterns lack the ability to judge correctly without bias or prejudice. They are very potential but do not have the ability to focus on goal for long. This is the only weakness they have. They need to have self-control on whatever they want to pursue in life.

xxii) Shape: OWOOW

Having a character that is commendable, these people are very popular among counterparts because they have this innate quality and will to help everyone out there. They are caring in nature. They are highly sensitive to people, their situations and emotions. They can understand and read people without talked into the matter. Also, they are highly creative and make reputable names for themselves in related careers.

xxiii) Shape: OWOWO

This kind of individual has a sharp mind with fast decision making and task execution ability. They are very quick to respond. As a result, sometimes due to lack of patience they may get quite aggressive. This aggression can act against them as far as interpersonal interactions are concerned. If they however overcome this particular stance, they can soar up above in their professional growth.

xxiv) Shape: WWOOO

This kind of person lacks art of presenting things in social circuit. He/she may also get superficial while interacting with others. However, they are straightforward in their behaviour for others. People may not accept their naïve views because they might take it up as shallow. They should not be surprised by this behaviour of others towards them. They also need to work hard upon their communication and oratory skills if they are involved in related occupations.

xxv) Shape: OOWOW

These individuals have high cognition. They are opportunists. They grab any chance coming their way. They can excel in fields relating to stocks, investments and finance. Their fortune increases with age. They need to nurture this speciality of theirs. It is quite uncommon.

xxvi) Shape: OOWWO

A person having the above mentioned combination of patterns in this sequence is a person of strong character. He/she is highly honest with himself as well as others. This also sets up their reputation amongst others. However, for them materialistic and monetary wealth matters. They need to be cautious getting betrayed in business or conned by others they trust. They need to be more diplomatic.

xxvii) Shape: OOWWO

They have enhanced interpersonal intelligence and social skills. They easily get help from influential people because of their jovial nature towards people. They however, look into others for guidance rather than looking into themselves. However, their association with people of importance aids in getting up the ladder of success. After a certain age they flourish in their prospective careers.

xxviii) Shape: OOWOO

A person having this sequence of patterns is of courageous nature. He/she is hardworking towards whatever task they are assigned to. They do have chances of making others envious or rival to them. Although it can be overcome if he/she works in this prospect and maintain harmony among others. They need to accept the fact that companionship of others are necessary as one moves further ahead in life. They need to take mature step towards this prospect with help of some counselling.

xxix) Shape: OWOOO

This type of person is very kind and humanitarian. They are easy to mingle with and maintain good rapport among friends. However, they lack the skills required for doing business and understanding the twists and turns of commercial sector. They are highly inclined towards academics and acquiring knowledge. However, due to their enhanced inner conscience and jovial attitude towards life, they succeed at being good teachers or scholars. They can also be spiritual masters as they have enhanced understanding of existence, purpose of life and values, morals and meanings of life.

xxx) Shape: WOOWW

The people having above mentioned combination of patterns in perfect sequence are quite reputable in their circles. They have strong yet nonintrusive character. They make peace with themselves and others out there. But they may get into small issues due to their pride. Unconsciously, they may hurt others, especially those whom are in important positions in his/her lives.

xxxi) Shape: WOOWO

People with this sequence are logical beings. They are practical in outlook. Yet they are quite simple in their take on matters related to day-to-day life. However, they lack a basic issue. They do not focus on fundamentals of whatever they pursue. This highlights their impatient nature. They need to overcome this hurdle to rise up the success ladder. They are destined to earn monetary wealth and earn respect from people.

xxxii) Shape: WOOOW

This class of people are very straightforward when it comes to putting their views on some matter before others. They have steady and strong character. They too have the chances of offending the wrong kind of people due to this straight forward nature. However, by the prime of their age they rise up the success ladder to important position. Then only they face positive changes in their professional life.

Chapter 4

Problem definition

So far, most of the Dermatoglyphic research has been focussed on analysing clinical condition, mental and physical disorders of an individual. Although, it is scientifically proven that dermal patterns are linked to brain cortical folds and hence related to our cognitive abilities, very less work has been done in validating this aspect. Studies in Dermatoglyphics conclude that certain intelligence types correspond to particular dermal patterns on specific fingers. Since the fingerprints need to be automatically detected for the patterns, pattern matching and recognition techniques needed to be developed. However, singular point and minutiae based detection techniques are widely available, this study makes an integrated approach towards all image processing tools and techniques required for the following purposes.

1. To enhance image quality of raw fingerprint data acquired.
2. To register affine transformations in acquired images and validate the test patterns to be same as template.
3. To match patterns automatically and classify them.
4. To extract ridges for ridge curvature based pattern classification and identification.

4.1 Enhance the acquired images using pre-processing tools

The images that are acquired using fingerprint scanner, are either unequally contrasting. Hence they need to be fixed using contrast enhancement techniques. Also, the different kinds of noises need to be removed using various smoothing and sharpening filters.

4.2 Validation of Fourier Mellin transform to register affine transforms in acquired images

The acquired images of same pattern are translated, shifted or rotated. The Fourier transform neglects the shift in original domain when computing in frequency domain, in this case image intensity plane. Also, the Mellin transform does not consider affine transforms. The log polar coordinate converts any translational shift into polar coordinate radius and angle.

4.3 Pattern classification using correlation based studies

The grayscale valued pixels have phase corresponding to their frequency values. A particular pattern with a specific pixel wise phase value is matched to another image having similar pattern.

4.4 Pattern recognition by finding gradient based block processed orientation field

Research has been done on fingerprint gradient based orientation field calculation in order to enhance the images. In this study, the technique is to be used for pattern recognition.

4.5 Ridge segmentation using Gabor filter banks

The accurately parameter defined set of Gabor filters shall filter out ridges. Since the ridges are not straight lines and curve all through the image, the bank of filters are proposed to be applied using block processing. Each filter output when accumulated, can provide enhanced image as well as segregated patterns of core and delta. This helps in recognizing the pattern.

5.6 Ridge identification using Classical Hough Transform

The classical Hough transform can easily detect standard geometrical shapes. In this thesis, it has been suggested that Hough transform be used as a block processing

function to detect ridges. This can further be used to count total number of ridges between delta and core of an individual's fingerprint pattern.

Implementation of proposed methodology

Fingerprints are patterned ridges. Quite surprisingly, there are fixed set patterns in which they can occur. Though, count of a pattern may vary in an individual. Occurrence of one or more patterns and that too, in which finger, accounts for Dermatoglyphic study of human intelligence and personality type.

Hence, a flexible method of automatic pattern classification is needed. To understand the effect, the prints of either hands are going to have on the algorithm, we need to know that an ulnar loop on right hand is a radial loop on left hand and vice versa. The images are captured and saved in png format so as to keep the maximum possible image information. The images are 8 bit, 256 grayscale and of equal dimensions of $480 * 320$ pixels. The image can be taken as a rectangle on a 2D plane with axes u and v . The number of pixels in image on u axis are m whereas on v axis in image are n . Although, when images are captured, they are in 3 dimensional grayscale format with red-green-blue compositions.

6.1 General tools for Image Enhancement

Enhancement is a very important for improving the relative appearance of an image for the purpose of extracting features and do pattern recognition. Every application of image processing requires customized processed images. Sometimes, the process of acquiring them results in incorporation of unnecessary noises like smudges, false prints. For the sake of maximal accurate processing, the enhancement algorithm must be stable and robust enough to clean patterns off any corruptions, correctly. The phenomenon resulting from enhancement techniques include noise removal, edge enhancement, image zooming, image subtraction, pseudo – colouring, contrast enhancement as well as geometric distortion correction. They are outcome of various types of algorithm including grey scale transformation, spatial operations and transform domain operations. Point wise operations include contrast enhancement and stretching, grey scale clipping, binarization or thresholding, inversion or negation, grey scale slicing, bit extraction, contrast compression, image subtraction and operations including histogram modelling or equalization.

6.1.1 Point wise operations

When an operation is applied on pixels such that a central pixel value gets manipulated, such spatial transformations are known as point wise pixel operations. The new grey level or intensity value of pixel in question is the result of grey levels of surrounding pixels in neighbourhood of original image in same spatial location (m, n).

$$v(m, n) = f\{u(m, n)\}, \quad \forall m = 0, 1, \dots, N-1;$$

$$(1)$$

$$f: \{0, 1, \dots, L_{max}\}$$

6.1.2 Contrast enhancement and contrast stretching

The contrast of an image can be well enhanced by linear stretching, histogram equalization or Gaussian stretching^[55]. In this study, we have implemented the conventional histogram equalization method.

i) Linear stretch

The linear stretch method is usually considered the standard method. This is because all the pixel intensity values are stretched or distributed homogenously across the complete range of intensity values. The pixel values range from 0 to 255. The pixels with most common intensity values are stretched the most as illustrated in figure 6.1.

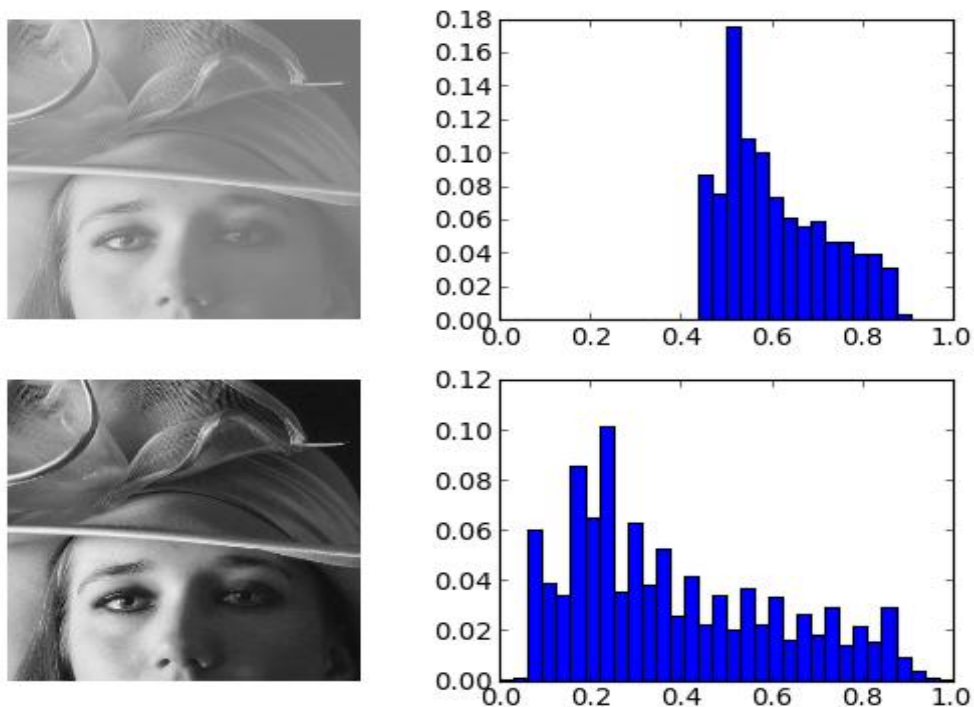


Fig 6.1: Effect of linear stretching

ii) Histogram equalization

Here, the pixels having same intensity values are increased in and around same location. Another aspect to be kept in mind is that pixels with most equal intensity values are stretched the most. In equalization [55 – 59], every grey scale level gets equally distributed number of pixels. Hence, every grey scale level holds almost equal number of pixels. A histogram does not contain any information about the spatial distribution of pixels. It is a nonlinear kind of stretching technique. The image gets darker at dark pixels and lighter at light pixels. Hence the contrast is well enhanced [19].

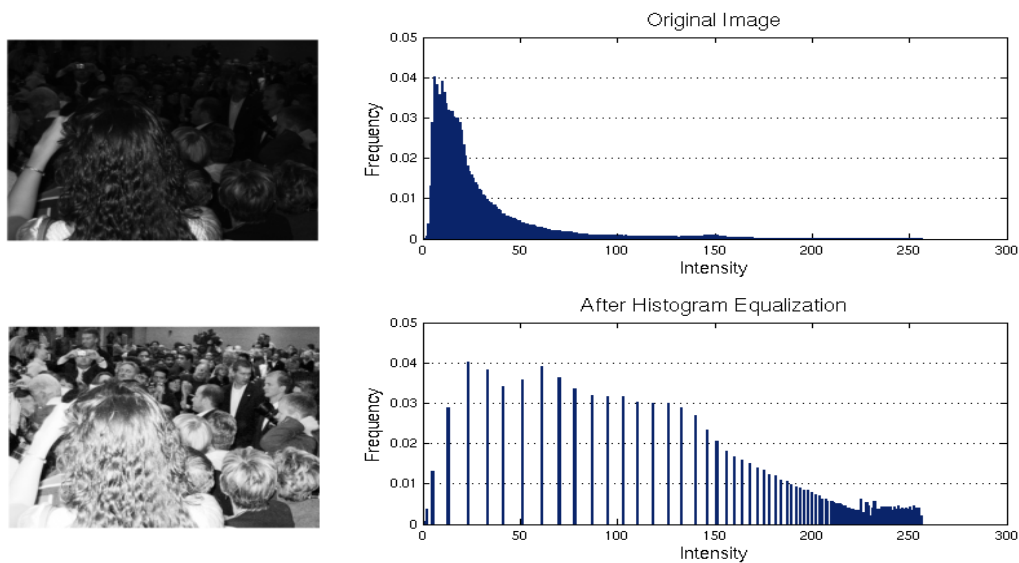


Fig 6.2: Original and equalized histogram

iii) Gaussian stretch

The original histogram is fitted to a normal Gaussian curve distribution. The mathematical expression for Gaussian curve is given by

$$F = \frac{1}{\sigma\sqrt{2\pi}} \exp\left(-\frac{(x-\mu)^2}{2\sigma^2}\right) \quad (2)$$

The images undergoing this operation showcase similar effects. Although the effects can be manipulated by the sigma (σ) and mu (μ) parameters, which denote standard deviation of intensity value of current pixel from the local average and mu, which signifies the mean intensity in local neighbourhood of pixel in question.

6.1.3 Spatial operations

A spatial operation performed on an image refers to discrete convolution or correlation implemented to local neighbourhood of a pixel [55-59]. The common operations applied, are averaging and low pass filtering. There is an image of size m

$\times n$. A kernel, with fixed or function dependent values is moved over the whole image in a set pattern. It is also termed as template or window. The kernel is either smaller or of same size as that of the image. In practice, a kernel is smaller and contains odd dimensions. This is due to the fact that central pixel of this template shall bring the change upon the pixel in question, of original image. If kernel dimensions are even, we cannot place (0, 0) on its central $a(i, j)$ pixel. The values contained in the kernel matrix are called filter weights. Spatial domain operations are expressed in terms of following notation

$$g(x, y) = T[f(x, y)] \quad (3)$$

where $g(x, y)$ is input image, $f(x, y)$ is output image and T is the operator on f defined over neighbourhood (x, y) .

i) Smoothing and low pass filtering

A common class of spatial averaging filter has equal weights. In the averaging operation, the weighted average replaces the central pixel. Averaging filters are better known as low pass filters. Since every pixel undergoes a change in its intensity values which is highly dependent upon its neighbouring pixels, there hardly remains any scope for abrupt intensity changes. As a result, high intensity components of image are removed. If $a(k, l)$ be assumed weight matrix with dimensions $k \times l$, then, filter is given by

$$a(k, l) = \begin{bmatrix} a(i-1, j-1) & a(i-1, j) & a(i-1, j+1) \\ a(i, j-1) & a(i, j) & a(i, j+1) \\ a(i+1, j-1) & a(i+1, j) & a(i+1, j+1) \end{bmatrix}$$

$$v(m, n) = \sum_{(k,l) \in w} \sum a_{k,l} y(m-k, n-l) \quad (4)$$

where $y(m, n)$ and $v(m, n)$ are input, original image and output, transformed image respectively.

$$v(m, n) = \frac{1}{N_w} \sum_{(k,l) \in w} \sum y(m-k, n-l) \text{ where } a(k, l) = \frac{1}{N_w}$$

N_w is the number of pixels in the window. Another spatial averaging filter used often is given by

$$v(m, n) = \frac{1}{2} \left[y(m, n) + \frac{1}{4} \{y(m-1, n) + y(m+1, n) + y(m, n-1) + y(m, n+1)\} \right] \quad (5)$$

The effects of smoothing filter are well illustrated in the following figure 6.3.



Fig 6.3: Effect of smoothing filter on image

ii) Sharpening and high pass filtering

A sharpening filter enhances the darkness or brightness of pixel. The key to its operation is that all values in the kernel sum up to one. As a result, the kernel does not bring about any change in pixels with constant intensity values. But if there is an abrupt change in grey level, high or low, the contrast gets boosted. Such an example of kernel is given below

$$\begin{bmatrix} -1 & -1 & -1 \\ -1 & 9 & -1 \\ -1 & -1 & -1 \end{bmatrix}$$

The effects a sharpening filter has on an image are shown in figure 6.4.

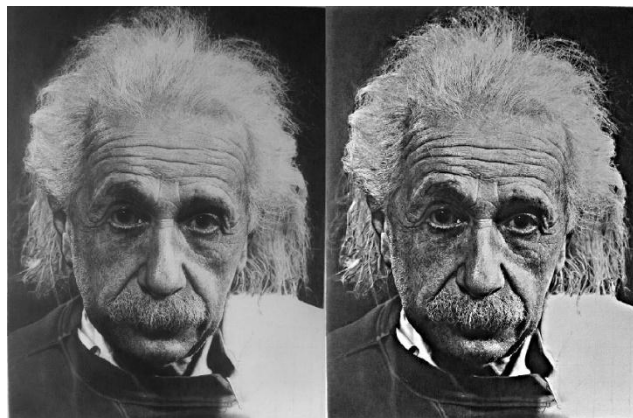


Fig. 6.4: Effects of sharpening an image

6.2 Application of Fourier Mellin transform to register affine transformations in fingerprints and do template matching

6.2.1 Image Registration

Image registration is a technique that aligns two similar images after they have undergone affine transforms. Some fixed data points are decided upon the image in the coordinate plane. The affine transforms shall shift them from initial coordinates. The transformed data points are again observed at a different time, from a different angle or level or even from a separate sensor. The affine transformations once detected, can be used to set the test image in a manner so that it can be perfectly superimposed with the available template. When they are perfectly aligned, the algorithm finds a central pixel which is used a point of reference, against the correlation between the images.

6.2.2 Affine Transformations

Any affine transformation is given by the transform which preserves the translation, rotation, shear, scaling, reflection, homothety etc ^[61]. The affine transform is such that the transform perceives the input as original even after there has been a rotation angle change in same plane, translation along horizontal and vertical direction. This is the reason why affine transforms are suitable for cylindrical coordinate system and not spherical coordinate system. When there is any rotational change on an image, it occurs on same plane of cylindrical coordinate system. The spherical coordinate have two angular dimensions wherein images cannot be included. The z axis is taken as reference, as it is common to both Cartesian and cylindrical coordinate systems. Also, spherical coordinate cannot contribute to the understanding of translation given by x_0 and y_0 . Hence, cylindrical coordinates are the base for preserving collinearity of points in a straight line or proportionate ratio of distances and angles even after transformation. For example, if an image goes through scaling s , horizontal and vertical transformation of x_0 and y_0 and some rotation given by θ , then the rotation – enlargement algorithm is given by

$$\begin{aligned} \begin{bmatrix} x' \\ y' \end{bmatrix} &= s \begin{bmatrix} \cos \alpha & \sin \alpha \\ -\sin \alpha & \cos \alpha \end{bmatrix} \begin{bmatrix} x - x_0 \\ y - y_0 \end{bmatrix} \\ &= s \begin{bmatrix} \cos \alpha (x - x_0) + \sin \alpha (y - y_0) \\ -\sin \alpha (x - x_0) + \cos \alpha (y - y_0) \end{bmatrix} \end{aligned}$$

If $a = s \cos \alpha$ and $b = s \sin \alpha$

Then scale factor, s is given by

$$s \equiv \sqrt{a^2 + b^2}$$

(6)

And the rotation angle is given by

$$\alpha = \tan^{-1} \left(-\frac{b}{a} \right)$$

(7)

The Fourier – Mellin is an important tool for image registration. The resulting spectrum is invariant to rotation, scaling, translation etc.

6.2.3 Fourier Transform – Translation Invariant

The Fourier transform decomposes a function in time into its frequency components. It represents a complex value function which has a real and imaginary component [61]. The real absolute value represents the magnitude of frequency at unit of original domain. The imaginary value gives the phase offset or the phase difference between two consecutive waves of same frequency.

For an absolutely integral function f , of independent variable x representing time (in seconds) and transformed variable ξ representing frequency (in hertz)

$$\begin{aligned} \hat{f}(\xi) &= \int_{-\infty}^{\infty} f(x) e^{-2\pi i x \xi} dt \\ &= \int_{-\infty}^{\infty} g(u) e^{-2\pi i f(u+a)} du \\ &= e^{-2\pi i f(a)} \int_{-\infty}^{\infty} g(u) e^{-2\pi i f(u)} du \\ &= e^{-2\pi i f(a)} G(f) \end{aligned}$$

(8)

The transform associates frequency domain representation to a function of time. The property of translation invariance can be understood from shifting property. If a function in time is shifted by some units, $g(t-a)$, the resultant Fourier spectra, $G(f)$, has constant magnitude in frequency domain.

$$F \{g(t-a)\} = \int_{-\infty}^{\infty} g(t-a) e^{-2\pi i x \xi}$$

(9)

That is, a time delay does not cause frequency content of $G(f)$ to change at all. Since data points in case of an image, are discrete pixels, the discrete Fourier transform is applied rather than using continuous Fourier transform. To make the calculations faster, the fast Fourier transform is used.

6.2.4 Need for Log – Polar conversion

Although an image is a two dimensional flat representation of intensity values, laid out on $x - y$ plane, a scaling or rotation alters the spatial resolution and pixel wise

relative frequency content. Analysing this effect is beyond the scope of Cartesian coordinate plane [62]. A much adaptable and easy to project coordinate system is provided by log – polar system. The mapping of Cartesian axes on logarithmic scale explains the scaling. The amount of scaling is given by radius of circle of polar plane.

The conversion of Cartesian parameters into log – polar space parameters include the following relations,

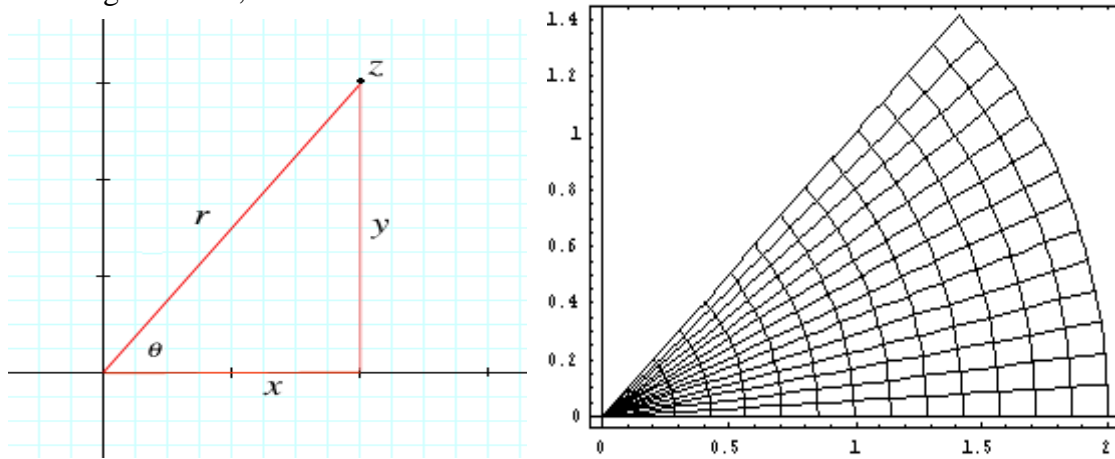


Fig 6.5: Log polar coordinate system

$$r = \sqrt{x^2 + y^2}$$

(10)

where r is radius of circle circumscribing the rectangle bound by x and y axes. The original image is in Cartesian plane. If the circle is inscribed inside the rectangle as the conversion boundary, some data points i.e. pixels lying outside may get ignored. Even if the conversion boundary circumscribes the rectangle, unwanted pixels may get covered and sampled. Since direct mapping of pixels from Cartesian to log polar space is not possible, average of central pixel and its neighbours is taken. The parameters of polar space, (ρ, θ) , used to represent input image are related to parameters of polar space used to represent output image, by

$$(\rho, \theta) = (e^r, \theta)$$

(11)

To map a random pixel (i, j) from input image, (x_i, y_j) , onto (m, n) axes of output image, (r_m, θ_n) , the following relation was used

$$x_i = \text{round}(\rho_m * \cos(\theta_n) + m_0)$$

$$y_j = \text{round}(\rho_m * \sin(\theta_n) + n_0)$$

(12)

Where, (m_0, n_0) is the central pixel.

6.2.5 Mellin transform

The Mellin transform is used to create a transform space where the input image can be mapped onto output coordinate space which is rotation, scale as well as translation invariant [62][63]. If some affine transformations are made to image in Cartesian plane, a DFT performed on same image transformed in log polar coordinate system shall recover all the changes. To speed up the calculations, we apply Fast Fourier transform instead of Discrete Fourier Transform.

The N periodic conventional Discrete Fourier Transform is given as

$$X_k = \sum_{n=0}^{N-1} x_n \cdot e^{-\frac{i2\pi kn}{N}}, \quad n \in N, \quad k = 0, \dots, N-1$$

(13)

But discrete Fourier transform decomposes the values into frequency components slowly. FFT on other hand, factorizes the N different combinations of transformations into sparse matrices. As a result, anyone can be easily accessed as a matrix component. It is also beneficial because sparse matrices are easily compressible due to lesser and only significant non zero elements. Hence, computational time is less. This algorithm can factorize the DFT matrix in either N^2 or $N \log(N)$ operations. The fast Fourier transform, decimation in time, is given by the following mathematical expression

$$\begin{aligned} \sum_{n=0}^{N-1} a_n e^{-2\pi i n k / N} &= \sum_{n=0}^{\frac{N}{2}-1} a_{2n} e^{-2\pi i (2n) k / N} + \sum_{n=0}^{\frac{N}{2}-1} a_{2n+1} e^{-2\pi i (2n+1) k / N} \\ &= \sum_{n=0}^{\frac{N}{2}-1} a_n^{even} e^{-\frac{2\pi i n k}{N/2}} + e^{-2\pi i k / N} \sum_{n=0}^{\frac{N}{2}-1} a_n^{odd} e^{-\frac{2\pi i n k}{N/2}} \end{aligned} \quad (14)$$

6.3 Phase only correlation based matching and pattern classification

The correlation based analysis is one of the most inevitable parts of pattern matching. An image is a display of colours, whether the frequency component lying in VIBGYOR or truecolor range or 8 bit grayscale range. It is an inevitable means of

finding correlation between frequency components of each and every pixel of the test image and find the score of matching to the pixel wise frequency component of template image. The most efficient form of correlation is the normalized cross correlation ^[15].

Mathematically, cross correlation measures the lag between the phase angles of a function at two different time periods. Since frequency is related to time, the lag concept can be applied to the frequency term also. Hence, when there are two images, one smaller than other or both are of same sizes, then the relative phase lag is calculated. If the two images are equal in size, then the template is placed over the test once, and every pixel is compared to its counterpart on the other image. When the template is smaller than test, then it is moved over the image as long as all the pixels have not been covered. In general, the correlation is the analysis of how much two identical functions are shifted or translated from each other in a particular axis ^[15] ^[63]. Maximum correlation is achieved when the shift has been nullified and both images are superimposed. Then, each and every point of the test image corresponds to the similar point on the template image. It is to be noted that, correlation can only be found in real valued functions and that imaginary quantities are not physically realizable for any matching. If by any chance, the function happens to be having any imaginary component, then conjugate of template image is taken for correlation calculation. As a result, conjugate of the template image shall result in positive aligned peaks corresponding to imaginary components.

6.3.1 Colour to grayscale conversion

Since we are solely interested in the count and formation information of ridges, the texture is not of major significance. As a result, the truecolor RGB needs to be converted into grayscale. This is accomplished by removing the hue and saturation and retaining the illumination. Also, the calculation complexity reduces. If the input is also a grayscale image but in single precision, then the same command can be used to convert the intensity image into a double image.

6.3.2 Binarization

A grayscale image is having a chance of having 256 shades of grey. There is very minute rate of change in grayscale shades across the pixels of the image. Hence, it becomes cumbersome to realize the gradient calculating filters for ridge detection. Hence, binarization operation is applied all over the image. A certain threshold level

is chosen. Any pixel having illumination intensity level equal or greater than the specified level, is given numeric value 1, while remaining all are assigned 0. As a result, the whole image is segregated into pixels having either 0 (absolute black) or 1 (absolute white) as intensity levels. The ridges can be observed clean. Unnecessary portions of the fingerprint image with intermediate illumination are left out. Image binarization is illustrated in figure 6.6 [22].

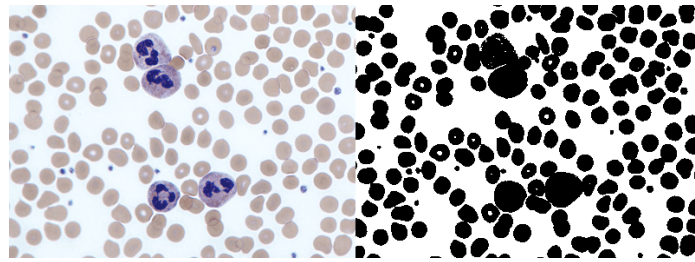


Fig 6.6: Binarization

6.3.3 Low pass Sobel filtering

The Sobel kernel is one of the high intensity variation edge detecting filter. It works by convolving with the test image in either horizontal or vertical direction. The kernel of Sobel filter has all integer values. A 3*3 sized kernel has been used. The kernel values determined have been mentioned below

$$\text{sob} = \begin{bmatrix} -1 & 0 & 1 \\ -2 & 0 & 2 \\ -1 & 0 & 1 \end{bmatrix}$$

A Sobel filter can be decomposed into a differentiator and an averaging filter. They are low pass smoothing filters and find derivative of the intensity level variation along the direction the kernel moves. While calculating the derivatives, there are two components of the gradient at each pixel of the image, one horizontal, G_x , and one vertical, G_y . The magnitude of the resultant gradient is the root of squares of both. While the angle is the arctangent of the slope of gradient.

$$\text{sob} = \sqrt{G_x^2 + G_y^2}$$

$$\theta = \tan^{-1} \frac{G_y}{G_x}$$

(15)

6.3.4 Normalized cross correlation

The process of cross correlation is similar to correlation except the fact that it includes two random variables, whereas autocorrelation is the correlation calculated between two equal functions, having some time or phase lag. Cross-correlation can

be compared to convolution in a way that it is the convolution between a functions, one of whom is an inverted version of the complex conjugate of the original image. If f and g are two functions that need to be cross-correlated, then the correlation between them can be represented as

$$f * g = f^*(-t) * g(t) \quad (16)$$

After the cross correlation has been done, it becomes clear at what point of time, the two signals align best ^[63-66]. As a result, the relative shift in time (or frequency) can be determined. Normalization is done so that the variations in illumination and brightness can be ignored. The process limits the correlated values into a limited range of [0,1]. The normalized cross correlation method is equal to the Pearson product moment correlation coefficient except the fact that it is in two dimensions while Pearson is a single dimension method. The overall correlation analysis provides the display as illustrated in figure 6.7.

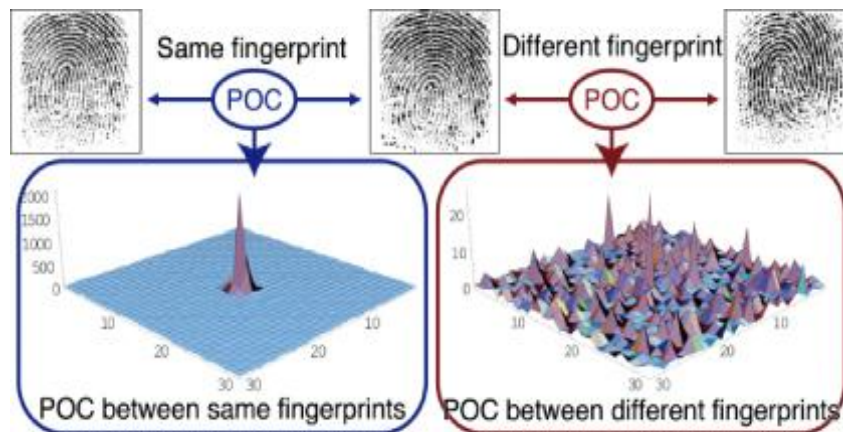


Fig 6.7: Correlation output graphics

6.3.5 Noise removal using non-linear filter

The non-linear filter is useful because while removing the noises from all over the image, it preserves high gradient or intensity variations, that is, the edges. The nonlinear type of filter used here is the median filter. The command used in the MatLab is `med2filt`. Median filter is applied to every pixel on the image by applying a kernel which comprises of the neighbours of the pixel ^[67]. For one dimensional signal, the kernel is formed of successive and predecessor pixels. While in case of images which are two dimensional functions, the kernel may either be box or cross shaped. The centre of kernel imposed image is replaced by the median of all the

pixel values. However, nonlinear means bear the nonlinear quadratic moments. In some cases, these moments may nullify some correlations between random images functions. As a result, true negatives of “zero” correlation are formed. The effect a median filter has on an image, is much alike the smoothing filter. The two dimensional median filter has been used because it is better than Gaussian filter to remove small and medium level noises, like speckle and salt and pepper noise. Its speciality is that it effectively removes noises without altering the edges and preserves them.



Fig 6.8 Effect of Median filtering on noisy image

6.3.6 Curve fitting and comparison

A statistical method has been adopted for assessing the nature of similar patterns and finally validating them to be classified under same category. The quadratic polynomial concept has been applied to the curvature of each and every ridge of fingerprint images. The algorithm interprets the ridges as a polynomial. The chance of similar dermal patterns to have similar quadratic polynomial interpretation is high. However, some ambiguity lies in the case of whorls. More or less, the different whorl patterns display identical curvatures. Due to this reason, the curve fits are similar. This the reason, all whorls have been categorised under one class. The confusion matrix is drawn for each class separately. Under every curve fitting analysis, the curve fits of all the fingerprint images having the same class patterns are observed.

6.4 Application of Gabor filter to segment the ridges along curvature direction

Gabor filters were first given by Dennis Gabor. They are a bank of linear filters. They specialize in cases where there are abrupt intensity changes. Hence, play crucial role in determining edge detection. They perform better in case of recognising dominant spatial frequencies and their respective orientations. A zero mean Gaussian curve is used as envelope function along with complex number oscillations oriented perpendicular to laid pattern ^[68]. Multiple resolution versions of image filtered by Gabor bank are obtained after subsampling, by keeping sizes of filter results and input images same. While detecting edges, an abrupt intensity change needs to be detected. If adjacent lighter or darker region represents the inner or outer areas around boundary, then, mathematically the edge is denoted by peak of a sinusoid. This sinusoidal form is obtained by doing a Gabor spectral analysis. If g is Gabor function, it is mathematically represented by

$$g(x, y, \theta, \varphi) = \exp\left(-\frac{x^2 + y^2}{\sigma^2}\right) \exp(2\pi\theta i(x \cos\varphi + y \sin\varphi))$$

(17)

where, x and y represent the coordinates of the plane, θ be spatial frequency and φ be the orientation. σ denotes standard deviation of Gaussian kernel ^[69]. It depends upon the distribution of spatial frequencies all through the image. The mathematical operation implemented by filter bank on image, is convolution. At any arbitrary point (x, y) on image I , when Gabor filter bank $g(x, y, \theta, \varphi)$ is applied, the convolution is given as,

$$g(x, y, \theta, \varphi) = \iint I(p, q)g(x - p, y - q, \theta, \varphi)dp dq$$

(18)

The crucial part of a Gabor filter is that it can be moved at any angle, over the image. Most effective results are obtained from images that have periodic high and low intensity pixels. For example, ridges of fingerprints, images having black and white stripes, and so on. The constant white pixels correspond to crest whereas the dark pixels signify the trough of complex sinusoid of filter. This is due to the fact that Gabor filters are phase sensitive. Response of real and imaginary parts of the complex sinusoid to any such sinusoid, shall result in a sinusoid. The angles and number of times the filters can be superimposed on the image, are user defined. It is exclusively based upon the requirement. The researcher finalises the most suitable projection. Figure 6.9 illustrates the effect a range of orientations and spatial frequencies of Gabor filter bank have on a randomly selected image .

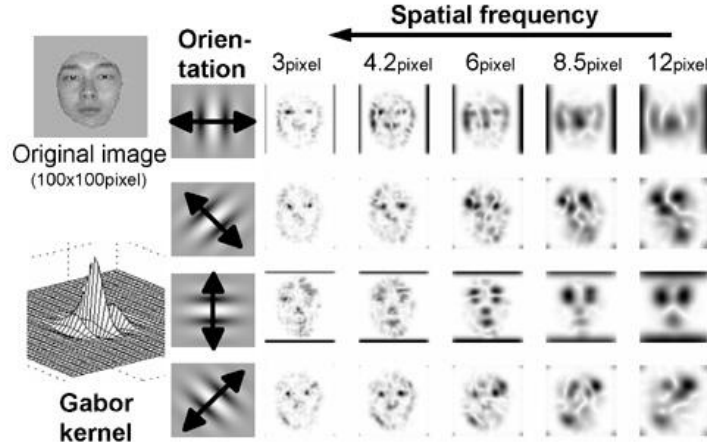


Fig 6.9: Effects of variable Gabor parameters on an image

6.4.1 Temporal Gabor filter

This is exclusively used for one-dimensional signals like speech and audio signals. Gabor filter bank used for such purposes prove to be excellent band pass filters [70]. Though phase sensitive, the response is squared so that oppositely polarised sinusoid responses do not cancel each other. In frequency domain, the magnitude of response is simply the modulus of complex frequency response or the real part of Fourier response. Taking Fourier response of Gabor function, we get

$$\begin{aligned}
 \hat{g}(f) &= k e^{j\theta} \int_{-\infty}^{\infty} e^{-j2\pi ft} w(at) s(t) dt \\
 &= k e^{j\theta} \int_{-\infty}^{\infty} e^{-j2\pi(f-f_0)t} w(at) dt \\
 &= \frac{k}{a} e^{j\theta} \hat{w}\left(\frac{f-f_0}{a}\right)
 \end{aligned}
 \tag{19}$$

where $\hat{w}(f) = w(f) = e^{-\pi f^2}$

6.4.2 Spatial Gabor filter

Spatial filter is applied on two dimensional envelope signals. Image is one such kind of signal. The image is characterised by such an envelope, defined by a single dimension carrier signal. This envelope is Gaussian in nature of its distribution. The formula for Gaussian kernel in space domain is given as follows

$$g(x, y) = s(x, y) w_r(x, y)
 \tag{20}$$

where $s(x, y)$ is a complex sinusoid, known as carrier and $w_r(x, y)$ represents the two dimensional Gaussian envelope. Since an image enhancement requires a spatial

Gabor filter, it is compulsory to know the nine parameters that govern the outcome. They include six variables of envelope and three of carrier - K, scale or magnitude factor of Gaussian envelope, the abscissa and ordinate of envelope, as well as angle of rotation of the envelope, location of peak of Gaussian envelope. Also, Cartesian coordinate components of spatial frequency (u_0, v_0) and phase of sinusoid carrier are taken into consideration.

6.5 Automatic ridge extraction algorithm of well – enhanced fingerprints

For a well enhanced fingerprint image, the following algorithm holds effective. The method yields all ridges of the fingerprint separately in different output graphic windows. The N – point connectivity of pixel of interest is core of this approach. This algorithm also takes into account, non-linear operations on specific image regions and pixels. The operations depend upon how different intensity pixels are arranged in a neighbourhood. A sequence or pattern of similar or pixels

6.5.1 Grayscale thresholding

The input image undergoes grey scale thresholding which is automatic. The user cannot define the multiple intensity levels at which each grey value can be coerced into. Hence, an equalization of intensity levels, leads to fair thresholding of each pixel into its nearest grey value.

6.5.2 Binarization

Next is the binarization operation. This parameter is user defined. It divides all the pixels into pixels with two intensity levels, one above the threshold value and one below. Since this categorisation is normalized into range from 0 to 1. There are infinite values between 0 and 1 which can be applied by user by hit and trial method. So, an algorithm was developed using simple image enhancement techniques that could handle false ridge lines, dots on ridges or irregular width of ridges. The images need to be sized equally.

6.5.3 Morphological transformation

i) Skeletonization

The skeletonization operation when applied to specific image regions, narrows the pixel width and creates spurs or single pixel width formations. This operation allows removal of pixel boundaries around a central region of interest without causing any breakage or disruption to the original continuous region. MatLab has the provision to

repeat same morphological operation infinite number of times, given that the user requires enhanced results. This helps in removing bridges between the concentric ridges because even true minutiae do not concern the scope of this study. The study is focussed solely on pattern of core of fingerprint. Also, it is most suitable morphological operation that effectively clears fingerprints of any unnecessary ridge formations that do not contribute to major pattern classes.

ii) Region filling

Sometimes fingerprint ridges have regular dots on them. When acquired as an image, these dots emerge as dark spots at regular intervals on the relatively brighter ridges. It is important that these dots should not be confused with minutiae dots or interfere with feature extraction mechanism of processing. Hence, it is crucial to remove such dots or 'holes', as they appear on ridges.

In such cases, the area within which this hole is present is considered to be the foreground whereas the region encompassing the ridge including hole come under the background pixel region. Region filling makes use of dilation and intersection operations. When a structuring element of suitable shape and size probes the region using dilation, the holes get filled up. The complement of image power set shows only the foreground regions, but with pixel value of background region from original image set. This complement of image is operated with intersection on dilated original image. This mechanism is well off made clear using following expressions and illustrated in figure 6.10 .

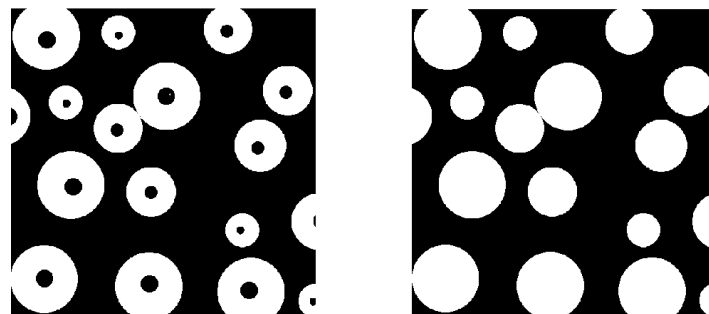


Fig 6.10 Region filling

Let A be a set of pixels and B be its structuring element. If all the pixels to be filled are numbered from 1 to p, then the hole filling is mathematically expressed as

$$X_k = (X_{k-1} \oplus B) \cap A^c \quad , \quad k = 1,2,3, \dots \quad (21)$$

where $X_0 = p$, is the number of iterations in the algorithm and it stops when $X_k = X_{k-1}$.

6.5.4 Region selection based on concept of pixel connectivity

The pixel connectivity implements the idea of extracting image components that are connected to each other through pixels within a neighbourhood ^[71]. For example, let there be a component A, defined by some pixels, within an image I. Assume a pixel, P, connected to one of the pixels of A such that this pixel, P shares its neighbourhood with some pixel of A too. As a result, a pixel of A is known. Then, all the remaining pixels of A can be very well identified by the following mathematical expression

$$X_k = (X_{k-1} \oplus B) \cap I \quad (22)$$

where B is the structuring element used to probe the image in order to extract connected regions. In this algorithm, a pixel is treated for extracting its neighbouring regions based on the condition that every pixel in the resized image is checked for being a ridge pixel. If it is one, then its 8 point connective neighbourhood pixels are extracted. If any one of those neighbourhood pixels are ridge pixels, then, that consequent neighbourhood is further extracted ^[72]. This phenomenon keeps on occurring in the form of iterations until the following condition of convergence occurs. The loop stops when

$$X_k = X_{k-1}$$

As a result, the final steady condition becomes $A = X_k$. This method has some loopholes, such as all ridge pixels are valued at 1. As a result, the above stated condition holds ineffective in terms of non-repeatability.

6.6 Comparison of existing and newly developed algorithms of determining gradient based fingerprint orientation field

In this algorithm, we make use of the ridges and their orientation in the pattern to extract feature corresponding to every class of pattern. Herein, the gradient map of original image is generated after it has been slightly pre-processed off any minor corruptions. This method incorporates various ridges, valleys and the direction in which they turn. As a result of which, the intensity field follows the ridge pattern. The ridges are long, continuous, and thin with ends and bifurcations in between. Ridge ends are termination points of ridges. A bifurcation point is where a single

ridge bisects into two sections. Although there are about 150 characteristic features of ridges, known as minutiae, we limit our directional field study only to ridges. A well-defined fingerprint image should be available with clean ridges and furrows. The pre-processing needs to cleanse the ridges off all falsely acquired smudges. A graphic example of a gradient image of a normal grayscale image is given in figure 6.11 [79].

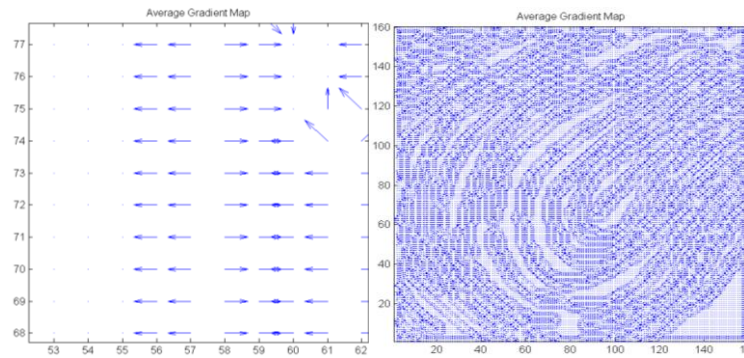


Fig 6.11: High resolution image of loop fingerprint pattern gradient field

6.6.1 Application of Gaussian filter

The Gaussian operator two dimensional filter is one of the blurring or smoothing filters. The Gaussian filter is based on the “bell shaped” Gaussian curve distribution. Although, the function does the work of an averaging or mean filter, but the kernel used, takes the typical shape of Gaussian curve. The Gaussian distribution for one dimension, dependent upon single variable x , is given by

$$G(x) = \frac{1}{\sqrt{2\pi}\sigma} e^{-\frac{x^2}{2\sigma^2}} \quad (23)$$

Where $G(x)$ is the Gaussian distribution, x is the variable and σ is the standard deviation.

Usually, with zero mean, the Gaussian distribution curve is centred at zero. In case of a two dimensional system like image, where there are two axes, isometrically symmetric, the Gaussian distribution takes a three dimensional form. The base of the distribution lies on the x - y plane whereas the $G(x,y)$ determines the height. The concept is illustrated in figure 6.12.

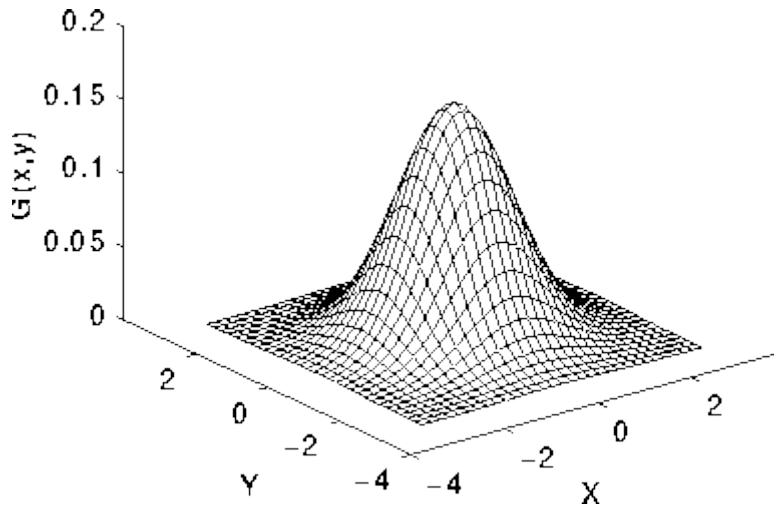


Fig 6.12: Two dimensional Gaussian distribution

The mathematical expression for the Gaussian distribution filter for two dimensional image space, is given by

$$G(x, y) = \frac{1}{2\pi\sigma^2} e^{-\frac{x^2+y^2}{2\sigma^2}}$$

(24)

Where the parameters have their usual meaning. The value of standard deviation is taken 0.5, by default.

6.6.2 Assigning optimal values to parameters

The significant Gaussian parameters are the window size of the kernel and the standard deviation. It has been observed that majority of the ridges are four to six pixel broad. A window size of 3*3 assures that the filter shall remove or zero down edges beyond the scope of its kernel size. The choice of window size depends on the application. A 3*3 kernel size would mean that the filter decays down till it reaches the third pixel, on either sides. Since we want to suppress the unwanted smudges that come along with the ridges, a sigma should be chosen accordingly. A sigma should make the Gaussian curve big enough to remove the smudge. All the operations are based on simple two dimensional convolution. The prime factor to be kept in consideration, while using the Gaussian mask is that it must die down to zero around the edges of the kernel.

6.6.3 Covariance calculation

To determine the edges, the sharpness of the boundary needs to be specially determined. This differentiates the edges or objects in this case, from the background. Hence, a difference lies between the texture and the sharpness details of the image. While the basic image retains all the details that have not been filtered out

by the Gaussian filter as well as the first order differentiation, the image reproduced after differentiation is different. This image has already secured information regarding the locations and curvatures of edges. The covariance finds the degree of variation between the original and the reproduced images. This difference shall correspond to the effect of changes made by the first and second order differentiation. This difference is mainly due to contrast. Larger the covariance value, higher is the variation. It can be mathematically represented as

$$cov(X, Y) = \frac{1}{N} \sum_{i=1}^n (X_i - X) (Y_i - Y) \quad (25)$$

6.6.4 Gradient direction and orientation calculation

The direction and orientation ^[70] can be found by taking magnitude and angle of double differentiated x and y components of the gradient. The gradient components in horizontal and vertical direction are given as

$$\begin{aligned} G_{xx}(x, y) &= \sum_{i=-\omega/2}^{\omega/2} \sum_{j=-\omega/2}^{\omega/2} 2 G_x(x+i, y+j) G_y(x+i, y+j) \\ G_{xy}(x, y) &= \sum_{i=-\omega/2}^{\omega/2} \sum_{j=-\omega/2}^{\omega/2} (G_x(x+i, y+j)^2 - G_y(x+i, y+j)^2) \\ \phi(x, y) &= \frac{1}{2} \tan^{-1} \frac{G_{xy}(x, y)}{G_{xx}(x, y)} + k\pi \end{aligned} \quad (26)$$

Where

$$k = \begin{cases} \frac{1}{2} & \text{when } (\phi(x, y) < 0 \cap G_{xy}(x, y) < 0) \cup (\phi(x, y) \geq 0 \cap G_{xy}(x, y) > 0) \\ 1 & \text{when } \phi(x, y) < 0 \cap G_{xy}(x, y) \geq 0 \\ 0 & \text{when } \phi(x, y) \geq 0 \cap G_{xy}(x, y) \leq 0 \end{cases}$$

7.1 Pre-processing for enhancement

The enhancement and pre-processing stage is the most crucial of all the stages. Whenever a raw data is acquired, it is bound to have unwanted information. Along with increasing the computational complexity, the noise adds to fake information which might be mistaken for useful data. Appropriate recognition of such misleading data is required. Even if complete removal is not fully achievable, smart techniques should be implemented for at least suppressing the distortions. The only aim is to make the resultant image fit for use.

There are various fundamentals applied in different stages of an enhancement algorithm. Some basic points to be kept in mind are as follows

- i. The properties of the image acquisition device and the condition in which the image is acquired, should be known well.
- ii. Make use of pixel redundancy in the reproduced image, as much as possible.
- iii. The neighbourhood of the pixel in question, determines the effect of the operation applied.
- iv. If a distortion or degradation needs to be addressed, it is very important to know the nature of the degradation.

7.1.1 Image Segmentation

i) Basic Global Thresholding

The modification of grayscale image to binary image is implemented using a threshold process ^[73] ^[74]. This threshold is determined either by user or by the algorithm itself, depending on some rules and constraints set by programmer. Threshold set, can be global, that is, same value applied all over image. Those pixels with intensity values lesser than threshold are set zero, those with intensity values higher than threshold are set one. At the end, all the pixels are either zero or one. It is the simplest method of image segmentation. A basic example has been shown below in figure 7.1.

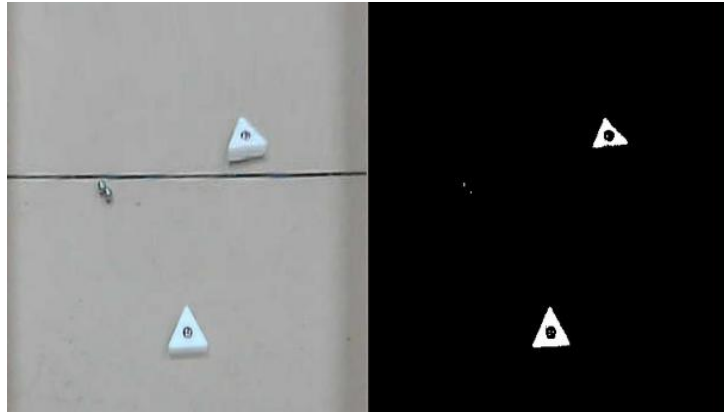


Fig 7.1: Basic Thresholding

ii) Optimum Global Otsu Thresholding

Thresholding may be viewed as a statistical decision theory problem whose objective is to minimize the average error incurred in assigning pixels to two or more groups ^[73] (also called classes). This problem is known to have an elegant solution known as the Bayes decision rule. It is based on probability density function (PDF) of intensity levels of each class and the probability that each class occurs in a given application. Otsu methods provides good amount of discrimination between the classes which is the variance. The basic idea is to provide a threshold giving the best separation between classes in terms of intensity values would be best or optimum threshold.

$$\sigma B^2 = P_1 P_2 (m_1 - m_2)^2 \quad (27)$$

Where $\sigma B^2 = \text{between - class variance}$

$$P_1(k) = \sum_{i=0}^k p_i \quad (28)$$

where $P_1(k)$ is probability that a pixel is assigned class 1 and is given by the above mentioned cumulative sum

$$\text{and,} \quad P_2(k) = \sum_{i=k+1}^{l-1} p_i = 1 - P_1(k) \quad (29)$$

The concept localized thresholding is clearer from the illustration given below.

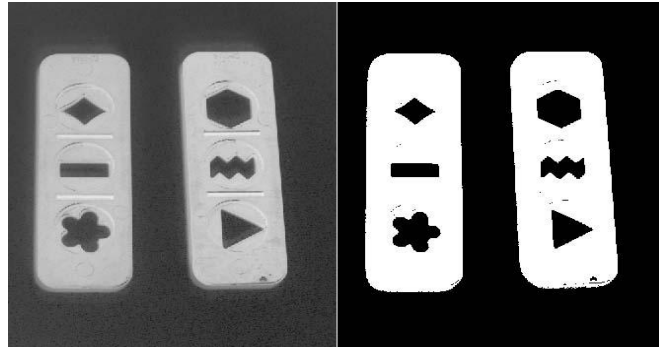


Fig 7.2: Otsu Thresholding ^[2]

7.1.2 Intensity Transformation

i) Histogram Equalization

This method usually increases the global contrast of many images, especially when the usable data of the image is represented by close contrast values. Through this adjustment, the intensities can be better distributed on the histogram ^{[75] [76]}. The image localities with lower contrast gain more contrast while the areas of higher contrast have their contrast reduced to the equalized level. Histogram equalization accomplishes this by effectively spreading out the most frequent intensity values.

The method is useful in images with backgrounds and foregrounds that are both bright or both dark. In particular, the method can lead to better views of bone structure in x-ray images, and to better detail in photographs that are over or under-exposed. A key advantage of the method is that it is a fairly straightforward technique and an invertible operator. So in theory, if the histogram equalization function is known, then the original histogram can be recovered. The calculation is not computationally intensive. A disadvantage of the method is that it is indiscriminate. It may increase the contrast of background noise, while decreasing the usable signal.

In scientific imaging where spatial correlation is more important than intensity of signal (such as separating DNA fragments of quantized length), the small signal to noise ratio usually hampers visual detection.

Consider a discrete grayscale image $\{x\}$, shown in figure 7.3(a) and let n_i be the number of occurrences of gray level i . The probability of an occurrence of a pixel of level i in the image is

$$p_x(i) = p(x = i) = \frac{n_i}{n}, 0 \leq i \leq L$$

(30)

L being the total number of gray levels in the image (typically 256), n being the total number of pixels in the image, and $p_x(i)$ being in fact the image's histogram for pixel value i , normalized to $[0,1]$.

Let us also define the *cumulative distribution function* corresponding to p_x as

$$cdf_x(i) = \sum_{j=0}^i p_x(j) \quad (31)$$

It is the normalized histogram of the image, shown in fig 7.3(d) .

We would like to create a transformation of the form $y = T(x)$ to produce a new image $\{y\}$, with a flat histogram, displayed in 7.3(b) and 7.3(d). Such an image would have a linearized cumulative distribution function (CDF) across the value range, i.e.

$$cdf_y(i) = iK$$

for some constant K . The properties of the CDF allow us to perform such a transform also called, Inverse distribution function. It is defined as

$$cdf_y(y') = cdf_y(T(k)) = cdf_x(k) \quad (32)$$

where k is in the range $[0,L)$. T maps the levels into the range $[0,1]$, since we used a normalized histogram of $\{x\}$. In order to map the values back into their original range, the following simple transformation equation (33) needs to be applied on the result:

$$y' = y \cdot (\max\{x\} - \min\{x\}) + \min\{x\} \quad (33)$$

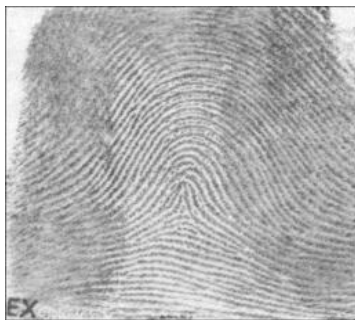


Fig 7.3 (a) Normal image



Fig 7.3 (b) Equalized image

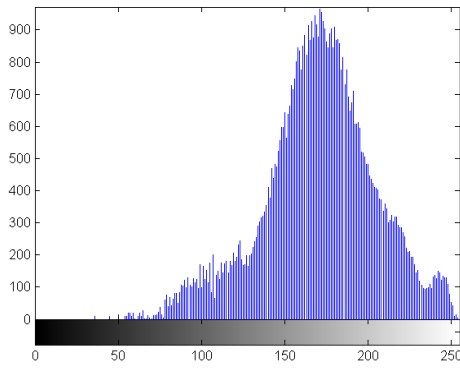


Fig 7.3 (c) Original histogram

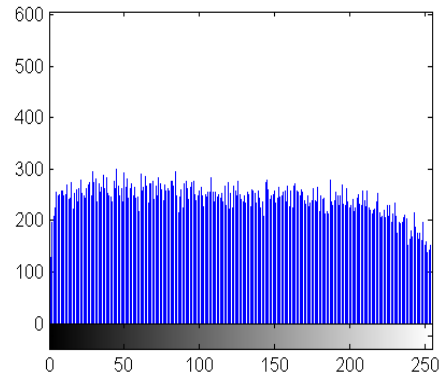


Fig 7.3 (d) Equalized histogram

histogram

7.1.3 Morphological Operation

The identification of objects within an image can be a very difficult task. One way to simplify the problem is to change the grayscale image into a binary image, in which each pixel is restricted to a value of either 0 or 1. The techniques used on these binary images go by such names as: blob analysis, connectivity analysis, and morphological image processing (from the Greek word *morphē*, meaning shape or form). The foundation of morphological processing is in the mathematically rigorous field of set theory; however, this level of sophistication is seldom needed. Most morphological algorithms are simple logic operations and very ad hoc ^[85]. In other words, each application requires a custom solution developed by trial-and-error. This is usually more of an art than a science. A bag of tricks is used rather than standard algorithms and formal mathematical properties.

i) Thinning

Thinning is a morphological operation that is used to remove selected foreground pixels from binary images, somewhat like erosion or opening. It can be used for several applications, but is particularly useful for skeletonization. In this mode it is commonly used to tidy up the output of edge detectors by reducing all lines to single pixel thickness. Thinning is normally only applied to binary images, and produces another binary image as output. The thinning operation is related to the hit-and-miss transform. Like other morphological operators, the behaviour of the thinning operation is determined by a structuring element. The binary structuring elements used for thinning are of the extended type described under the hit-and-miss transform (*i.e.* they can contain both ones and zeroes).

The thinning operation is related to the hit-and-miss transform and can be expressed quite simply in terms of it. The effect is displayed in fig 7.4(a) and 7.4(b). The thinning of an image I by a structuring element J is mathematically given by

$$thin(I, J) = I - hitandmiss(I, J) \quad (34)$$

Thinning is the dual of thickening, *i.e.* thickening the foreground is equivalent to thinning the background.



Fig 7.4(a)



Fig 7.4(b)

ii) Boundary Extraction

The operation of boundary extraction uses a structuring element of any regular shape which erodes the major image and subtracts the eroded image from the original image itself [77]. What is left out is only the boundary of objects within the major image. If we are using $M * M$ structuring element of 1s, it would result in a boundary between $M/2$ pixels thick. The effect has been duly illustrated in figure 7.5 (a) and (b).



Fig 7.5(a)

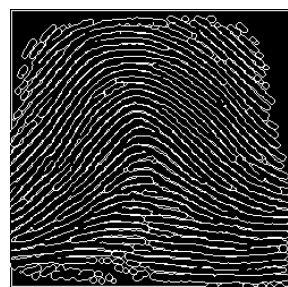


Fig 7.5(b)

iii) Skeletonization

In digital image processing, morphological skeleton is a skeleton (or medial axis) representation of a shape or binary image, computed by means of morphological operators. The original and skeletonized images are shown in figures 7.6(a) and 7.6(b).

Morphological skeletons are of two kinds:

1. Those defined by means of morphological openings, from which the original shape can be reconstructed
2. Those computed by means of the hit-or-miss transform, which preserve the shape's topology.



Fig 7.6 (a)

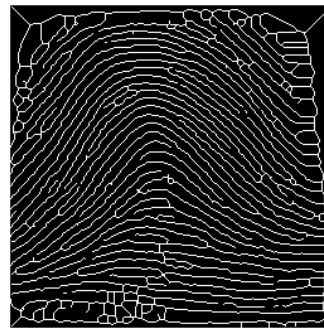


Fig 7.6(b)

iv) Opening

The opening of an image f by a structuring element s (denoted by $f \circ s$) is an erosion followed by a dilation, causes opening of image. The mathematical expression of opening is given by

$$f \circ s = (f \ominus s) \oplus s$$

(35)

Opening is so called because it can open up a gap between objects connected by a thin bridge of pixels^[77]. Any regions that have survived the erosion are restored to their original size by the dilation. The effect of opening of an image is shown in figures 7.7(a-c).

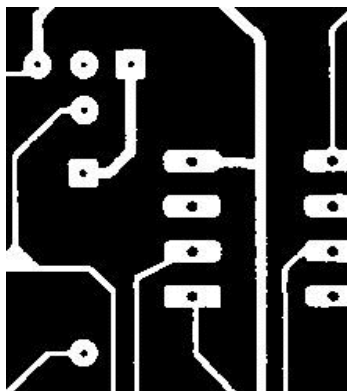


Fig 7.7(a) -

Binary image

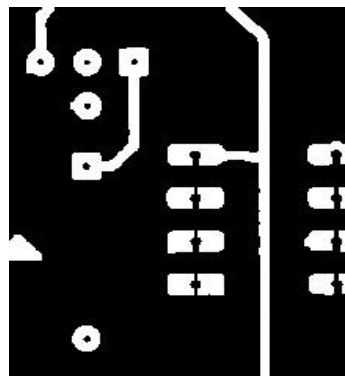


Fig 7.7(b) : $f \circ s$ (5×5 square)

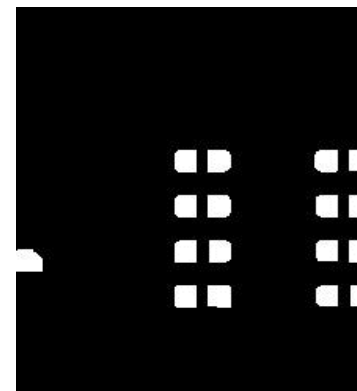


Fig 7.7(c) : $f \circ s$ (9×9 square)

Opening is an idempotent operation: once an image has been opened, subsequent openings with the same structuring element have no further effect on that image:

$$(f \circ s) \circ s = f \circ s \quad (36)$$

7.2 Fourier Mellin Transform for Registering Affine Transformations

The affine transformation are inevitable as far as acquisition of raw fingerprint images is concerned. While acquiring fingerprint images using electronic fingerprint scanners, it is very common for the images to vary in brightness, spatial resolution, clearness, etc. For accurate pattern recognition, the template needs to align to images of same pattern, taken at different times, under different conditions. Specially, where human fingerprints are concerned, human error like slight shift of finger press can cause a pattern to get smudged or rotated at some angle. It may also happen that due to varied size of digits of different subjects, same dermal ridge pattern might be scaled up for one subject than other. The methods generally consist of the following basic steps:

1. Detect features
2. Match corresponding features
3. Infer geometric transformations
4. Use the geometric transformation to align one image with the other

They might hamper the process of correct fingerprint pattern recognition due to the spatial ambiguity caused. A large number of false positive may arise. Hence, Fourier Mellin transform is applied. To check the accuracy of the method applied, correlations between similar as well as different dermal patterns have been done. The results for correlation between similar dermal patterns have been shown in figure 7.8 to figure 7.19. The different dermal patterns matched for the correlation, are displayed from figure 7.20 to figure 7.52.

7.2.1 Similar Dermal Patterns

- i. RADIAL LOOP – RADIAL LOOP

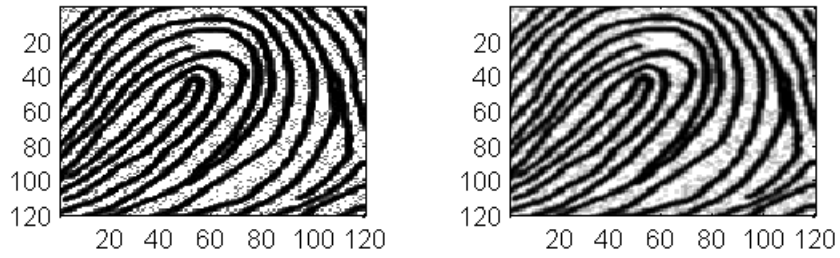


Fig 7.8 - Template and Test image – Radial Loop

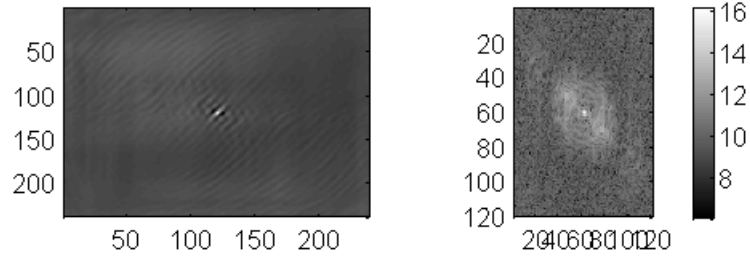


Fig 7.9 - High pass filtered spectrum of input image (using windowing technique)

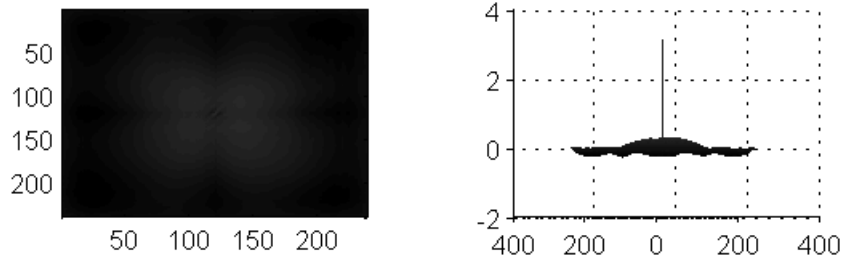


Fig 7.10 : Phase and Magnitude Correlation between test and template

ii. TENTED ARCH – TENTED ARCH

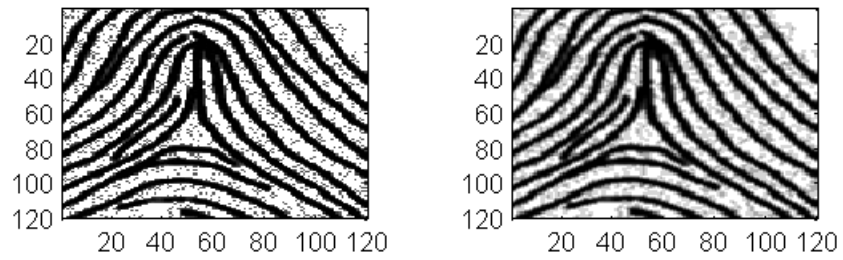


Fig 7.11 : Template and Test images – Tented arch

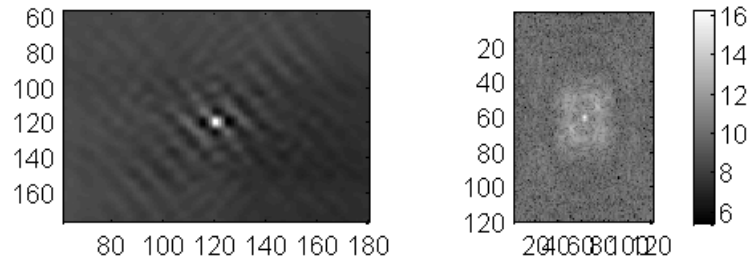


Fig 7.12: High pass filtered spectrum of input image (using windowing technique)

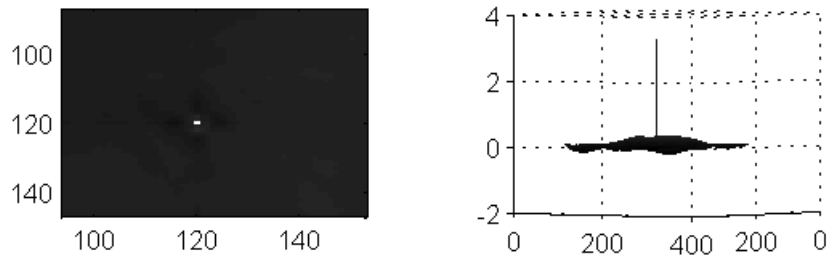


Fig 7.13: Phase and Magnitude Correlation between test and template

iii. ULNAR LOOP – ULNAR LOOP

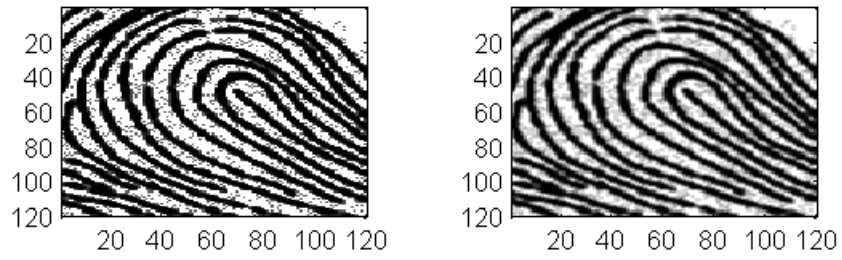


Fig 7.14: - Template and Test image – Ulnar Loop

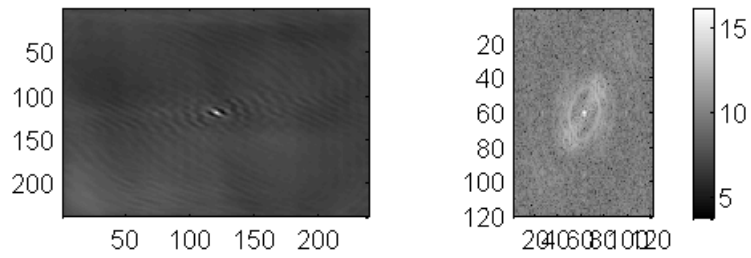


Fig 7.15: High pass filtered spectrum of input image (using windowing technique)

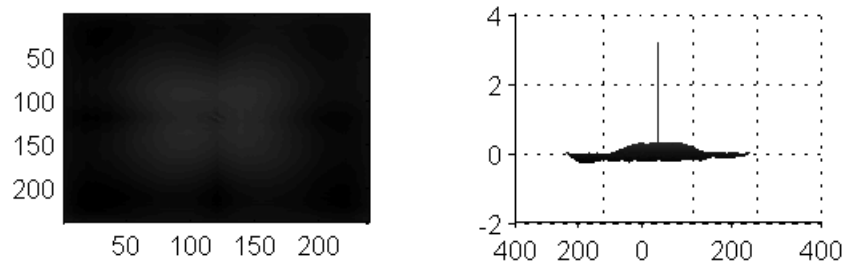


Fig 7.16: Phase and Magnitude Correlation between test and template

iv. WHORL – WHORL

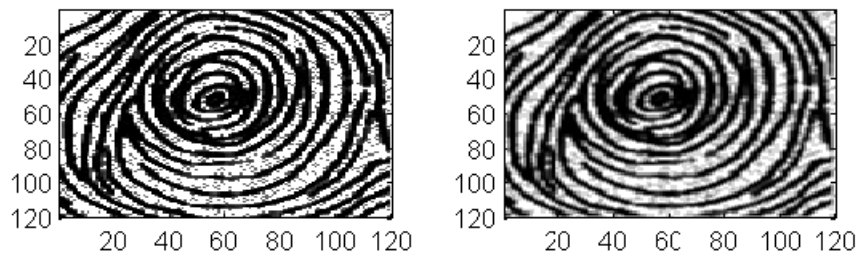


Fig 7.17: Template and Test image – Whorl

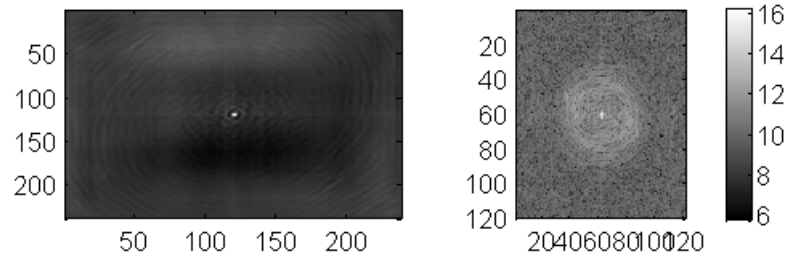


Fig 7.18: - High pass filtered spectrum of input image (using windowing technique)

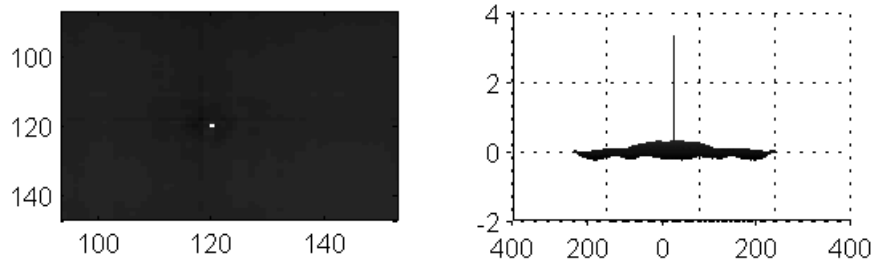


Fig 7.19: - Phase and Magnitude Correlation between test and template

7.2.2 Different Dermal Patterns

i. TENTED ARCH – VARIANT

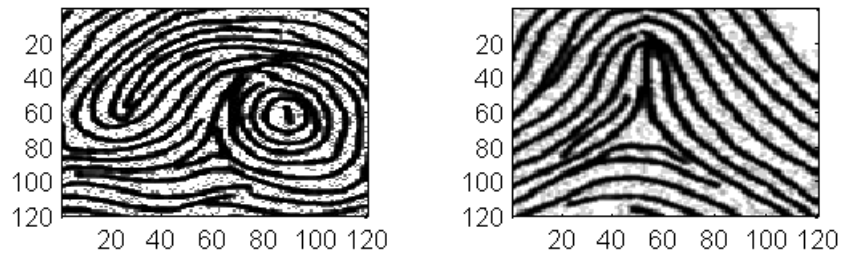


Fig 7.20: Template and Test image – Variant and Tented Arch

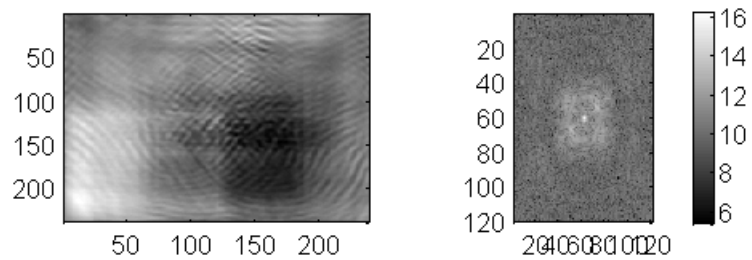


Fig 7.21: High pass filtered spectrum of input image (using windowing technique)

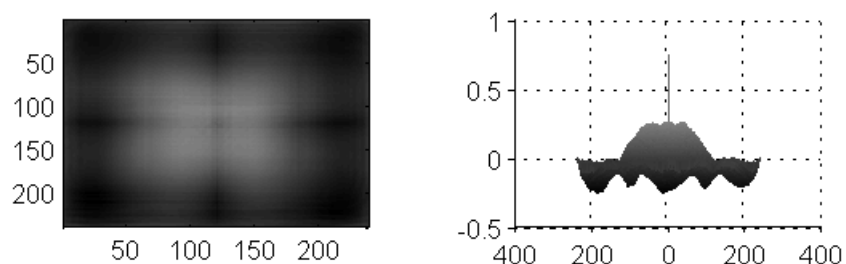


Fig 7.22: Phase and Magnitude Correlation between test and template

ii. ULNAR LOOP – VARIANT

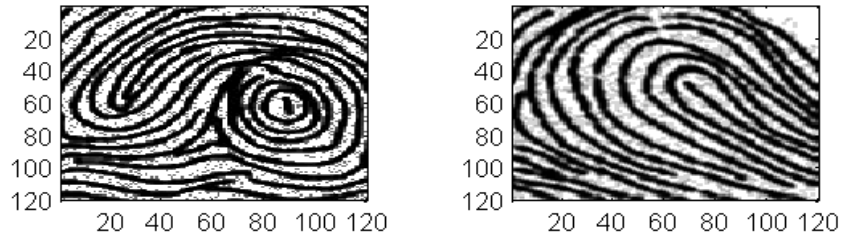


Fig 7.23: Template and Test image – Variant and Ulnar loop

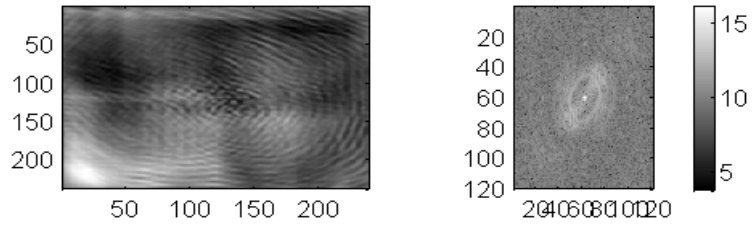


Fig 7.24: High pass filtered spectrum of input image (using windowing technique)

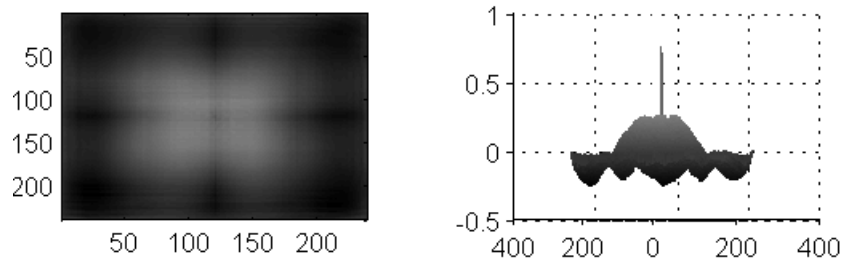


Fig 7.25: Phase and Magnitude Correlation between test and template

iii. WHORL – ARCH

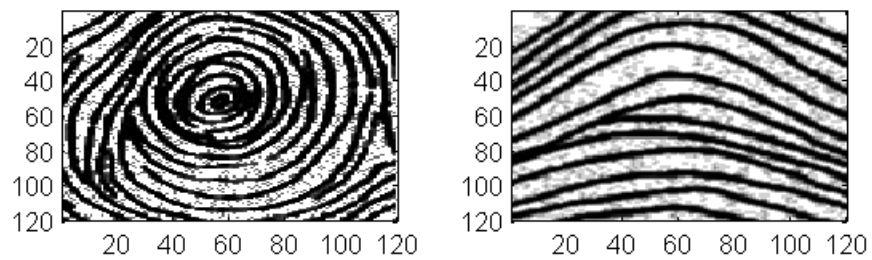


Fig 7.26: Template and Test image – Whorl and Arch

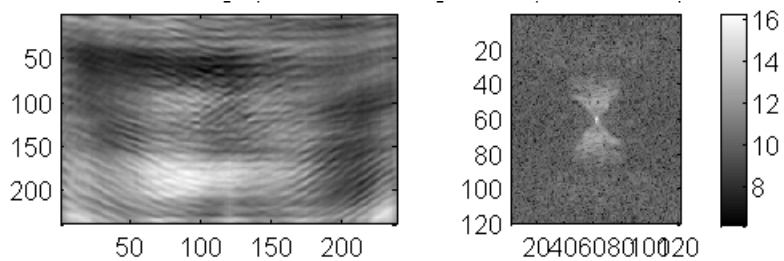


Fig 7.27: High pass filtered spectrum of input image (using windowing technique)

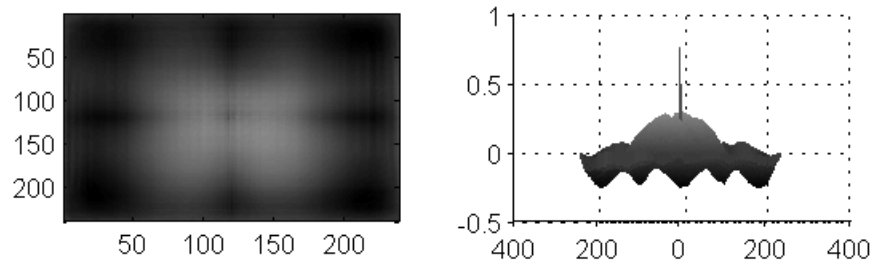


Fig 7.28: Phase and Magnitude Correlation between test and template

iv. WHORL – RADIAL LOOP

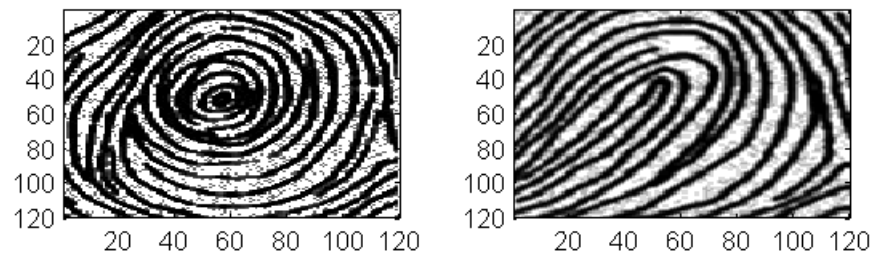


Fig 7.29: Template and Test image – Whorl and Radial loop

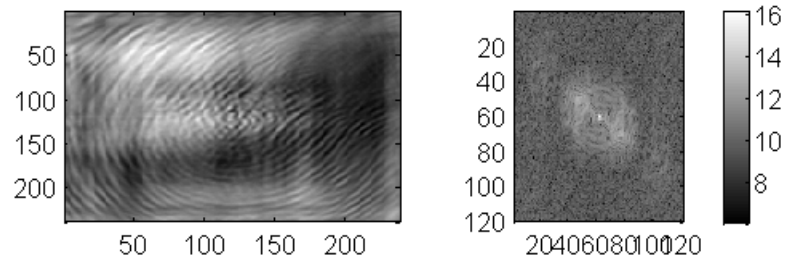


Fig 7.30: High pass filtered spectrum of input image (using windowing technique)

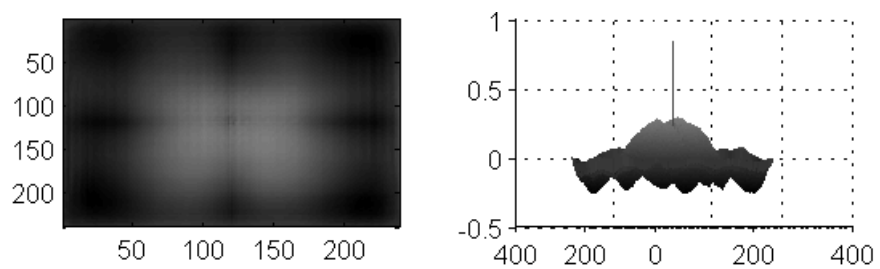


Fig 7.31: Phase and Magnitude Correlation between test and template

v. WHORL – TENTED ARCH

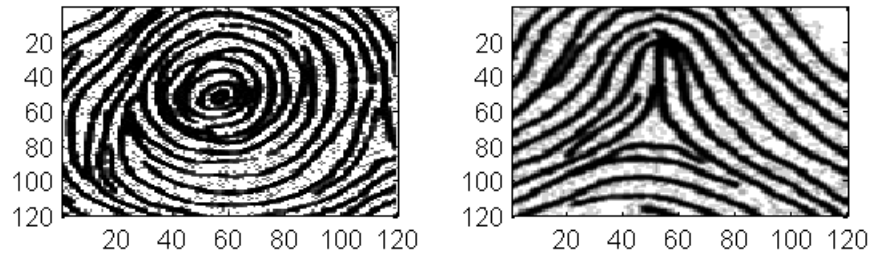


Fig 7.32: Template and Test image – Whorl and Tented arch

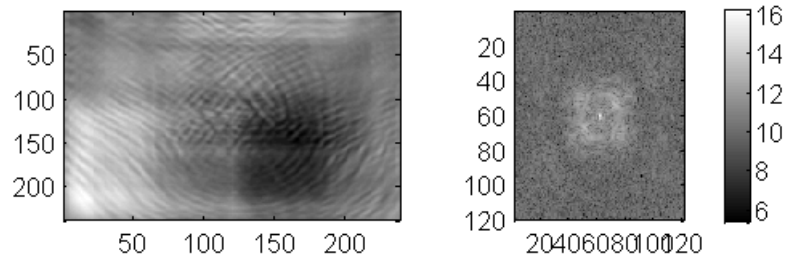


Fig 7.33: High pass filtered spectrum of input image (using windowing technique)

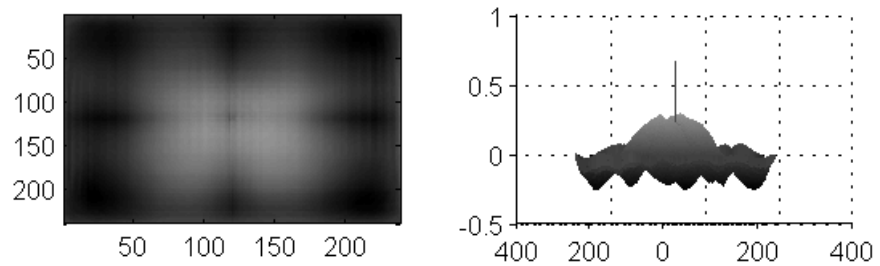


Fig 7.34: Phase and Magnitude Correlation between test and template

vi. WHORL – ULNAR LOOP

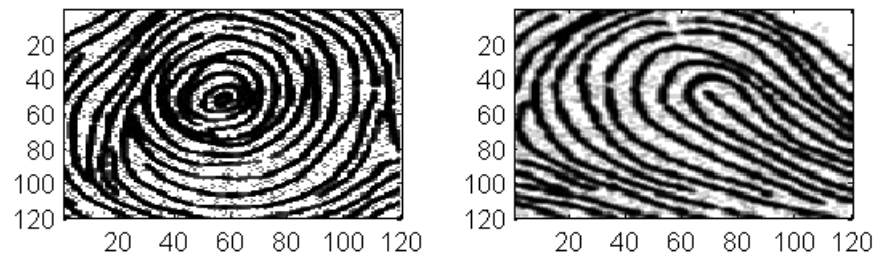


Fig 7.35: Template and Test image – Whorl and Ulnar loop

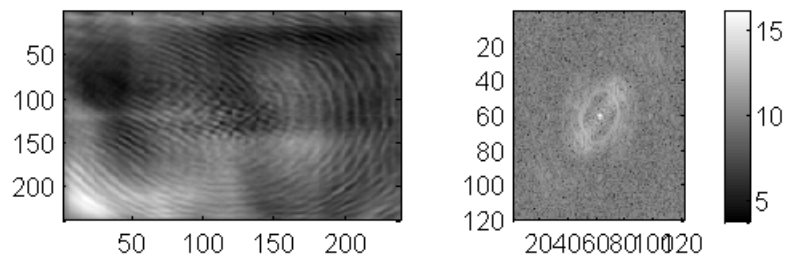


Fig 7.36: High pass filtered spectrum of input image (using windowing technique)

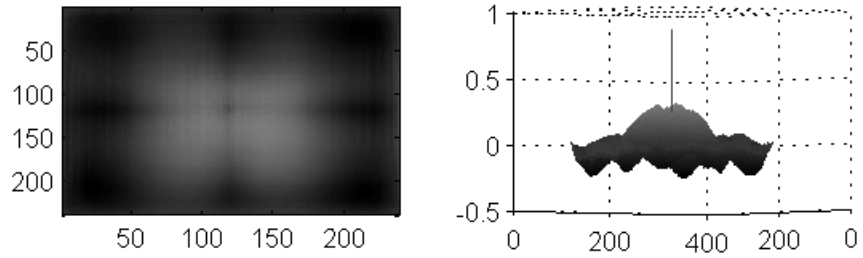


Fig 7.37: Phase and Magnitude Correlation between test and template

vii. WHORL – VARIANT

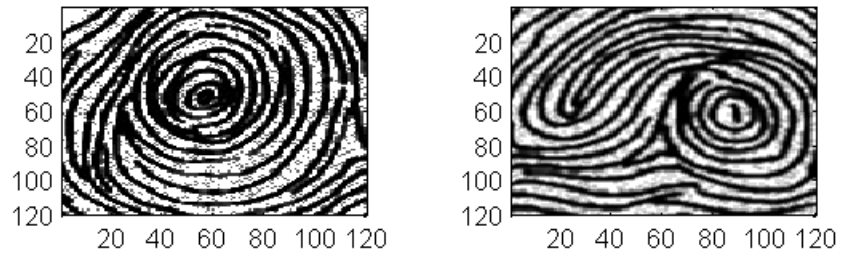


Fig 7.38: Template and Test image – Whorl and Variant

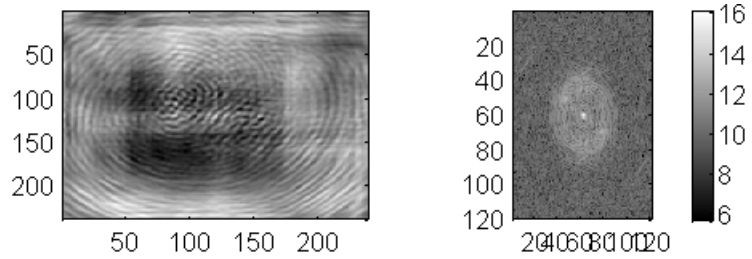


Fig 7.39: High pass filtered spectrum of input image (using windowing technique)

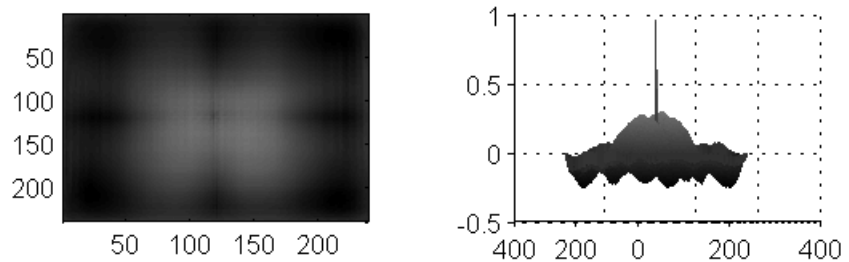


Fig 7.40: Phase and Magnitude Correlation between test and template

viii. RADIAL LOOP – ULNAR LOOP

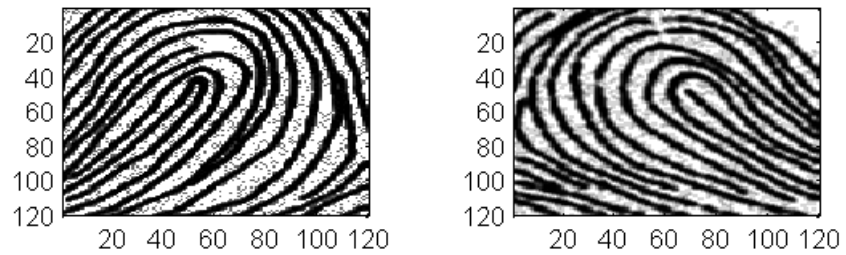


Fig 7.41: Template and Test image – Radial loop and Ulnar loop

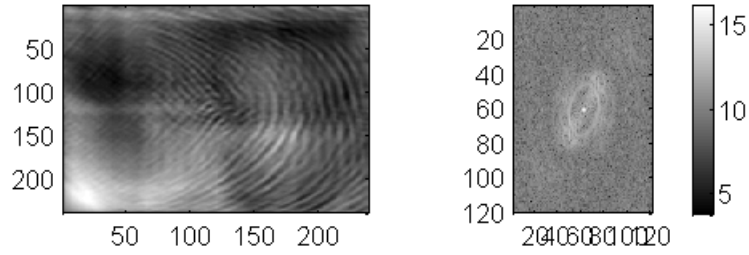


Fig 7.42: High pass filtered spectrum of input image (using windowing technique)

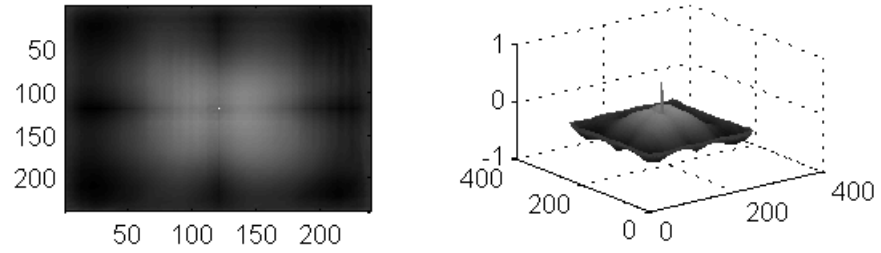


Fig 7.43: Phase and Magnitude Correlation between test and template

ix. RADIAL LOOP – VARIANT

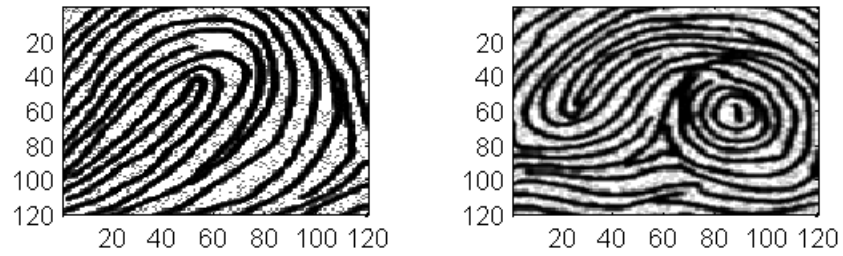


Fig 7.44: Template and Test image – Radial loop and Variant

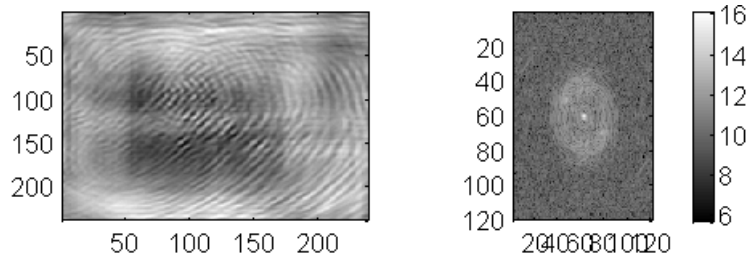


Fig 7.45: High pass filtered spectrum of input image (using windowing technique)

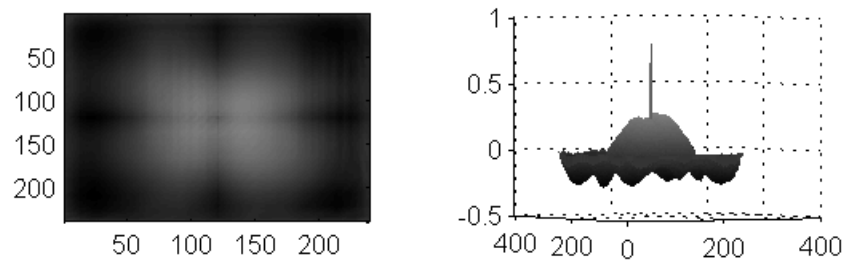


Fig 7.46: Phase and Magnitude Correlation between test and template

x. RADIAL LOOP – TENTED ARCH

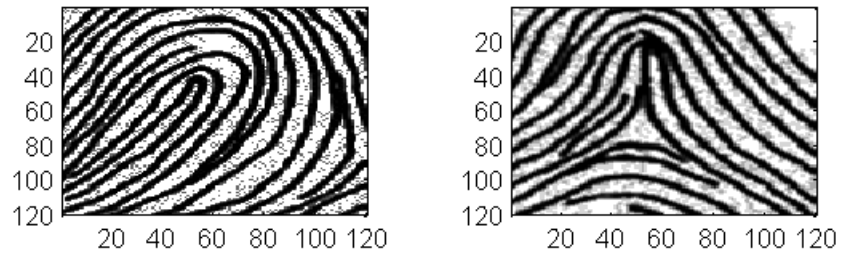


Fig 7.47: Template and Test image – Radial loop and Tented arch

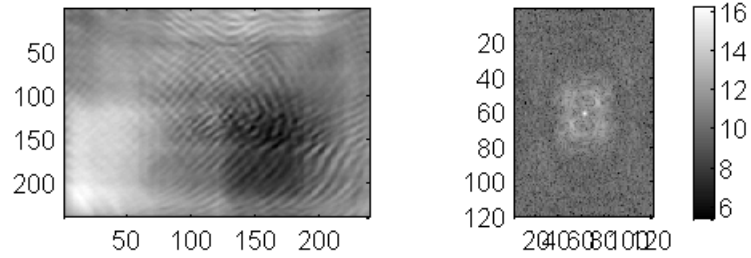


Fig 7.48: High pass filtered spectrum of input image (using windowing technique)

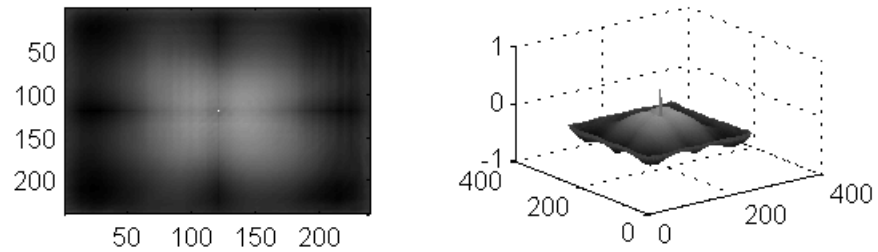


Fig 7.49: Phase and Magnitude Correlation between test and template

xi. ULNAR LOOP – TENTED ARCH

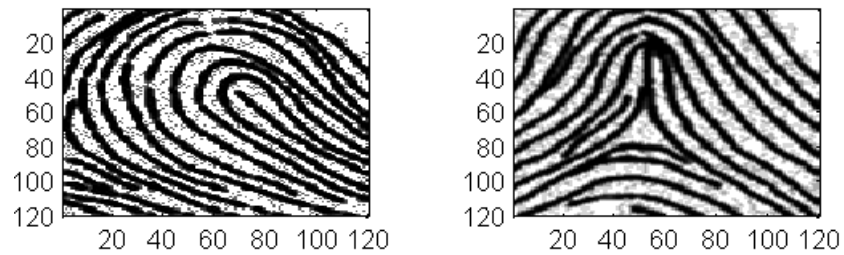


Fig 7.50: Template and Test image – Ulnar loop and Tented arch

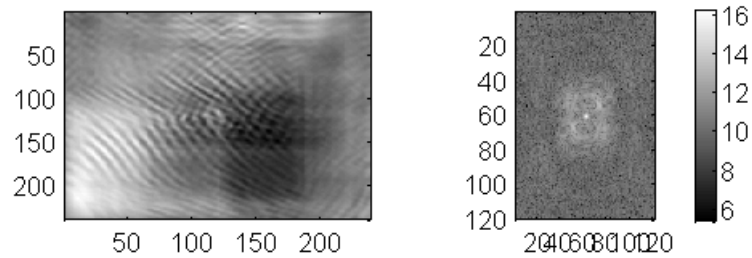


Fig 7.51: High pass filtered spectrum of input image (using windowing technique)

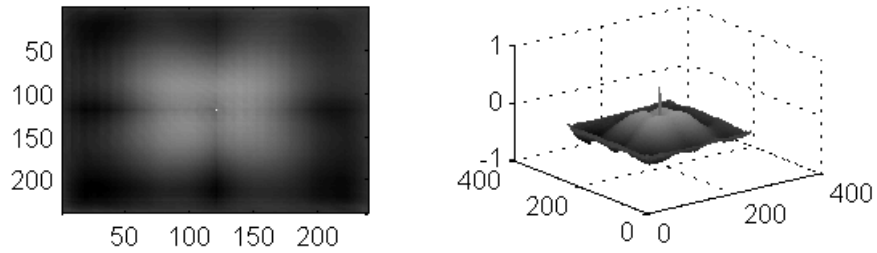


Fig 7.52: Phase and Magnitude Correlation between test and template

7.2.3 Overall spectrum behaviour

Amongst all the patterns that were correlated amongst each other, it was found that when the test and template images were of same pattern, the amplitude spectrum of correlation matrix showed a singular maxima with a rough estimate on standard deviation found to be 3.3, which is quite high. This signifies that that the maxima has been a true positive. The peak is attained at centre of x-y plane since the peak has been zero shifted after the correlation matrix was FFT filtered. Those where two different patterns are being matched display multiple peaks. This signifies that due to similarity of curvature amongst dermal patterns at some places give rise to such peaks. It is important know that these peaks have magnitude almost half of the maxima that was obtained in previous case. Same behaviour has been observed in case of phase correlation plots.

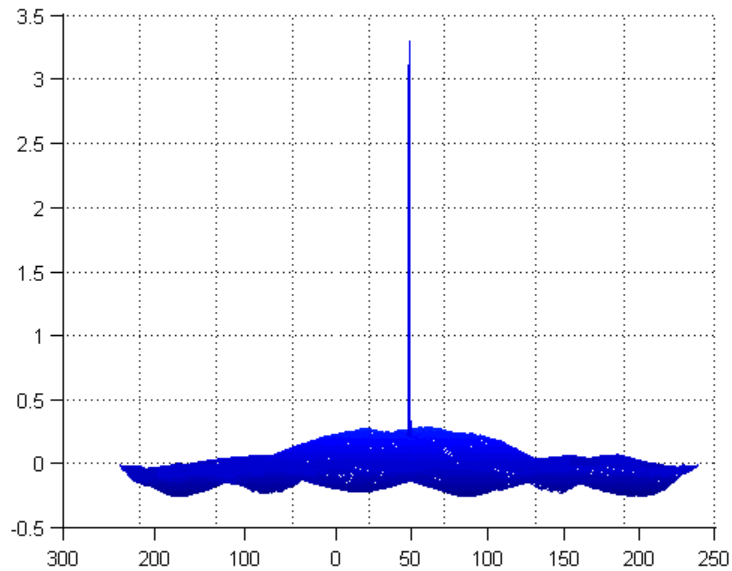


Fig 7.53: Amplitude spectrum of correlation matrix of matched patterns

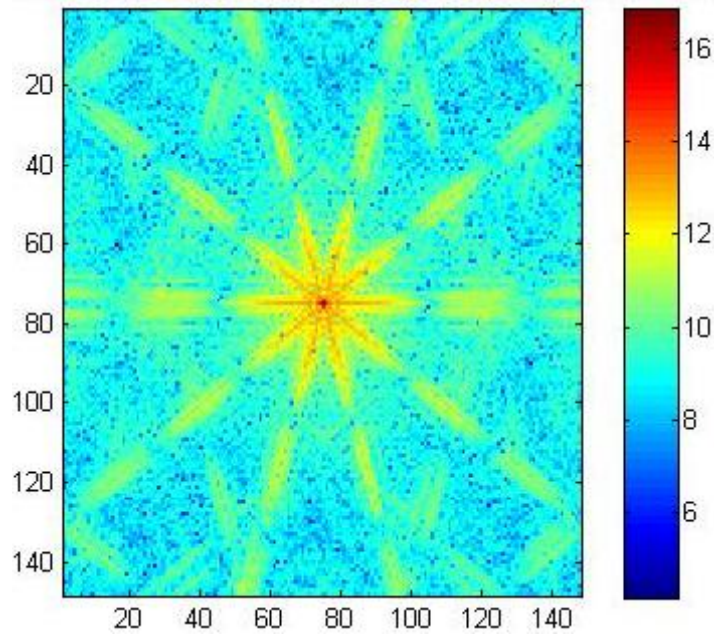


Fig 7.54: High pass filtered magnitude spectrum (post windowing)

Each pattern is cross-correlated ^[64] ^[66] with every other pattern. For the algorithm to function properly, the correlation score between similar patterns must be higher than between different patterns. Apart from tented arch, all other patterns have shown highest correlation score when matched to themselves. To validate the reliability of the algorithm, comparisons have been done in normalized scale, i.e. all comparison scores within one pattern category come under same scale. Table 1 displays the actual scores obtained during cross-correlation process. The graphic is given in chart 7.1.

	Whorl	Arch	Tented arch	Radial loop	Ulnar loop	Variant
Whorl	0.634	0.458	0.395	0.509	0.448	0.483
Arch	0.458	2.044	0.342	0.95	1.716	-4.061
Tented arch	0.395	0.342	0.554	0.85	1.688	4.066
Radial loop	0.509	0.95	0.85	1.148	0.929	0.952
Ulnar loop	0.448	1.716	1.688	0.929	1.899	-4.022
Variant	0.483	-4.061	4.066	0.952	-4.022	-3.87

Chart 7.1 – Score display of all patterns correlated to every other pattern

The following charts from 7.2 to 7.6 display scores of six categories of patterns individually correlated with all patterns, including itself.

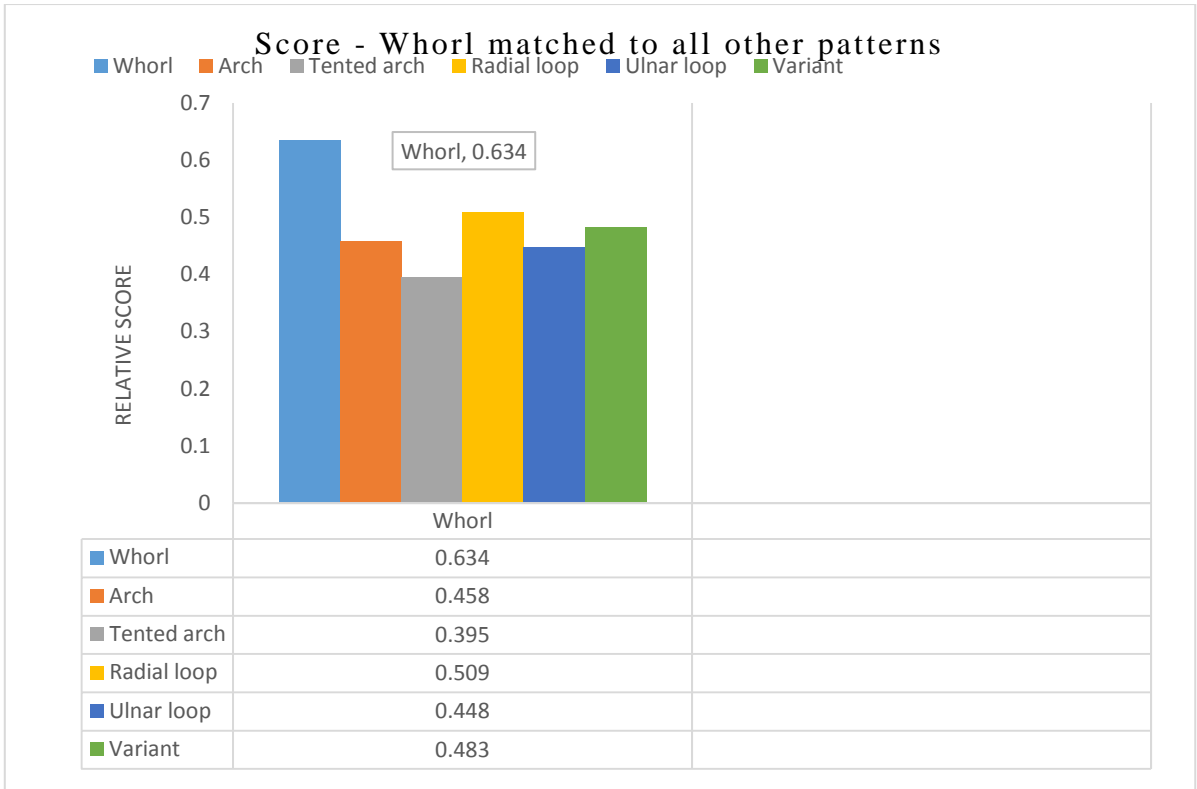


Chart 7.2 – Score display of Whorl correlated to all patterns

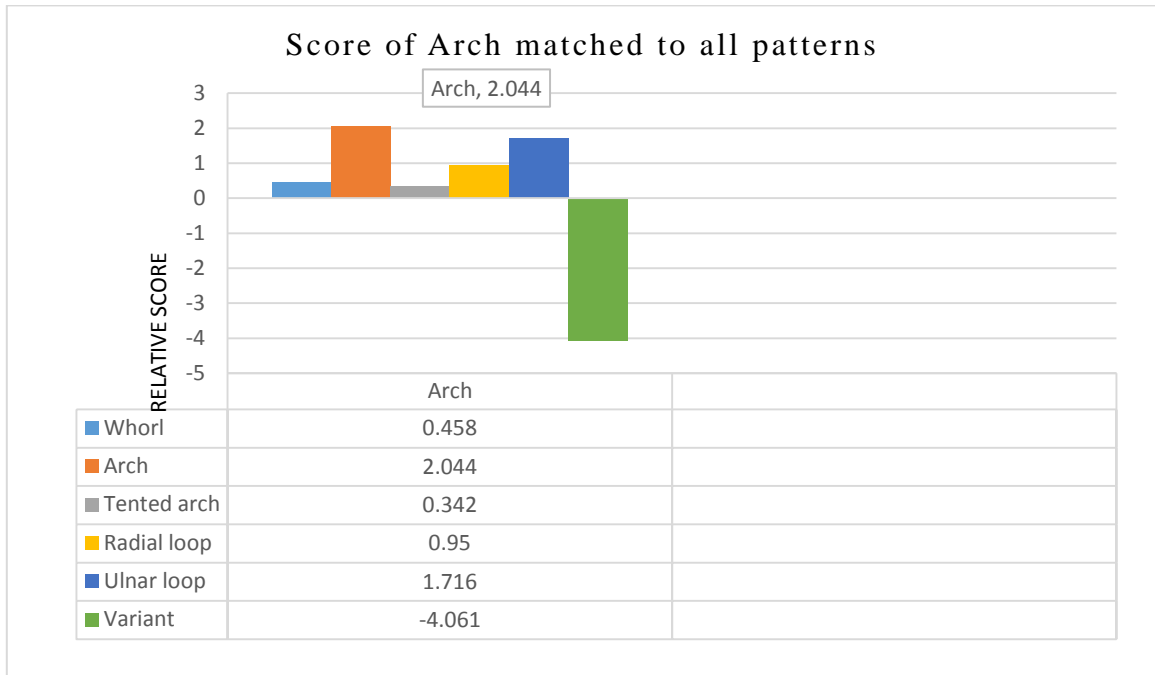


Chart 7.3 – Score display of Arch correlated to all patterns

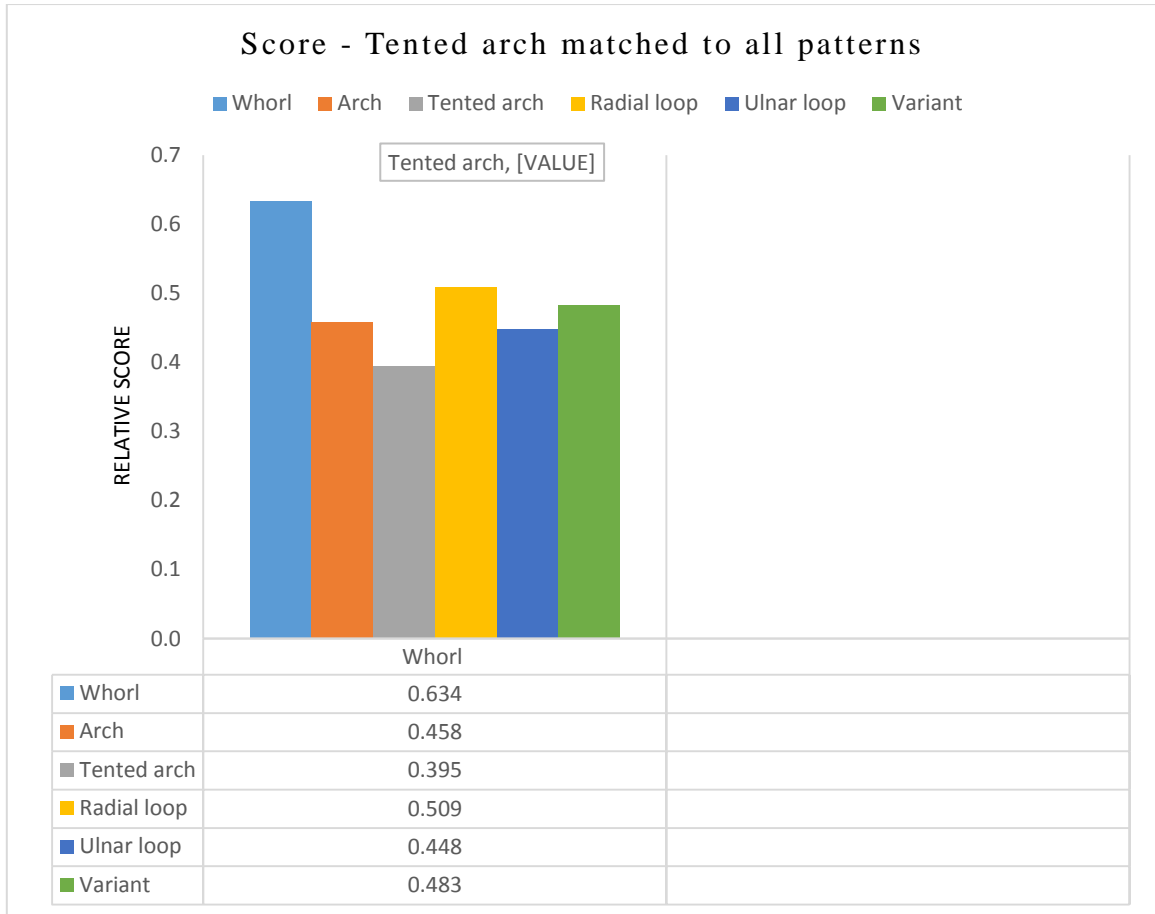


Chart 7.4 – Score display of Tented arch to all patterns

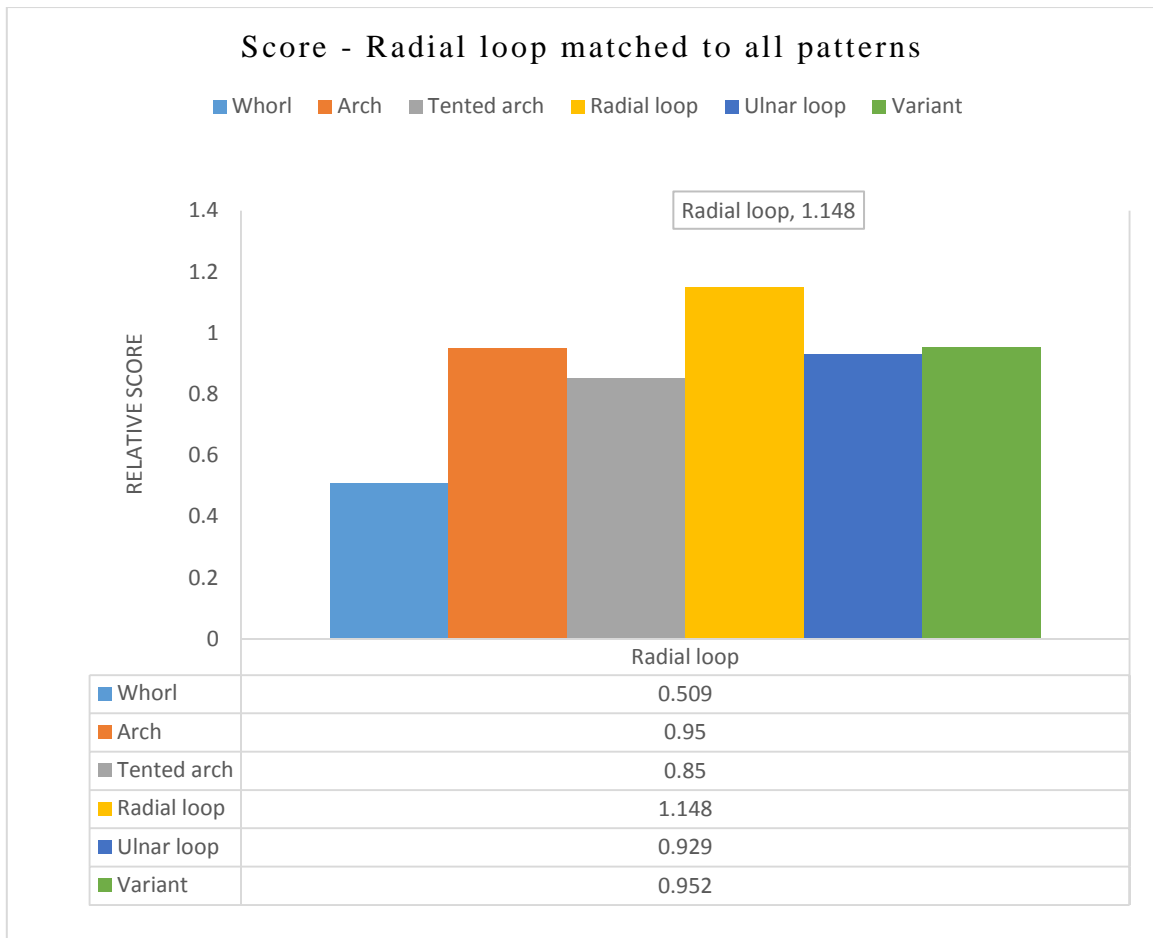


Chart 7.5 – Score display of Radial loop correlated to all patterns

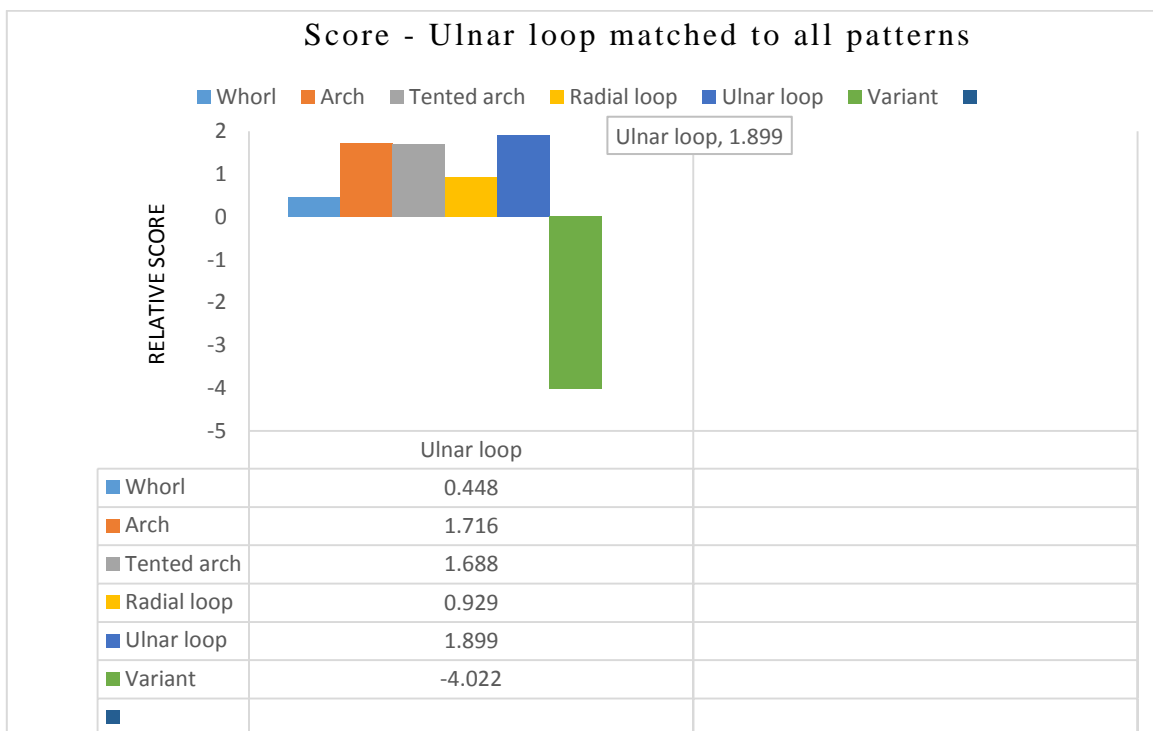


Chart 7.6 – Score display of Ulnar loop correlated to all patterns

Expected result

	Whorl	Arch	Tented arch	Radial loop	Ulnar loop	Variant
Whorl	High					
Arch		High				
Tented arch			High			
Radial loop				High		
Ulnar loop					High	
Variant						High

Obtained result

	Whorl	Arch	Tented arch	Radial loop	Ulnar loop	Variant
Whorl	High					
Arch		High				
Tented arch						High
Radial loop				High		
Ulnar loop					High	
Variant						High

7.3 Automatic Ridge Extraction using Control point selection

The neighbourhood of a pixel is one of the most important aspects in image processing applications. There alter the behaviour of the mathematical tool applied on the pixel. In this methodology, we focus our study on the connectivity of a pixel. The connectivity tells how a pixel is connected to its neighbouring pixels. The pixel in question may have the directly connected pixels, in its north south east and west directions. This is called 4-point connectivity. Such pixels have an edge in common with the pixel of interest. There is yet another type of pixel connectivity, called the 8-point connectivity. If any pixel either shares an edge or a vertex with the pixel in question, then that pixel is an 8-point neighbour of the given pixel.

An image feature is any portion of an image that can potentially be identified and located in both images. Features can be points, lines or corners. Once selected, they need to be matched. For a feature in one image, one must

determine the corresponding feature in other image. The command *cpselect* selects different user defined control points. For the image to be registered against, these are called the base points whereas for the image to register, the control points are known as input points. From a set of matched feature points, a geometric transformation function is inferred that maps features in one image to the locations on other image. The image we undertook in our case, might be rotated, shifted horizontally, that is, translated or even scaled. Together these features are called *affine transformations* [61][62]. Once these transformations have been detected, the unknown image can be registered to be a modulated version of the original.



Fig 7.55: Control point selection

The control point selection tool gives a wide applicability to the user, as shown in figures 7.55 and 7.56. The tool comes with other sister tools where a unit vector matrix can be transformed according to the test image to detect the transformations that the test image itself goes through. The template can be much related to the test only with some non-symmetric or reflective or even affine type. The affine transform includes all possible changes that occurred on spatial level.

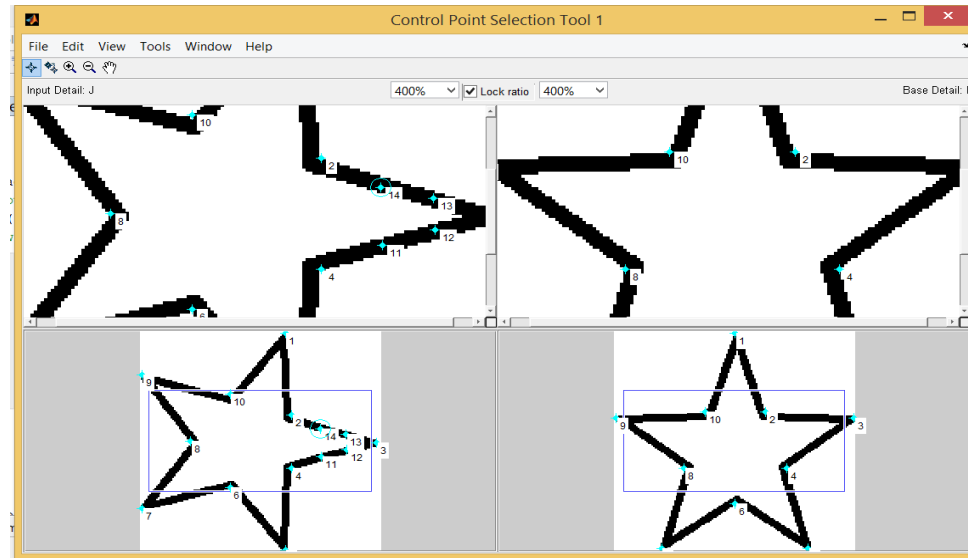


Fig 7.56: Control point Selection

As a result, when the foreground pixels of a pattern are selected, the connected neighbourhood pixels get selected too. Using Graphic User Interface (GUI), the ridges can be extracted by choosing some of the pixels on the ridges.

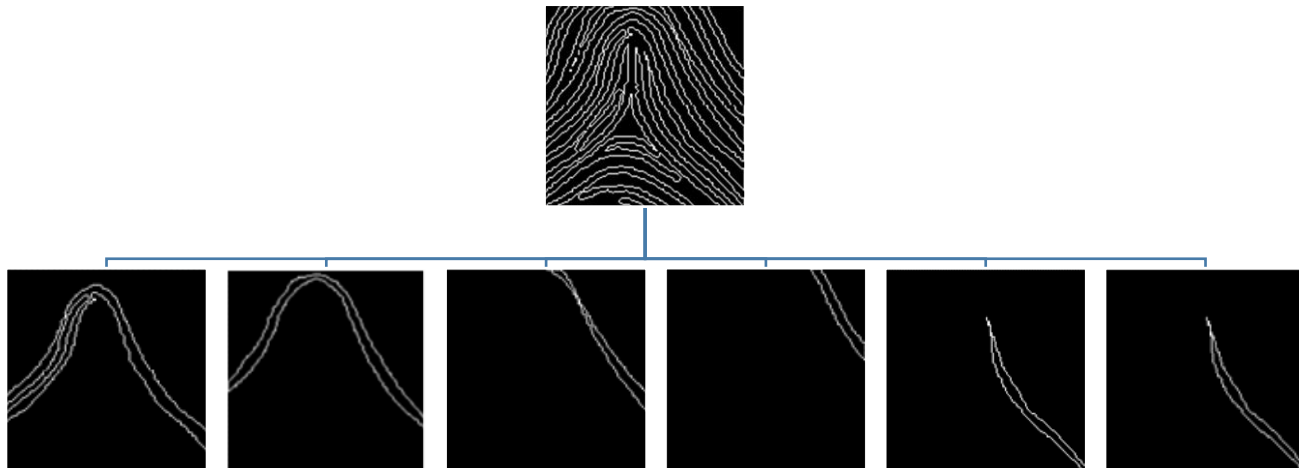


Fig 7.57: Ridges extracted from Arch pattern

7.4 Gradient calculation for block processing

The gradient image of a fingerprint pattern is the representation of direction in which the intensity of adjacent pixels either increase or decrease. The ridges in fingerprint images are brighter at the centre and becomes lesser bright as one moves towards the edge of the ridges. All the explanations are made on the basis of the ridges being white or one intensity value and background pixels being black or zero valued.

The Sobel filter is applied to the image and the gradient is calculated. The horizontal and vertical components of the gradient provide local intensity orientation on a ridge. Hence, a continuous vector field is obtained. This is shown in figure 7.58. The markings have been made prominent using ‘quiver’, which is the outcome of point wise cosine and sine of local estimated orientation [79].

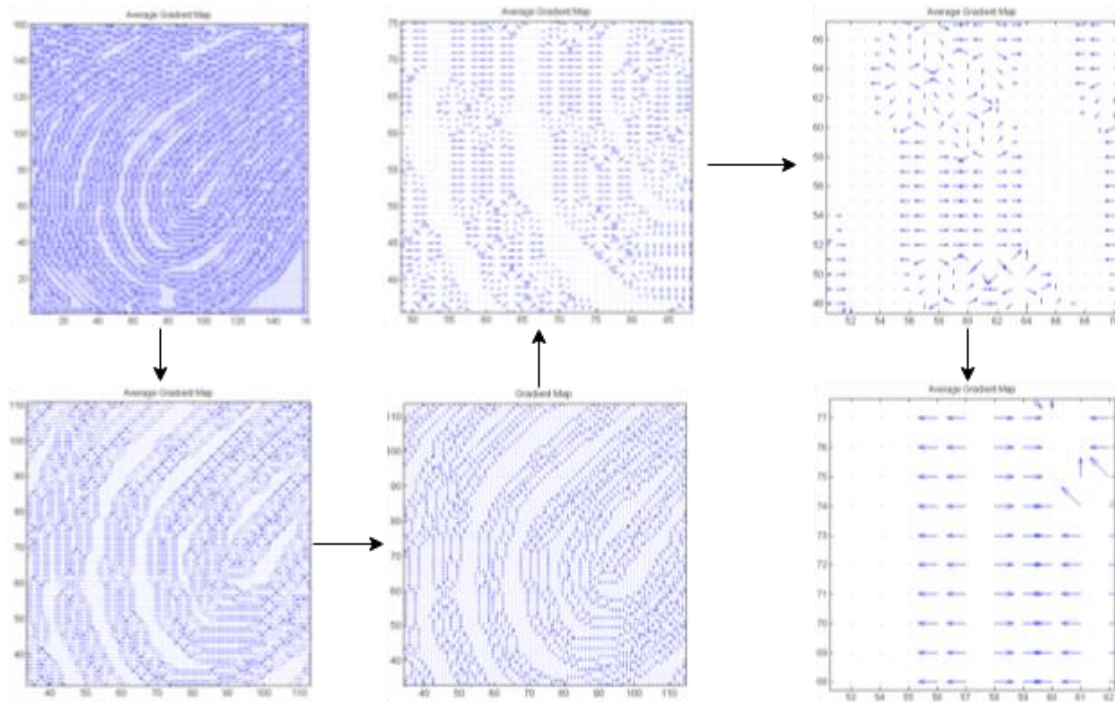


Fig 7.58: Local Intensity Orientation Field of Loop

7.5 Classical Hough Transform for ridge identification

The hough transform is used to detect objects within an image which are lines, circles or ellipses. Here, the ridge count present on a fingertip, between the core of the pattern and the farthest delta needs to be counted. Hence, classical hough transform is applied [78]. The line in cartesian plane is converted into its polar coordinates. Since only preliminary study has been done in this method, few of the line segments with high accumulator bins have been identified and marked. The original image is shown in figure 7.59, while the image with marked/detected ridges and corresponding phase plot is illustrated in figure 7.60. The vertical and horizontal axes of the phase plot denote the radius (ρ) and angle of point wise polar coordinate, respectively [78-81].



Fig 7.59: Original (unenhanced) input image

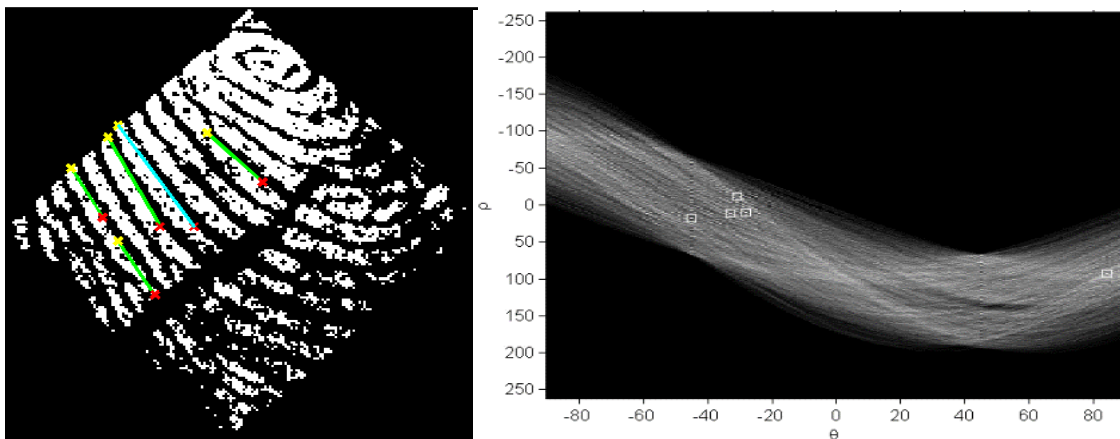


Fig 7.60: Ridges detected as part of line segment recognition (left)

Hough peaks detected in phase plot, corresponding to ridge detection

(right)

7.6 Gabor filter visualization of fingerprint ridge segmentation

The Gabor transform is a digital signal processing transform which is used to identify the segments of signals where there is some change in frequency or phase over a period of time. It is an upgraded special version of short time Fourier analysis (STFT). The window function applied in a Gabor transform is a Gaussian distribution curve ^{[68][69]}. Parameters included are psi, gamma or aspect ratio, lambda or wavelength, psi or phase angle. Every pattern has its unique spatial frequencies and their orientation. A range of frequencies and orientations have been chosen to view the response of the Gabor filter banks. The



Fig 7.61: Gabor bank filtered fingerprint images

observations have been made in the range of 0° to 180° , at every 30° of orientation. It has been observed that patterns can be best classified according to the orientation of the ridges. The orientation angles need to be defined in the algorithm. Results are displayed in figure 7.61.



Fig 7.61 (cont.): Gabor bank filtered fingerprint images

7.7 Confusion matrix for loop – Accuracy tested!

Out of 24 loop patterns, 21 could be correctly recognised as loop patterns. The algorithm failed to recognise 3 out of 24 loop patterns to be loops and categorised them otherwise. Out of 34 whorl patterns, the automatic algorithm could correctly identify 28 as whorls. Six whorl patterns fell out of the class of categorisation. Hence, 85 percent accuracy is achieved.

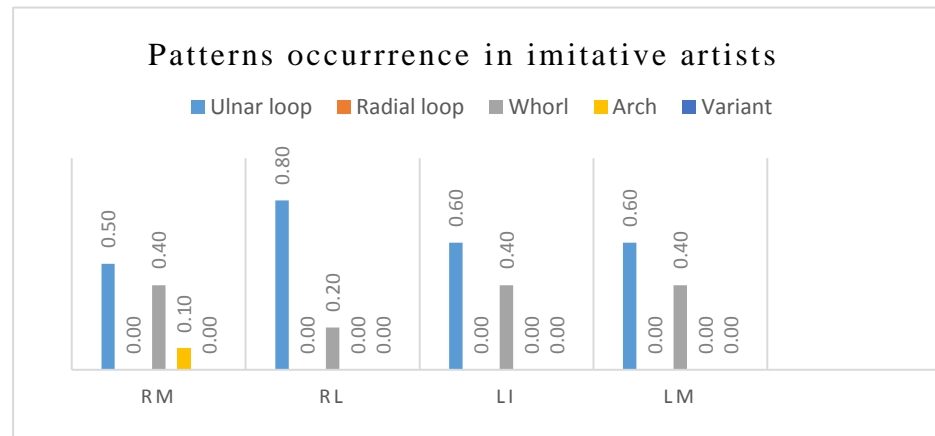
Confusion matrix		Display	
		True	False
Patterns	Loop	21/24	3/24
	Whorl	28/34	6/34

Fig 7.7: Confusion matrix

7.8 Trend in pattern occurrence on fingers corresponding to fine and gross artistic skills

According to the texts that have been gone through, it is hypothesized that following fingers are related to the aforementioned skills and talents. To validate

our assumptions, subjects who are recognized in the field of artistic intelligence,



have been requested to provide their complete set of fingerprints. The per unit occurrence of all patterns, namely, ulnar loop, radial loop, whorl, arch and variant, has been computed. The results for imitative and creative artistic intelligence are displayed in charts 7.7 and 7.8 respectively.

7.8.1 Imitative skill and proficiency

- i) Right middle finger (Finger movement)
- ii) Right little finger (Observational skill)
- iii) Left index finger (Spatial Intelligence)
- iv) Left middle finger (Art and Rhythm sense)

Chart 7.8: Pattern occurrence frequency in imitative artist fingers

7.8.2 Creative skill and proficiency

- i) Right middle finger (Finger movement)
- ii) Left thumb (Creative ability)
- iii) Left index finger (Spatial Intelligence)
- iv) Left middle finger (Art and Rhythm sense)

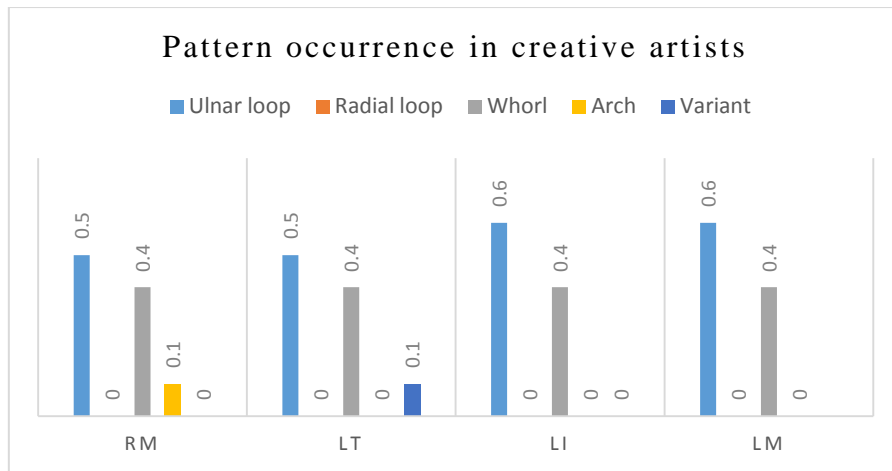


Chart 7.9: Pattern occurrence frequency in creative artist fingers

Conclusion

The theory of multiple intelligence has grabbed the attention of researchers and people from every walk of life, all over the world. The role multiple intelligence plays in categorising people with highly developed intelligence into the profession that suits their innate potentials. The schools are the most benefitted. Hundreds of educational institutes all over the world have adapted a screening method based on a child's fingerprints. It guides the faculty to teach the subject in a manner he/she has been created with. Also, if it becomes known that which career prospect is most suitable for a child according to his/her prominent innate intelligence, then it becomes easier for the child to pursue such career path which in most cases, also turns out to be rewarding. Also, in most of the cases of adults, who are helplessly stuck in jobs that they are unable to relate with, dermatoglyphics is their key to recognise their inherent potentials. It helps enterprises to hire only those who are best suitable for the job. The unnecessary pressure an individual goes through while building a career out of something he/she is not made for, can be averted. Also, people with disabilities can delve into jobs that they are skilled of, from birth. The study of dermatoglyphics can be briefly summarized in the following points.

1. The neural correlates to the various types of intelligences and personality types have a profound connection with specific areas of human brain.
2. The Neocortex is the connection between two differently functional brain halves. The left and right brain halves are not completely isolated from each other and so does the logical intelligence not remain unaffected from the emotional intelligence quotient and vice versa.
3. The fingerprints are the way to understand how our brain is wired up since our births.
4. People can be counselled regarding their behavioural characteristics, inherent potentials, skills and knack.
5. The Fourier Mellin transform and the POC based methods are the effective methods for pattern matching. The former method gives five out of six correct matches in case of similar patterns. The dissimilar patterns are also correctly mismatched.

Future scope

1. The case of tented arch in which the pattern matching technique failed to match with its similar pattern can be worked upon in future.
2. The gradient method can further be worked upon, once the gradient field is calculated, the ridge directional field can be obtained. It will help characterise a pattern in the form of quiver fields. Hence, a pattern can be identified from its gradient orientation field.
3. The ridges segmented from the original enhanced image using the Gabor set of filters, can be used to characterise patterns and hence form a classifier system.
4. The ridges identified using the Classical Hough transform can be used between the core of a pattern and the farthest delta to count the number of ridges in order to relate the TFRC to the intellectual potential of the person.
5. Pixel connectivity can efficiently detect ridges if some intelligent algorithm can select pixels along the curvature of ridges.

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