IMAGE PROCESSING AND FEATURES EXTRACTION OF FINGERPRINT IMAGES

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ABSTRACT

Several fingerprint matching algorithms have been developed for minutiae or template matching of fingerprint templates. The efficiency of these fingerprint matching algorithms depends on the success of the image processing and features extraction steps employed. Fingerprint image processing and analysis is hence an essential step to the efficient matching and classification of fingerprint features. To demonstrate the importance of the image processing of fingerprint images prior to image enrolment or comparison, the set of fingerprint images in databases (a) and (b) of the FVC (Fingerprint Verification Competition) 2000 database were analyzed using a features extraction algorithm. This paper presents the results of the features extraction of the datasets of the FVC 2000 database. It also discusses the limitations of the FVC database and recommends what can be done to improve proprietary databases.

KEYWORDS: Fingerprint, image processing, features extraction, minutiae, segmentation, alignment, binarization, thinning, filtering, intraclass variation, interclass variation, FVC 2000.

INTRODUCTION

Research in biometrics and its applications has increased at geometric rates since the beginning of the 21st century with the increase in terrorism and all physical and virtual threats. The fingerprint biometrics has gained the interest of many researchers. A fingerprint is either a latent, patent or ink impression of the ridge pattern of a fingerprint. The ridge pattern comprises ridges and furrows as shown in figure 1.

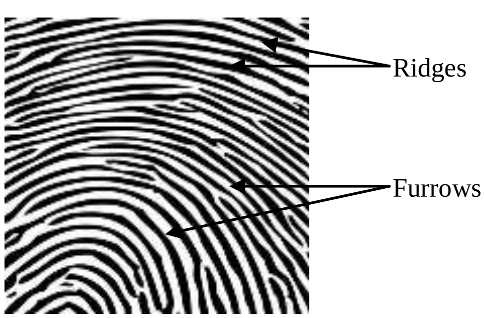

Figure 1: Fingerprint ridges and furrows

The ridge flow of each human finger is unique and this is the basis for fingerprint recognition. The uniqueness of fingerprints implies that a copy of a person's fingerprint can always be traced to the owner. A patent fingerprint image is an image acquired through the use of an image acquisition device, like a fingerprint scanner. Fingerprints are typically used for recognition problems. Recognition systems are either verification or identification systems. A fingerprint recognition system recognizes a person when it finds a match between the user's fingerprint and an enrolled fingerprint. The certainty of finding this match is based on the universal fact that no two human fingerprints are similar, and fingerprints do not change with time. Therefore, a user's fingerprint would always be the same as that user's enrolled fingerprint.

1.1 Fingerprint Class Types

Fingerprints are classified according to their ridge flow patterns. The major classes shown in figure 2 are left loop, right loop, whorl, arch and tented arch [1]. Some other classes not common are central pocket loop and double loop.

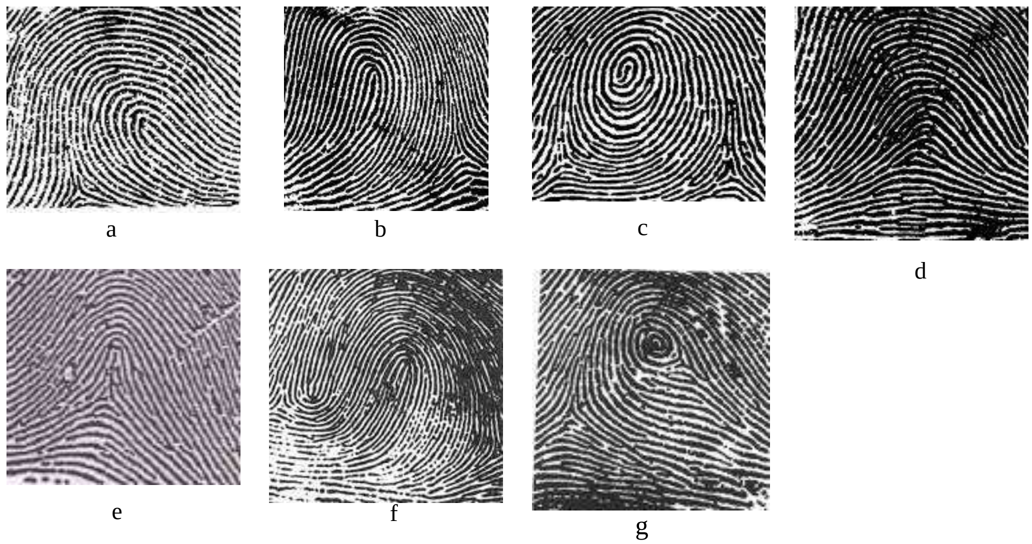

Figure 2: Classes of fingerprints; a) right loop b) left loop c) whorl d) arch e) tented arch f) whorl double-loop g) central pocket loop

In the right loop the ridge patterns flow like a loop from the bottom right direction to the top left. The ridges in the left loop flow from the bottom left to the top right direction. In whorls the ridges flow in a spiral pattern and the center to the innermost ridge is the core. Arches and tented arches are somewhat similar. They have no loops and hence no core. The double loop is like a combination of figures (a) and (b) classes of fingerprints. The central pocket loop is a loop with a whorl inside the loop. The classes of fingerprints are not evenly distributed. About 90% of humans have loops and whorls classes of fingerprints. Arches and tented arches constitute about 10% of fingerprints with rare cases of double loop and central pocket loop. The fingerprint features are discussed in greater details in section 2.

FINGERPRINT FEATURES

2.1 Minutiae-based and Pattern Matching

Fingerprints can be matched based on pattern matching or minutiae-matching [2, 3]. In pattern matching the grey level colours are used. The features used for minutiae-matching are some salient features which their pattern arrangement uniquely characterize each and every individual.

Templates for minutiae-matching are smaller in size than those for pattern matching because of the elimination of redundant data and extraction of only meaningful data for matching in the original fingerprint image. Templates for pattern matching are large because no part of the original image is lost. The large template size with no data loss guarantees accurate matching pixel-wise at the cost of space. The minutiae-based templates are less in size but require more sophisticated algorithms.

2.2 The Three Levels of Fingerprint Features

There are three levels of fingerprint features. Level 1 is a characteristic of the ridge flow pattern [4]. They are easily seen by the eyes. They are called singular features and are the macro details (visible features). The arrangement of the singular features helps in classification and registration of fingerprints

[5, 6].They include the loop, core, whorl and delta. The loop is the point of highest curvature in a ridge flow pattern. The core is the central point to the loop or according to Sir Henry in 1900, the north most point of the innermost ridge line. The delta is a point where ridge flows form a delta point. A delta is a space created by ridge patterns flowing from three different directions. The flowing ridges appear to repel themselves. All classes of fingerprints apart from the arch and tented arch have these singular features. Figure 3 shows three of the five major classes of fingerprints with their singular features.

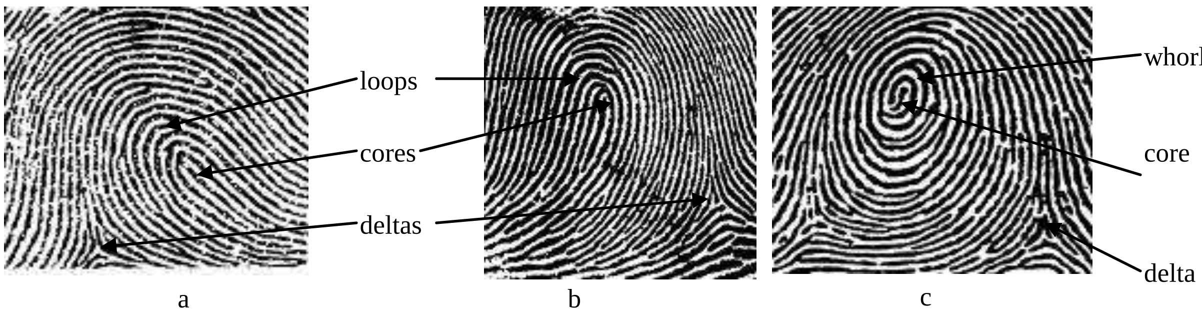

Figure3: Three of the five major classes of fingerprints with their level 1 features a) right loop b) left loop c) whorl

Right loop has its loop to the right of the delta. Left loop has its loop to the left of the delta. Whorl has a spiral with a centre (the core) and two deltas to the side.

The singular features are useful for registration and alignment of fingerprints prior to features extraction and matching. Arch fingerprints do not have singular features making it difficult to classify them.

The Level 2 features are called minutiae details or Galton details named after the inventor. These are minute details in the fingerprint, not that visible to the human eyes. Their arrangement in each and every human is unique; hence no two people will ever have the same arrangement of these minutiae patterns. This is the basics for minutiae-based matching in fingerprint identification. There are many minutiae details but the types utilized are the ridge-end and bifurcation minutiae. Other types include the lake, island, spur, crossover, independent ridge. Figure 4 shows the ridge-end and bifurcation minutiae.

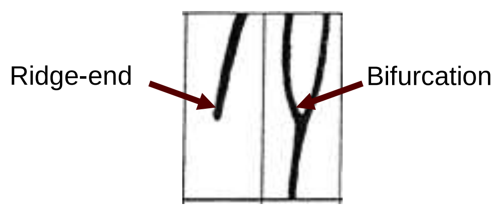

Figure 4: Ridge-end and bifurcation minutiae

The important aspects of the minutiae used in minutiae-based matching are the x,y locations and angle of inclination as shown in figure 5.

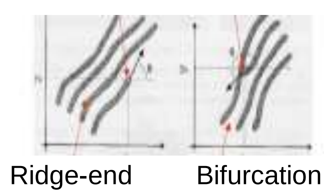

Figure 5: X,Y locations and angles of a ridge-end and bifurcation minutiae

Level 3 features are the micro details not visible to the human eyes. They are the skin sweat pores embedded in the ridges. The level 3 features are very useful in Forensic identification [7].

3. IMAGE PROCESSING OF FINGERPRINT IMAGES

The acquired fingerprint is never as clear as it is in real life due to noise caused by the sensors used, dirt in user's finger, or bad enrolment and other causes.

Prior to feature extraction, the image must be processed to obtain an image devoid of noise, and further processed to put the image in a form ready for feature extraction. Processing of fingerprint image basically requires the following steps as shown in figure 6.

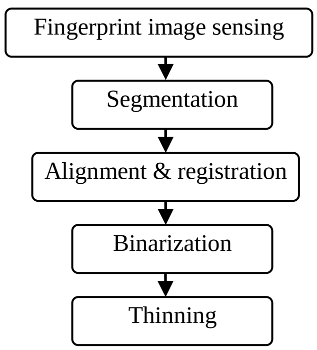

Figure 6: The stages involved in the image processing of a fingerprint.

3.1 Fingerprint Sensing

The fingerprint is sensed via an image sensing device like a life scan device. Sensing can be done using an optical scanner, thermal or capacitive scanner. High resolution scanners are recommended because the higher the resolution of the scanner, the better the quality of image acquired. Scanners should have good resolutions. Fingerprint image scans of 500dpi (dots per inch) [8] is usually recommended.

3.2 Fingerprint Image Segmentation

Scanned fingerprint images do not appear as clear binary images meaning that a great work has to be done on pre-processing the image. The image has different shades of colours which are relevant or irrelevant. Image segmentation is removing the fingerprint area (foreground which comprises ridges and valleys) from the background area which has no useful information. Image segmentation must come before the following steps because it helps prevent the following algorithms from processing the entire fingerprint image, improves the variance thresholding and prevents introduction of false minutiae during minutiae extraction [9]. Hence it is a very important step. Sometimes the fingerprint image may not have a distinct background from the foreground as seen in low quality fingerprints [10] and hence more complex algorithms may be used to carefully segment foreground from background. Several fingerprint image segmentation algorithm have been proposed by [11, 10, 9].

3.3 Fingerprint Alignment

Alignment of fingerprints is essential to accurate matching. Fingerprint sensing even when supervised is not enrolled according to a fixed and certain direction. It is always likely that a user's enrolled fingerprint can have a different angle during enrolment and another angle while matching. It is important to pre-align fingerprint images according to a particular or common orientation to reduce the complexity of fingerprint matching algorithms. The detection of singular points helps in the alignment of fingerprints [12] and in fingerprint registration. The singular points comprise the core and delta features whereas the local features include the bifurcation and ridge-ends as shown in figure 7. The common method of alignment is with respect to the core. Core alignment can be very difficult. There are several algorithms proposed for core alignment in fingerprints [13, 14]. Several authors use the Poincare index method [15] to detect the core. A well done fingerprint registration facilitates an error-free fingerprint matching.

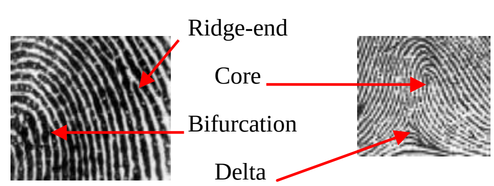

Figure 7: (a) Fingerprint local and (b) singular features

3.4 Binarization

Binarization is the act of converting the grey code image to a binary image. In other words, the domain of the set of pixel values in the binary image is just 0 and 1's. Binarization is not common to all kinds of images, for example multicolour images do not need binarization, while fingerprint images need two colours, black and white. Binarization makes it easier for efficient image processing of the fingerprint image. It standardizes image intensity values into two groups, either 0 or 1 by applying some thresholding technique. A threshold say T is chosen such that any point of a pixel location p (x, y), with value greater than or equal to T becomes a 1, else a 0 [12]. The point of a pixel in an image is p (x, y) as intensity images are 2-dimensional. The thresholding can be a global or local thresholding, though local works best for unclear fingerprint images in which image intensity varies. Global thresholding is applied globally to the whole segmented image while local thresholding is applied to blocks of pixels, one after the other. The threshold in this case varies for each block. Peter Meenen and Reza Adhami [16] gave a summary of the methods employed in binarization of fingerprint images. Recently, there have been better approaches to binarizing fingerprint images rather than simply thresholding [17, 18] more stages of filtering are applied prior to binarization. GUO Lei et al [17] applied thresholding, Gaussian blurring, and region growth prior to binarization. Binarizing the fingerprint creates a maximum contrast between ridges and furrows and facilitates minutiae extraction.

3.5 Thinning

Thinning is what facilitates the detection of minutiae types in a fingerprint image. Prior to minutiae extraction, the widths of the fingerprint ridges are thinned to 1 pixel width, by successive elimination of pixels at the edges. There are fingerprint thinning algorithms available, an earlier type [19] and recent algorithms [20, 21, 22]. The thinned ridges shown in figure 8c are called skeletons.

A problem inherent in thinned ridges is the introduction of false minutiae. False minutiae could arise from broken ridges appearing as ridge ends when thinned. This can be overcome with the use of minutiae filtering algorithms after minutiae detection. Alternatively, thinning can be avoided and minutiae detected using direct grey-scale extraction. For the purposes of the illustration of binarized and thinned fingerprint ridges, the original fingerprint in figure 8 (a) was binarized as shown in 8 (b) and thinned in 8 (c). The original fingerprint image was acquired using a Microsoft fingerprint scanner.

Figure 8: (a) Original fingerprint (b) binarized fingerprint and (c) thinned ridges of a fingerprint

Note that figures 8 (b) and 8 (c) are different from figure 8 (a) because of missing ridges at the top of the images. The faded ridges at the bottom of figure 8 (a) are not well captured in the binarized image of 8 (b) and the thinned ridges in the image of figure 8 (c).

4. FEATURE EXTRACTION OF A FINGERPRINT IMAGE

The features to be extracted are the bifurcation and ridge ends minutiae. This includes the p(x, y) location and the orientation of the minutiae types.

Starting from the thinned image the stages of feature extraction are as shown in figure 9.

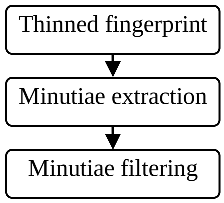

Figure 9: The stages of minutiae-based feature extraction of a fingerprint

4.1 Minutiae extraction

The method employed by many authors for detecting minutiae and minutiae types in thinned fingerprint images is the crossing number (CN) technique [23, 24]. The crossing number seems to have varied definitions among authors, however, the thinned skeletons are scanned pixel-wise, the arrangement of the black and white pixels which looks like a randomly organized colours in a chess-board, is examined based on a certain rule to detect whether there is a bifurcation minutiae, ridge-end minutiae or nothing.

The algorithm proposed by [23, 24] checks a black pixel in the neighbourhood of eight pixels; the black pixel is hence in the centre. A round examination of the eight pixels would show how many times there is a change from black to white pixels or white to black between two adjacent pixels, similar to an examination of a change of state from 0 to 1 in a binary counter. The round count and subsequent difference or change is known as the crossing number. The crossing number (cn), is then the count of this change in a neighbourhood of eight pixels, to a black pixel in the center.

According to JuCheng Yang et al [23] a cn of 2 is a ridge-end, 6 is a bifurcation, and 4 is not definite. Some other authors divide these figures by 2 to get the crossing number, cn. Bir Bhanu et al [25] combined the crossing number with logical templates to extract minutiae. Figure 10 combines the three types of crossing numbers in a single diagram. There are three masks covering the groups of nine pixels to demonstrate the point. In the left upper mask, a black pixel is surrounded by five white and three black pixels. A count of 6 is obtained corresponding to a bifurcation minutia. In the lower middle mask, a count of 2 is obtained corresponding to a ridge-end. In the rightmost mask, a count of 4 is obtained corresponding to nothing.

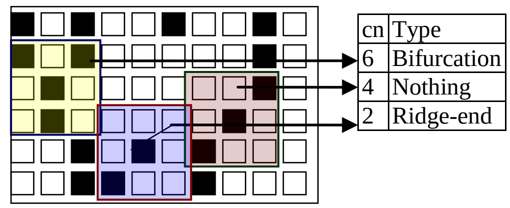

Figure 10: Detection of minutiae types using the crossing number technique

When this is applied to the whole binarized and thinned image, the termination and bifurcation features are gotten with their respective x,y coordinates and inclination angles.

4.2 Minutiae filtering

Some of the minutiae detected in the above method are unauthentic and need to be filtered out using an algorithm. As mentioned earlier, a side effect of thinning is the likely introduction of false minutiae. Other sources could be from the sensor used, and so on. Some of the ridge ends that appear facing themselves probably arise from broken ridges, gaps, and some of the bifurcations are false. Those false minutiae need to be filtered out. Shlomo Greenberg et al [26] proposed an algorithm to remove false ridge ends that appear perpendicular to the ridges and having gap length less than 10 pixels. There are some other algorithms that detect and filter minutiae without going through thinning, in other to avoid more introductions of false minutiae. Dario Maio and Davide Maltoni [27] proposed an algorithm that uses grey scale methods to extract minutiae in fingerprints and consequently passed through another algorithm that uses a neural network classifier to determine authentic and unauthentic minutiae.

5. EXPERIMENTS AND RESULTS.

The experiments show the practical feature extraction stage in fingerprint recognition. The fingerprints used were from databases (a) and (b) of the FVC 2000 database. There were a total of 880 fingerprint images corresponding to 8 images per subject or person. The FVC database is a standard database used for the evaluation of fingerprint algorithms and fingerprint scanners. In other words, the Biometrics research community is expected to use the FVC database without modifications.

A features extraction algorithm developed in C++ programming language was used to extract the x, y locations of the bifurcation and ridge-end minutiae in each of the 880 fingerprint images. Due to lack of space, only the first three images of two different subjects from 880 impressions would be illustrated. The 6 impressions of the persons fingerprint were taken at different times.

Table 1 shows the x, y coordinate locations of the extracted features of three different impressions of the same subject. Table 2 shows the features coordinates of subject 2.

Table 1: Extracted fingerprint minutiae x, y coordinate locations of subject 1

Subject 1					
Impression 1		Impression 2		Impression 3	
x	y	x	y	x	y
46	93	170	39	62	64
74	93	266	57	192	64
200	96	85	67	104	90
113	121	158	68	174	91
186	125	132	70	147	93
156	126	91	82	107	105
117	136	73	94	88	118
97	148	204	100	220	124
233	158	89	131	104	156
114	185	170	141	186	165
195	195	212	145	229	170
242	202	124	158	138	183
156	214	127	173	144	197
153	228	194	177	210	199
223	232	205	186	222	210
32	234	181	196	197	219
234	241	117	197	132	221
142	252	107	202	131	227
210	252	224	213	243	237
132	257	203	215	221	239
256	269	250	229	270	254
233	271	194	232	214	257
		49	245	65	269
		234	253	151	276
		137	259	255	279
		210	259	228	283
		262	261		
		81	273		
		239	274		
		177	279		
		123	283		
		180	287		

Table 2: Extracted fingerprint minutiae x, y coordinate locations of subject 2

Subject 2					
Impression 1		Impression 2		Impression 3	
x	y	x	y	x	y
153	20	135	38	125	27
137	32	203	59	140	43
151	53	183	69	241	47
40	67	196	92	98	73
110	83	85	96	234	87
175	104	153	118	161	96
48	114	215	144	125	103
144	114	87	146	35	104
97	122	142	151	250	107
116	125	186	158	84	111
20	136	153	161	100	115
147	142	63	162	139	135
153	143	189	170	165	135
181	145	179	171	195	140
213	148	185	173	148	142
164	152	191	182	174	146
188	153	218	185	257	156
273	159	199	189	39	157
138	160	253	192	114	159
129	167	225	193	230	164
58	168	46	194	142	168
244	169	170	196	119	169
161	175	93	199	151	172
158	179	163	204	88	178
135	180	173	216	142	181
145	185	192	216	200	187
155	187	168	218	156	197
104	189	285	218	165	212
165	191	200	219	44	227
215	195	137	227	95	229
166	205	251	239	164	233
172	205	75	240	82	243
45	210	205	246	229	243
180	222	212	261	204	256
63	234	91	269	184	258
109	236	138	273	164	270
244	248	210	283		
99	253				
199	267				
222	268				
64	271				
179	278				

It can be noticed that the number of minutiae points per impression and the x, y coordinates of each of the points in a group of 3 impressions from the same subject vary considerably. The impressions vary considerably for the following reasons. There are differences

- due to captured or sensed area of the fingerprint
- due to the varying orientations of the fingerprint on the scanner
- as a result of the varying pressure of the fingerprint on the scanner.

The differences between the impressions of the same finger are called intraclass variations as shown in table 1 only or table 2 only. Differences in impressions of different fingers are called interclass variations as shown in tables 1 and 2. Clearly then, one of the greatest challenges facing fingerprint matching techniques is how to achieve low intraclass variations and high interclass variations. The intraclass variations in tables 1 and 2 are illustrated in figures 11 and 12 respectively by plotting their x, y coordinates in scatter diagrams.

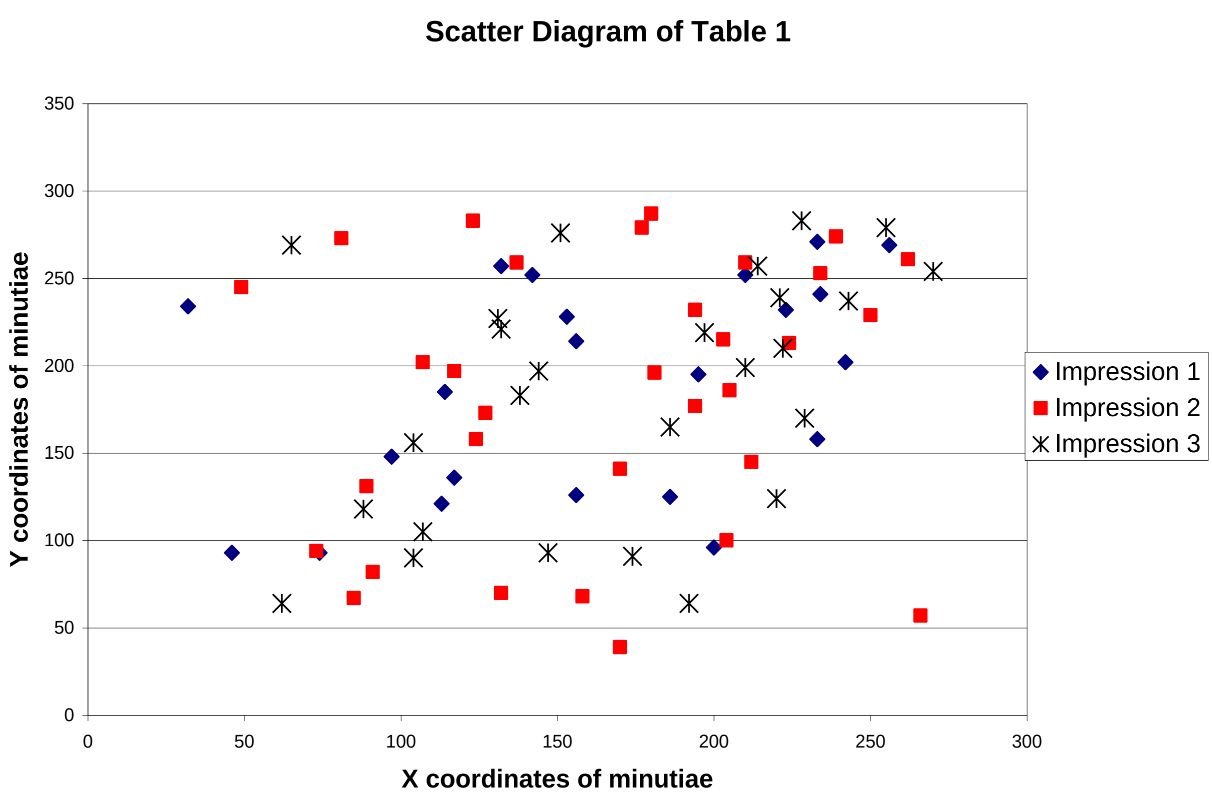

Figure 11: Scatter diagram of minutiae locations in table 1

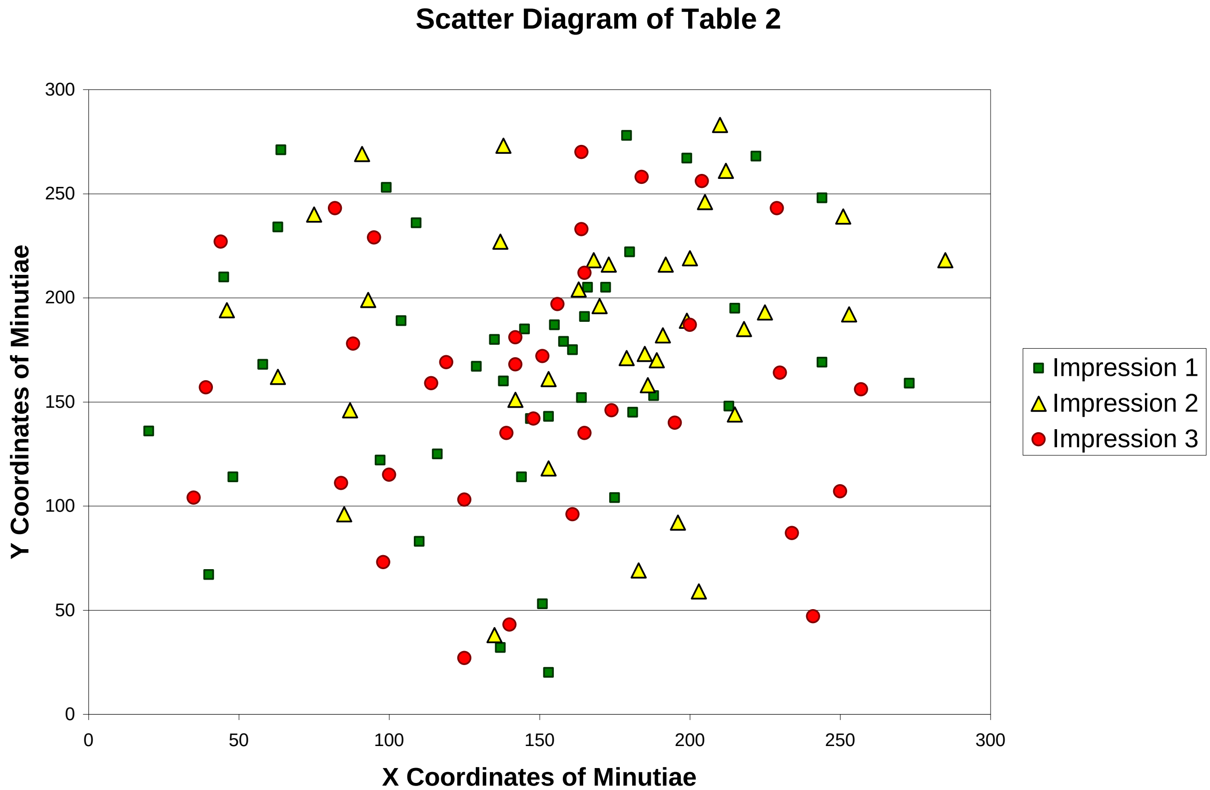

Figure 12: Scatter diagram of minutiae locations in table 2

The scatter diagrams of figures 11 and 12 show that the minutiae points have varying x, y coordinates with different impressions of the same fingerprint. This is visible from the distances between points in impressions 1, 2 and 3 of each subject. If there were no variations, the x, y locations of the three impressions would all overlap.

6. CONCLUSION.

The results obtained show that there is a fairly high interclass variation and a fairly low intraclass variation. This result can be explained by the type of fingerprints used. The fingerprints in the FVC 2000 database used had a lot of noise due to differences in the captured area, the varying orientations of fingerprint on the scanner and varying pressure on the scanner. That explains why in practical applications like in the embassies, the acquisition of fingerprints is supervised such that the captured fingerprints are of high quality. So in obtaining datasets for a proprietary fingerprint database for fingerprint recognition, concerted efforts are made to obtain high quality fingerprints.

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