PERGAMON

Pattern Recognition 35 (2002) 2653–2663

PATTERN RECOGNITION
THE JOURNAL OF THE PATTERN RECOGNITION SOCIETY

www.elsevier.com/locate/patcog

On the similarity of identical twin fingerprints ☆

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Received 5 September 2001; accepted 1 November 2001

Abstract

Reliable and accurate verification of people is extremely important in a number of business transactions as well as access to privileged information. Automatic verification methods based on physical biometric characteristics such as fingerprint or iris can provide positive verification 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 verification are sufficiently unique to distinguish one person from another. 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 verification system can successfully distinguish identical twins though with a slightly lower accuracy than nontwins. © 2002 Pattern Recognition Society. Published by Elsevier Science Ltd. All rights reserved.

Keywords: Fingerprint; Verification; Identical twins; Performance evaluation; Biometrics

1. Introduction

Biometrics, which refers to automatic identification of people based on their physical or behavioral characteristics is inherently more reliable than traditional knowledge-based (password) or token-based (access card) methods of identification. Traditional methods are prone to fraud because tokens may be stolen and passwords may be guessed. On the other hand, biological characteristics cannot be forgotten, easily shared or misplaced. Moreover, biometrics-based authentication requires that the person to be authenticated be present at the point of authentication to provide his biometric measurement. While the traditional verification methods can establish an absolute "yes/no" verification (either the password provided is correct or it is incorrect), biometrics, on the other hand, determines the degree of "similarity" between the person to be authenticated and the claimed identity. It has been shown that various biometric characteristics are able to establish a "positive verification" with a very high level of confidence.

A number of verification systems based on different biometric characteristics have been developed [1]. For a physical or behavioral characteristics to be useful for verification in an automatic system, it must have the following properties: (i) universality (everyone possesses the characteristic), (ii) permanence (the characteristic remains invariant over life time), (iii) collectible (the characteristic is easy to capture), and (iv) distinctiveness (the characteristic is different for everyone). As the biometrics-based verification is becoming more pervasive, there is a growing interest [2,3] 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

☆ An earlier version of this paper appeared in the Proceedings of the Third International Conference on Audio- and Video-Based Biometric Person Authentication, Halmstad, Sweden, June 2001, pp. 211–216.

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PII: S0031-3203(01)00218-7

diversity within the human population as well as the random processes affecting the development of the embryo [4,5]. Since two individuals can be arbitrarily close with respect to their genetic constitution (e.g., identical twins, the only other genetic relationship that may come close to identical twins is the possibility of human clones. Cloning is a method of producing a baby that has almost the same genetic makeup as its parent [6]), 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 cannot 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 verification based on face and hand geometry will fail to distinguish them. It is, however, claimed that identical twins can be distinguished based on their fingerprints, retina, thermogram, or iris patterns (although, there are conflicting reports on how subtle this distinguishing information is [2]). 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 automatic 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 (thermogram and retina based person verification is based on features extracted from the underlying vasculature) patterns as well.

2. Fingerprint formation

Fingerprint is the pattern of ridges on the tip of our fingers. It is one of the most mature biometric technologies and is considered a legitimate proof of evidence in courts of law all over the world. Fingerprints are fully formed at about 7 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. Fingerprints are routinely used by forensic science labs and identification units for criminal investigations. 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 verification because of the availability of inexpensive and compact solid state scanners [7] as well as its superior and proven matching performance over other biometric technologies.

Biological organisms, in general, are the consequence of the interaction of genes and environment. It is assumed that the phenotype is uniquely determined by the interaction of a specific genotype and a specific environment. Physical appearance and fingerprints are, in general, a part of an individual's phenotype. In the case of fingerprints, the genes determine the general characteristics of the pattern. Fingerprint formation is similar to the growth of capillaries and blood vessels in angiogenesis [8]. The general characteristics of the fingerprint emerge as the skin on the fingertip begins to differentiate. However, the flow of amniotic fluids around the fetus and its position in the uterus changes during the differentiation process. Thus, the cells on the fingertip grow in a microenvironment that is slightly different from hand to hand and finger to finger. The finer details of the fingerprints are determined by this changing microenvironment. A small difference in microenvironment is amplified by the differentiation process of the cells. There are so many variations during the formation of fingerprints that it would be virtually impossible for two fingerprints to be alike. But since the fingerprints are differentiated from the same genes, they will not be totally random patterns either. We could say that the fingerprint formation process is a chaotic system rather than a random one [8].

How does one assess whether two fingerprints are identical? In order to reliably establish whether two prints came from the same finger or different fingers, it is necessary to capture some *invariant* representation (features) of the fingerprints: the features which over a life-time will continue to remain unaltered irrespective of the cuts and bruises, the orientation of the print with respect to the medium of the capture, occlusion of a small part of the finger, the imaging technology used to acquire the fingerprint from the finger, or the elastic distortion of the finger during the acquisition of the print.

Several representations have been used to assess the fingerprint similarity. At a coarse level, a pattern class similarity (Level 1 information) depends upon categorization of the overall fingerprint pattern into a small number of classes; the five major classes are: whorl, right loop, left loop, arch, and tented arch. At a finer level, fingers can also be distinguished based on their ridge thickness, ridge separation, or ridge depths. Ridge count feature measures the number of ridges between two salient points (e.g., core and delta) on a finger. The most widely used measure of fingerprint similarity is based on minute details (minutiae [10] (Level 2 information)) of the ridges: if the relative configuration (e.g., placement and orientation) of ridge anomalies (endings and bifurcations) of two fingers is similar, then their minutiae-based similarity is high (see, Fig. 1). The primary focus of our work is the fingerprint similarity based on the fingerprint minutiae information. In addition to the fingerprint features described in this section, location and densities of the minute sweat pores (Level 3 information) have also been found to contain information helpful for distinguishing individuals [11].

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