On Analysis of Rural and Urban Indian Fingerprint Images

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Abstract. This paper presents a feasibility study to compare the performance of fingerprint recognition on rural and urban Indian population. The analysis shows that rural population is very challenging and existing algorithms/systems are unable to provide acceptable performance. On the other hand, fingerprint recognition algorithms provide comparatively better performance on urban population. The study also shows that poor images quality, worn and damaged patterns and some special characteristics affect the performance of fingerprint recognition.

1 Introduction

Fingerprints are considered reliable to identify individuals and are used in both biometric and forensic applications [1]. In biometrics applications, it is used for physical access control, border security, watch list, background check, and *National ID System* whereas in forensics applications, it is used for latent fingerprint matching for crime scene investigation and to apprehend criminals and terrorists. The use of fingerprints for establishing the identity was started in the 16th century and thereafter several studies were performed for anatomical formation, classification, recognition, categorizing features, individuality of fingerprints, and many others. Over the last two decades, research in fingerprint recognition has seen tremendous growth. Several automated systems have been developed and used for civil, military and forensic applications. FBI-AFIS, US border security, and EU passport/ID system are few examples of large scale applications of fingerprint biometrics.

A carefully designed fingerprint recognition system should be stable and robust to environmental dynamics and variations in data distribution. However, in real world applications, establishing the identity of individuals can be very challenging. Sensor noise, poor quality, and partial capture may affect the performance of fingerprint recognition algorithms. Further, interaction between an individual and sensor can cause variations in image quality and biometric features. Poor quality images, therefore, contribute to the difficulty in detecting features from the image and hence decrease the recognition performance.

Indian environment is comparatively different compared to western and European countries. Due to the amount of manual work an average Indian do every day, fingerprint features are, generally, affected and it is very difficult to

perform a reliable feature extraction and matching. Current state-of-the-art algorithms/systems also are trained for recognizing good quality fingerprints and are not tailored for fingerprints with worn and damaged patterns. Moreover, there are no published results that demonstrate the effectiveness of fingerprint recognition algorithms in austere Indian environment.

In this research, we have performed a study that evaluate the performance of automatic fingerprint recognition algorithms on a small set of images pertaining to Indian rural and urban population. Our analysis uses verification and identification accuracies in analyzing the input biometric samples that are obtained from diverse and disparate environment. Next section describes the details of experimental protocol and our analysis.

2 Experimental Evaluation on Indian Rural and Urban Population

The study is performed with two commercial fingerprint recognition systems and implementation of two algorithms from literature. This study is conducted using two fingerprint databases that contain images from rural and urban Indian population. In this section, we briefly describe the algorithms/systems, databases used for validation and experimental analysis.

2.1 Algorithms and Systems Used For Experiments

This study is performed using existing algorithms from literature and state-of-the-art fingerprint recognition systems:

- Implementation of minutiae feature extraction and matching [2] termed as Algorithm - A
- Implementation of filterbank based feature extraction and matching [3] termed as Algorithm - B
- Two commercial fingerprint recognition systems, termed as System - C and System - D[1]

2.2 Fingerprint Database

To perform this study, two sets of fingerprint databases are prepared. The first fingerprint database is prepared in urban settings i.e. population including undergraduate/graduate students and working class individuals. We capture right hand and left hand index finger image from 75 individuals using a 1000 ppi optical scanner. Therefore, there are total 150 classes and for each class, we capture 10 samples. Total number of images in urban fingerprint database is 1500. The second fingerprint database is prepared in rural settings in which images are

[1] Our license agreements for commercials systems do not allow us to mention product names.

from villagers, farmers, carpenters and housewives. Similar to urban fingerprint database, rural fingerprint database contains images from 150 classes (i.e. 75 individuals and for each individual, we capture right and left index finger) and the 10 samples per finger. Total number of images in rural database is also 1500.

2.3 Experimental Analysis

From both the fingerprint databases, we select three samples per class as training and rest as testing. We perform both verification (1:1 matching) and identification (1:N) experiments, and compute both verification accuracy at 0.01% false accept rate (FAR) and Rank-10 identification accuracy. Further, random cross validation is performed for 10 times using the training-testing partitioning. At each cross validation trial, for each database and comparison, there are 525 genuine pairs and 5,47,575 impostor pairs. We perform two sets of experiments,

- Verification and identification experiments on *urban* fingerprint database.
- Verification and identification experiments on *rural* fingerprint database.

The ROC plots in Fig. 1 and identification accuracies in Table 1 summarize the results of the two experiments. The key results and analysis of our experiments are summarized below.

1. Experiments with urban fingerprint database show that all the algorithms and system yield verification accuracy in the range of 86 - 93%. Similarly, higher performance is achieved in terms of Rank-10 identification accuracy. We observe that with high quality images, algorithms/systems provide accurate results whereas the performance suffers when the fingerprint quality is poor or with limited number of minutiae (i.e. reduced region of interest).
2. Experiments with rural fingerprints show remarkable results. Since the database contains several non-ideal poor quality fingerprint images, accuracy (both verification and identification) of the algorithms/systems reduce significantly. On this database, best accuracy is around 60% which is certainly not acceptable in real world large applications. Decrease in performance is mainly because of the poor quality images which cause either missing or spurious fingerprint features.
3. We analyzed fingerprint images in rural and urban databases, specifically those causing errors. We found that there are some specific causes that are more relevant in Indian sub-continental region compared to western and European countries. For example, as show in Fig. 2, Lawsonia Inermis (commonly knows as heena or mehandi) can cause significant differences in quality of fingerprint images. Widely used by women in Indian sub-continent during festivals, heena is applied on hand/fingers and when applied, fingerprint sensors may not properly capture fingerprint features.
4. Another important cause is due to manual labor work. In general, rural population perform several manual tasks that cause worn and damaged fingerprint patterns. As shown in Fig. 3, it becomes difficult to capture good

quality images due to damage in fingerprint patterns. Further, we analyzed that in most of the fingerprint images from rural settings, scars and warts (Fig. 4) are predominant and affect the performance of fingerprint recognition.

5. In our study, we performed another experiment in which images were shown to 15 individuals and asked to perform identification. Note that all these individuals were initially trained to recognize fingerprints. We recorded their response such as feature(s) playing important role in decision/matching process. We observed that although human mind processes multiple features, there are certain features which are important while identifying analogous fingerprints. In general, the first feature which is widely used is the central pattern such as core, delta, loops, and whorl (level-1). The second most important feature is the direction of ridges followed by the ridge contour (shape). For some specific images, scars and warts play an important role. Other important features are - ridge bifurcation and ending (minutiae) in local regions, incipient ridges, clarity of pores, dots, and special features such as hooks and eye formation.

Table 1. Rank - 10 identification accuracy of different fingerprint recognition algorithms/systems.

Algorithm/System	Urban	Rural
Algorithm - A	84	48
Algorithm - B	88	56
System - C	90	64
System - D	91	64

3 Conclusion

In large scale deployment of fingerprint recognition systems, specially in Indian environment, there are some challenges involved. Along with the sensor noise and poor image quality, presence of scars and warts, and deteriorating ridge/minutiae patterns in fingerprints from rural population affect the data distribution. Since there is no research that evaluates the performance of automatic fingerprint verification/identification in Indian population, we studied the performance using standard fingerprint recognition systems and fingerprint databases collected from the rural and urban Indian population. The results show that on the rural database, these algorithms/systems are unable to provide acceptable performance. However, for the database collected from the urban population, fingerprint systems provide comparatively better performance. The analysis reveals that it is difficult to extract features from the fingerprints of

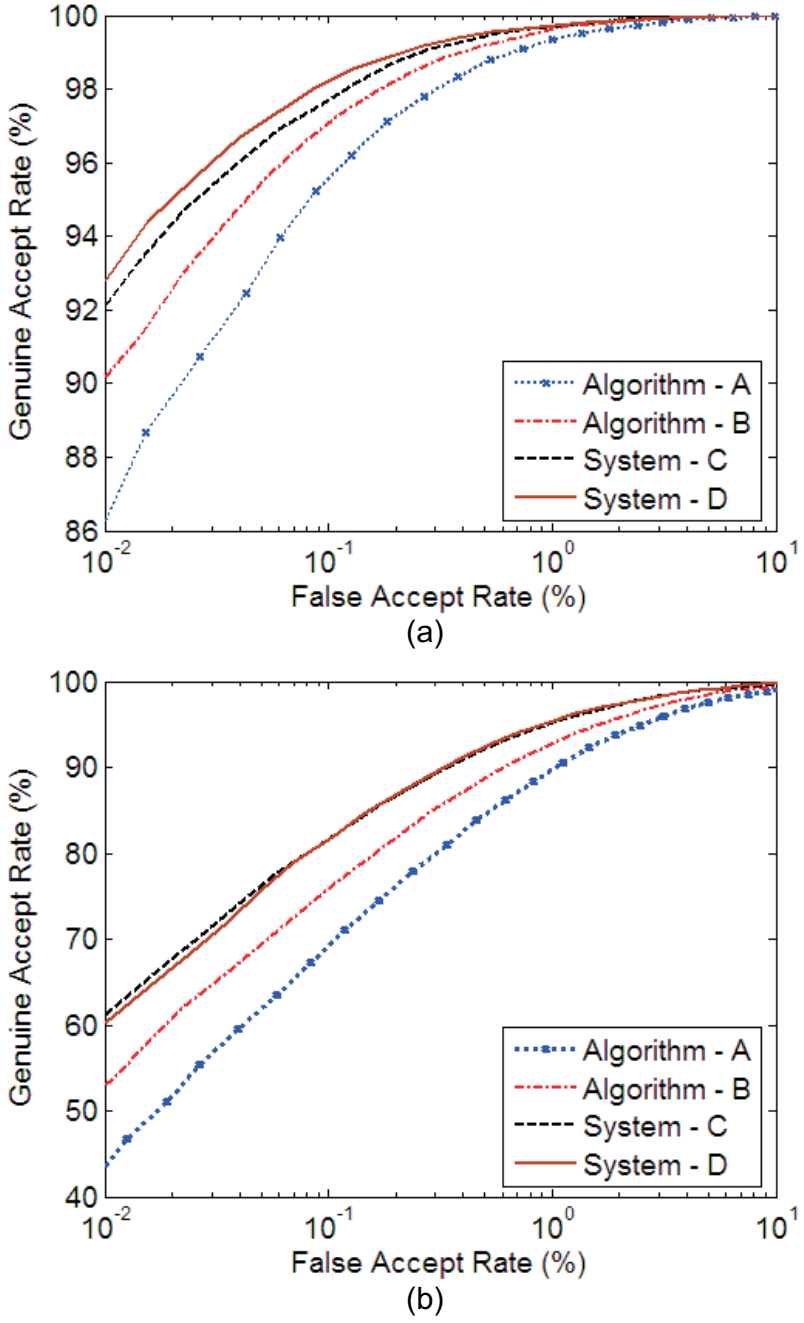

Fig. 1. Fingerprint verification performance using (a) urban fingerprint database and (b) rural fingerprint database.

Fig. 2. Difference in image quality can cause reduced performance: 35 years old housewife in rural settings (second image with heena/mehandi applied on the finger).

Fig. 3. An example illustrating a case when it is difficult to capture good quality fingerprint images.

Fig. 4. There are some features such as scars and warts that are difficult to analyze in current algorithms/systems.

people who do a lot of manual work which in-turn affects the performance of standard systems.

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