Twin Test: On Discriminability of Fingerprints

Anil K. Jain[1], Salil Prabhakar[1] and Sharath Pankanti[2]

[1] Dept. of Comp. Sci. and Eng., Michigan State University, East Lansing, MI 48824
[2] IBM T. J. Watson Research Center, Yorktown Heights, NY 10598

Abstract. *Automatic identification methods based on physical biometric characteristics such as fingerprint or iris can provide positive identification with a very high accuracy. However, the biometrics-based methods assume that the physical characteristics of an individual (as captured by a sensor) used for identification are distinctive. Identical twins have the closest genetics-based relationship and, therefore, the maximum similarity between fingerprints is expected to be found among identical twins. We show that a state-of-the-art automatic fingerprint identification system can successfully distinguish identical twins though with a slightly lower accuracy than nontwins.*

1 Introduction

A number of identification systems based on different biometric characteristics have been developed. As the biometrics-based identification is becoming more pervasive, there is a growing interest [1, 2] in determining the distinctiveness of biometrics characteristics in order to establish the performance limits of such systems. The distinguishing nature of physical characteristics of a person is due to both the inherent individual genetic diversity within the human population as well as the random processes affecting the development of the embryo [3, 4]. Since two individuals can be arbitrarily close with respect to their genetic constitution (e.g., identical twins), a pessimistic evaluation of identity discrimination based on biometrics may need to rely solely on an assessment of diversity in the traits due to random process affecting human development. Such an assessment strategy would necessarily rely on biometric samples from individuals who are identical/similar in their genetic constitution.

The extent of variation in a physical trait due to random development process differs from trait to trait. By definition, identical twins can not be distinguished based on DNA. Typically, most of the physical characteristics such as body type, voice, and face are very similar for identical twins and automatic identification based on face and hand geometry will fail to distinguish them. See Figure 1 for a photograph of an identical twin pair. It is, however, claimed that identical twins

Fig. 1. Photograph of identical twin sisters.

can be distinguished based on their fingerprints, retina, thermogram, or iris patterns. The focus of this study is to quantitatively determine the similarity of fingerprints in identical twins. We further attempt to assess the impact of this similarity on the performance of fingerprint-based verification systems. Since both, human iris and angiogenesis follow a development pattern similar to fingerprints, we believe the results of this study may be qualitatively applicable to other biometric identifiers such as iris, retina and thermogram as well.

2 Fingerprints

Fingerprints are the pattern of ridges on the tip of our fingers. They are one of the most mature biometric technologies and are considered legitimate proofs of evidence in courts of law all over the world. Fingerprints are fully formed at about seven months of fetus development and finger ridge configurations do not change throughout the life except due to accidents such as bruises and cuts on the finger tips. More recently, an increasing number of civilian and commercial applications (e.g., welfare disbursement, cellular phone access, laptop computer log-in) are either using or actively considering to use fingerprint-based identification because of the availability of inexpensive and compact solid state scanners as well as its superior and proven matching performance over other biometric technologies.

An important question in fingerprint matching is: which characteristics of the fingerprints are inherited? A number of studies have shown a significant correlation in the fingerprint class (i.e., whorl, right loop, left loop, arch, tented arch) of identical twin fingers; correlation based on other generic attributes of the fingerprint such as ridge count, ridge width, ridge separation, and ridge depth has also been found to be significant in identical twins. In dermatoglyphics studies, the maximum generic difference between fingerprints has been found among individuals of different races. Unrelated persons of the same race have very little generic similarity in their fingerprints, parent and child have some generic similarity as they share half the genes, siblings have more similarity and the maximum generic similarity is observed in the monozygotic (identical) twins, which is the closest genetic relationship [5].

Monozygotic twins are a consequence of division of a single fertilized egg into two embryos. Thus, they have exactly identical DNA except for the generally undetectable micromutations that begin as soon as the cell starts dividing. Fingerprints of identical twins start their development from the same DNA, so they show considerable generic similarity. However, identical twins are situated in different parts of the womb during development, so each fetus encounters slightly different intrauterine forces from their siblings. As a result, fingerprints of identical twins have different microdetails which can be used for identification purposes [6]. It is claimed that a trained expert can usually differentiate between the fingerprints of identical twins based on the minutiae (dis)similarity [6]. Thus, there is anecdotal evidence that minutiae configurations are different in identical twins but to our knowledge, no one has systematically investigated or quantified how minutiae information in identical twins is (un)related in the context of an automatic fingerprint-based authentication system. This paper focuses on analyzing the similarity between fingerprint minutiae patterns of identical twin fingers.

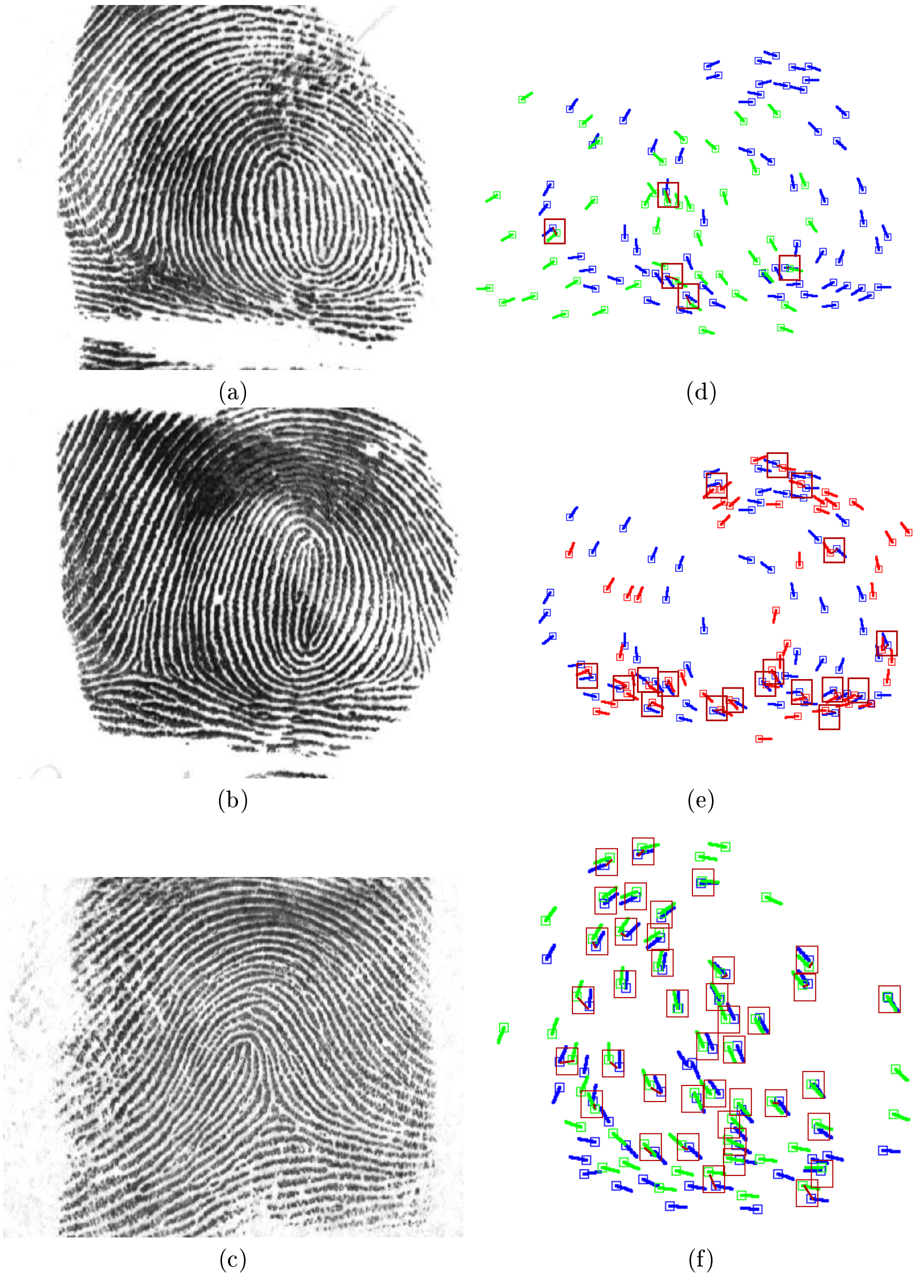


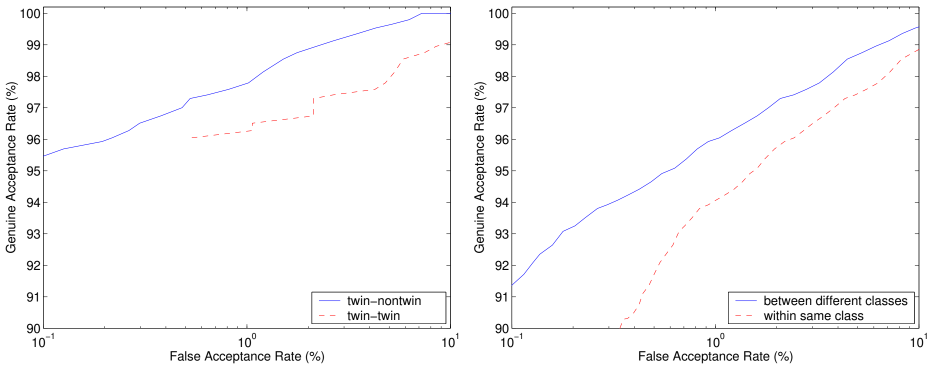
Fig. 2. Minutiae matching for twins. (a) and (b) are fingerprint images of identical twins while the fingerprint in (c) is from another person. (d) Minutiae matching for twin-nontwin (matching of (b) and (c), matching score = 3). (e) Minutiae matching for twin-twin (matching of (a) and (b), matching score = 38). (f) Minutiae matching for two impressions of the same finger (these images are not shown here) of a person (matching score = 487). The "matched" minutiae pairs are shown by bounding boxes.

3 Experimental Results

An arbitrary subset of the rolled identical twin fingerprints collected for the NHLBI twin study [7] is used in our experiments. The fingerprints of the index fingers of 100 pairs of identical twins were scanned at 500 *dpi* resolution. Due to differences in paper quality and degradation of the print over time, several of these fingerprints are of poor quality. As a result, we used only 94 pairs of identical twin fingerprints in our study. Using the algorithm described in [8], we matched every fingerprint in our twin database with every other fingerprint. The twin-twin imposter distribution was estimated using 188 (94×2) matchings between the 94 twin fingerprint pairs whereas the twin-nontwin imposter distribution was estimated using $17,484$ ($94 \times 93 \times 2$) matchings. The twin-twin imposter distribution was found to be slightly shifted to the right of the twin-nontwin distribution indicating that twin-twin fingerprints are generally more similar than twin-nontwin fingerprints. The two-sample Kolmogorov-Smirnov test [9] showed that the twin-twin and twin-nontwin distributions are significantly different at 99.9% level. A genuine distribution of matching scores is generally estimated by matching multiple fingerprint images of the same finger. Since we had access to only a single impression of the fingers in our twin database, we approximated the genuine distribution for twin-twin matching from the genuine distribution of the NIST9 CD No. 1 [10] fingerprint database which consists of $1,800$ fingerprint images taken from 900 independent fingers, two impressions per finger. The ROC curve (Figure 3(a)) shows that, due to the similarity of twin fingerprints, the ability of the system to distinguish identical twins is lower than its ability to distinguish twin-nontwin pairs. An illustration is shown in Figure 3. However, contrary to claims made in popular press [1], the automatic fingerprint identification system can still be used to distinguish between identical twins without a drastic degradation in identification performance.

If an application demands an FAR of 1%, to safeguard against twin fraud, we can set the operating point of the system pessimistically at a threshold that corresponds to an FAR of $\sim 0.3\%$ for twin-nontwin matchings and an FAR of $\sim 1.0\%$ for twin-twin matchings. This threshold corresponds to an FRR of 3.5%. This means that in the worst case scenario (when all the people accessing the system are twins), the system will falsely accept 10,000 people out of one million at the expense of falsely rejecting 35,000 people. In the best case (when there are no twins accessing the system), only $3,000$ people will be falsely accepted while falsely rejecting $35,000$ people. In practice, the system will falsely accept between $3,000$ and $10,000$ people (between 0.3% and 1%), depending upon the fraction of twins in our sample population of one million while falsely rejecting $35,000$ people.

Dermatoglyphics studies have suggested that there is high class similarity in the fingerprints of identical twins. To confirm this claim, we manually classified the 94 pairs of identical twin fingerprints in our database into five classes (right loop, left loop, whorl, arch, and tented arch). The class correlation between the index fingers of identical twins is found to be 0.775 (fraction of identical twin pairs whose index fingerprints have the same class label). The natural proportion of occurrence of each of the five major classes of fingerprints in the index finger



(a) (b)

Fig. 3. ROC curves for (a) twin-twin and twin-nontwin minutiae matchings, and (b) effect of fingerprint class type on the matching score.

is .3252, .3648, .1703, .0616, and .0779 for whorl, right loop, left loop, arch, and tented arch, respectively. If we randomly choose two index fingerprint images from a large database, the probability that these two fingerprints will have the same class label is equal to 0.2718. Thus, there is only 0.2718 chance that two randomly chosen index fingers will have the same type which is much lower than the 0.775 chance that the fingerprints of two identical twins will have the same class label.

We believe that the global similarity of fingerprints (shown as class similarity) is, to a certain extent, responsible for the local similarity (shown in the matching performance). Consider two fingerprints that belong to the same class (e.g., right loop). Since the minutiae can exist only along the ridges (although at random locations), the matching score between these two fingerprints is likely to be higher than the matching score between two sets of random point patterns. To study the correlation of class information with the matching performance, we computed the genuine distribution from $3,600$ matchings between the two impressions of the same finger from $1,800$ good quality fingerprint pairs from the NIST4 database [10]. The between-class and within-class distributions were computed from about $130,000$ matchings each. The ROCs for between-class and within-class matchings are shown in Figure 3(b). Note that the magnitude of the shift between the two ROCs in Figure 3(b) is of the same order of magnitude as the one manifested in Figure 3(a). Hence, we conjecture that the larger similarity observed in identical twins is due to the high class correlation in their fingerprint types.

4 Conclusions

One out of every eighty births results in twins and one third of all the twins are monozygotic (identical) twins. Some identical twins have been reported to be involved in fraud, which can be called as "twin fraud", since people mistake the identities of the identical twins. There have been cases reported where an identical twin was sentenced for a crime that was committed by his/her sibling [1]. Fertility treatments have resulted in an increase in the identical twin birth rate (in fact, according to a study by Robert Derom [1], the identical twin birth rate is about twice as high for women who use fertility drugs). Further, because of the medical advances in the treatment of premature babies, population of identical twins is increasing. We have shown that even though identical twin fingerprints have large class correlation, they can still be distinguished using a minutiae-based automatic fingerprint identification system; though with slightly lower accuracy than nontwins. Our results suggest that the marginal degradation in performance may be related to the dependence of the minutiae distribution on fingerprint class.

What are the implications of our empirical results in person identification applications? In authentication applications, marginal degradation in accuracy performance will have almost no effect on "evil" twins posing as impostors. In large scale fingerprint based identification applications, a small degradation in authentication accuracy may imply a significant degradation in the recognition accuracy. Further, if the degradation in the performance is dependent on the class correlation which in turn depends on the genetic constitution (as suggested by the dermatoglyphics studies), it may imply that benefits reaped by composition of ten-finger information may have been overestimated in the literature. Further, the magnitude of performance degradation of a minutiae-based fingerprint matcher may depend upon the genetic relationship among a target population corpus. Both of these effects may need further investigation; more research is necessary for class-independent minutiae-based matchers. Finally, the case of fingerprint classification for the binning of population to increase efficiency of fingerprint based search may not be very effective in genetically related population.

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