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Vulnerabilities of fingerprint reader to fake fingerprints attacks

Marcela Espinoza *, Christophe Champod, Pierre Margot

Institut de Police Scientifique, School of Criminal Sciences, Batochime, University of Lausanne, CH-1015 Dorigny, Lausanne, Switzerland

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ABSTRACT

The purpose of this research is to assess the vulnerabilities of a high resolution fingerprint sensor when confronted with fake fingerprints. The study has not been focused on the decision outcome of the biometric device, but essentially on the scores obtained following the comparison between a query (genuine or fake) and a template using an AFIS system. To do this, fake fingerprints of 12 subjects have been produced with and without their cooperation. These fake fingerprints have been used alongside with real fingers. The study led to three major observations: First, genuine fingerprints produced scores higher than fake fingers (translating a closer proximity) and this tendency is observed considering each subject separately. Second, scores are however not sufficient as a single measure to differentiate these samples (fake from genuine) given the variation due to the donors themselves. That explains why fingerprint readers without vitality detection can be fooled. Third, production methods and subjects greatly influence the scores obtained for fake fingerprints.

1. Introduction

Within the framework of the project entitled "Applying Biometrics to Identity Documents" funded by the Swiss Science Foundation, it has been identified that, among all the attacks that can be directed against a fingerprint biometric system, spoof attacks are those presenting the highest risk. Spoof attacks involve the submission of a fake fingerprint on a reader. They represent a considerable risk because of the availability of the target (the reader), the low fabrication costs and the ease of implementation.

Vitality detection methods have been developed to help assessing the authenticity of the test sample and thus protect fingerprint readers against spoof attacks [2,3,7–9,13–16,20–24,29]. At the present day, the efficiency of these methods is limited, in particular in the case of an application such as the introduction of biometric identity documents. Indeed, most national programs deployed use standard livescan optical devices without any vitality detection, certainly due to economical reasons.

Researches related to vulnerabilities of fingerprint readers using fake fingers are now abundant [4,5,10,17,24–27]. Most of the time, the sensors used in such studies are optical, but capacitive sensors have also been tested in the literature [18,28]. All experiments showed that fingerprint sensors offering an acquisition of about 500 dpi can be fooled by fake fingerprints even if the template and the communication channels are protected by appropriate encryption. Nowadays, there is a global trend towards the adoption of higher resolution fingerprint scanner, with a resolution of 1000 dpi. In previous research, many types of fake fingers were tested but the results were most of the time expressed as acceptation rates only. Reporting results this way require to set a decision threshold [19] which makes the investigation of the underlying issues more difficult. Finally, previous researches have been done using gelatin and silicon artificial fingers. Results obtained with gelatin fingers are strongly dependent on the age of the fake finger, due to the loss of water with time, making the silicon fingers becoming rigid [16]. To overcome these drawbacks, two other materials have been chosen for this experiment to elaborate artificial fingers. Note that the terms "fake" or "artificial" fingers are also used in this paper to designate fake fingerprints even if fake samples are not a reproduction of an entire finger but only of the fingertip presenting the fingerprint pattern.

The purpose of this study is to assess the vulnerabilities of a higher resolution fingerprint sensor (operating at 1000 dpi) without applying a decision threshold but only considering the comparison scores returned by the matcher. This will allow to better understand the processes involved in the reproduction of fake fingerprint information.

2. Materials and methods

2.1. Preparation of the fake fingers

Fake finger fabrication processes can be classified in two groups according to the primary production of the print: direct casts and indirect casts. Direct casts are fabricated by pressing the finger on a soft material which hardens with time. This method allows obtaining an inverted 3D representation of the original print. These casts are easy to elaborate and of good quality. However, most of the time, the

* Corresponding author. Tel.: +41 021 692 46 30; fax: +41 021 692 46 05.
E-mail address: marcela.espinoza@unil.ch (M. Espinoza).

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Fig. 1. Illustration of a deposited fingermark (left), the final image (middle) obtained after processing it using Adobe Photoshop® CS2 (including manual correction of artifacts), and a capture (right) obtained from the final fake fingerprint elaborated with glue from the indirect cast printed on an acetate sheet.

Fig. 2. Illustration of a fake made of latex, produced from Siligum mould using the direct method.

fabrication process requires the cooperation of the subject whose print will be represented. Other methods can also be considered, like the use of amputated fingers or drugs to make unconscious the subjects. Indirect casts are obtained from a plane image picture. This method does not require cooperation of the subject since latent fingermarks (appropriately detected) can be used as the starting material. Latent fingermarks are composed by natural secretions left by friction ridge skin on a surface during a contact. Fingermarks are most of the time invisible to naked eye and requires the application of various detection techniques procedures (optical, physical or chemical) to obtain a contrast between the fingermarks and the substrate [6]. Compared to the direct cast technique, the indirect method requires using more complex techniques and resources, but technical information and materials are available in open sources for anyone, even with no forensic background.

Once the initial cast is elaborated (obtained directly or indirectly), the second step of the elaboration process consists in pouring a liquid or mould a soft material in the cast. It results in a tri-dimensional representation of the original fingerprint which can be used in a fingerprint optical or capacitive reader. The choice of the casting materials is essential, since all steps of the elaboration process inevitably introduces losses of quality and alterations of the original information. The materials have thus been chosen according to the following criteria: First, the best

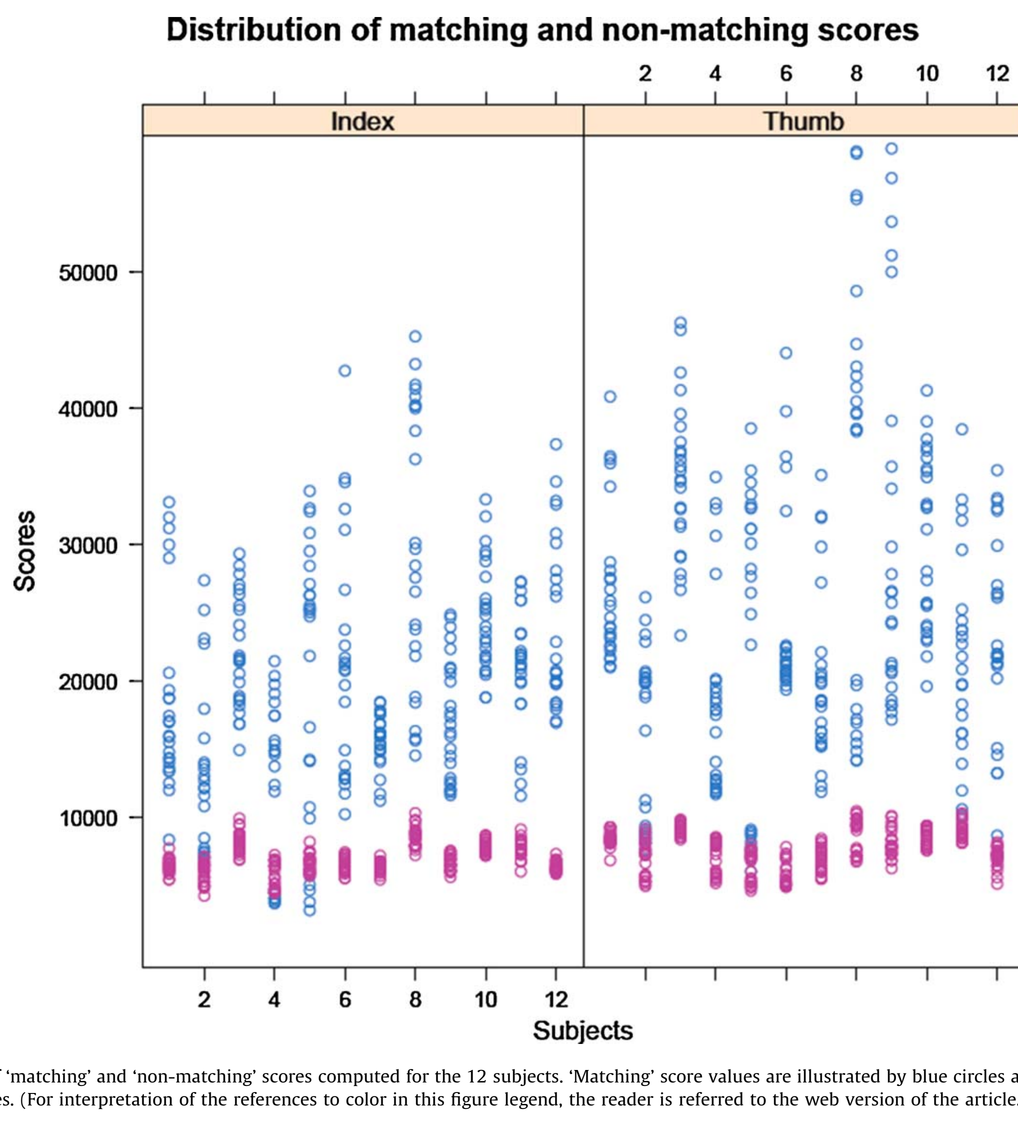

Fig. 3. Illustration of 'matching' and 'non-matching' scores computed for the 12 subjects. 'Matching' score values are illustrated by blue circles and 'non-matching' score values by pink circles. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of the article.)

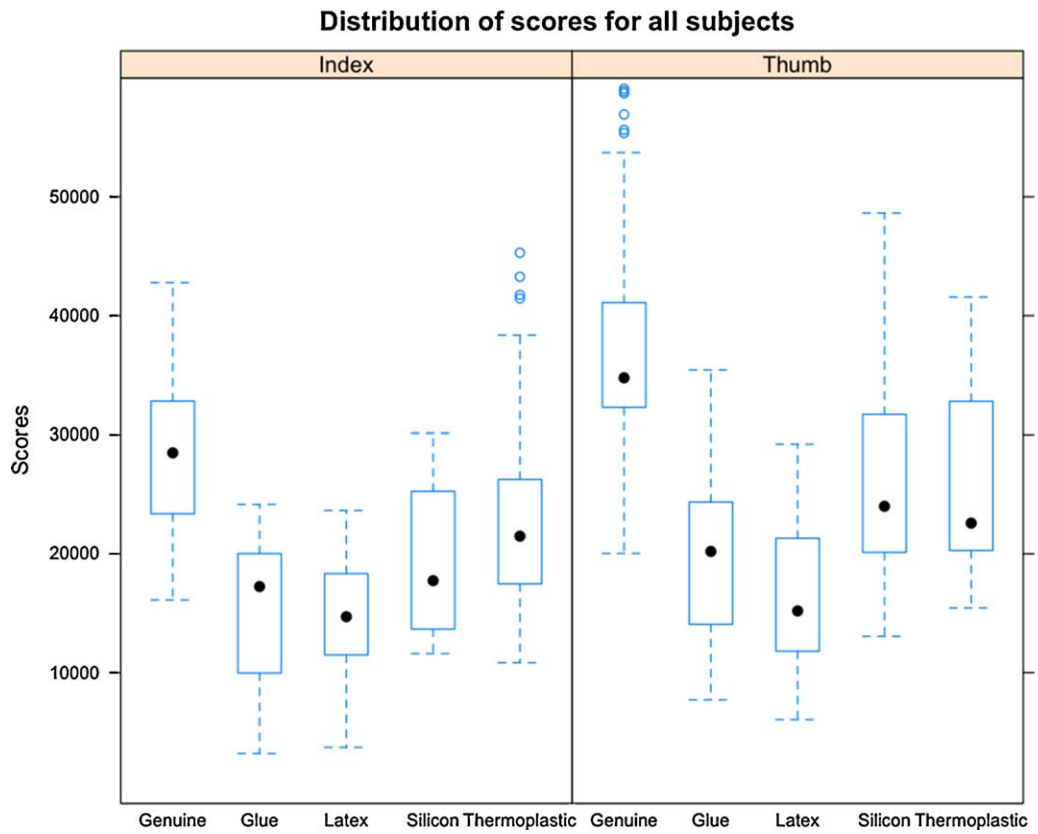

Fig. 4. Boxplot illustrating 'matching' scores computed for all subjects, for genuine index and thumb and for all types of query (genuine and fake). The results obtained for genuine fingerprints are illustrated in the first column. The two next columns illustrate the results obtained for fake fingerprints elaborated from indirect casts (glue and latex), and the two last columns the results obtained for fake fingerprints elaborated from direct casts (silicon and thermoplastic).

casting materials are those which allow maximal reproduction of the fingerprint details (in terms of resolution). Second, the casting and pouring/moulding materials should not chemically interact (to avoid reduced quality of the end result).

In this study, both fabrication processes, direct and indirect, have been tested. Two materials were chosen for the production of direct casts: thermoplastic and silicon. The chosen thermoplastic, named Utile Plast and produced by Pascal Rosier, is melted by putting it in boiling water. When the thermoplastic becomes transparent and soft, it is removed from water and the finger is pressed against it for 3–5 min until the mould becomes less transparent. For silicon, different types of products have been tested for this experiment. The product which has finally been

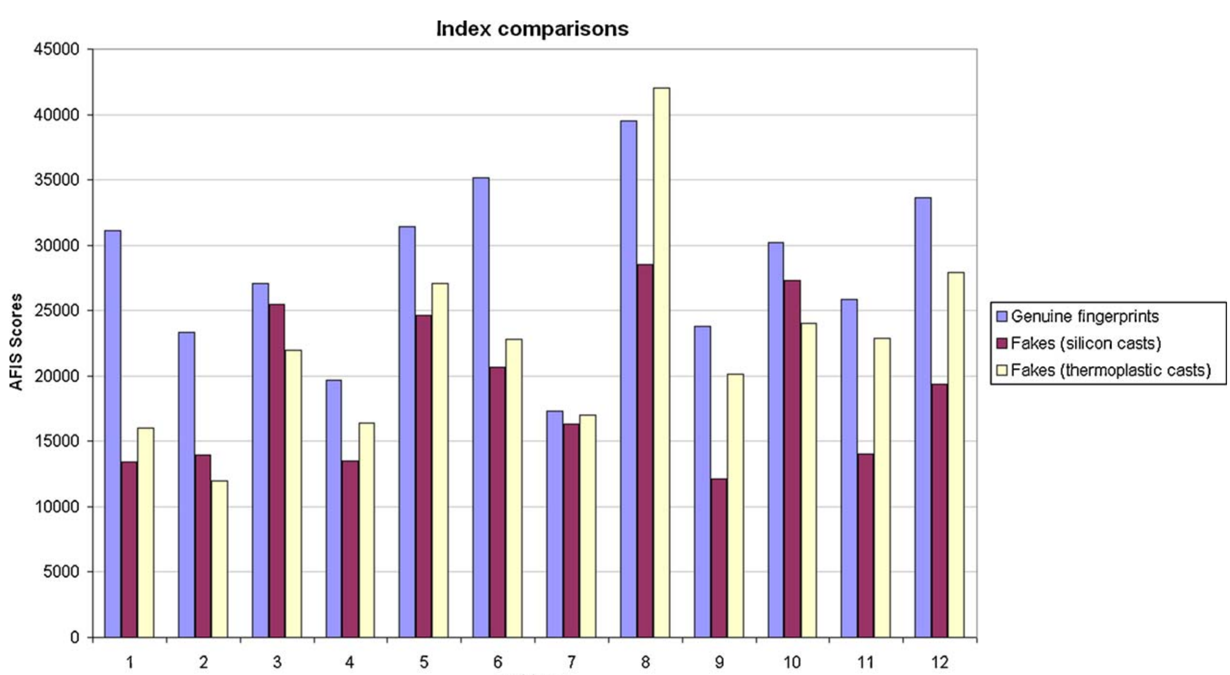

Fig. 5. Illustration of 'matching' scores computed for right indexes and fake fingerprints elaborated from direct casts.

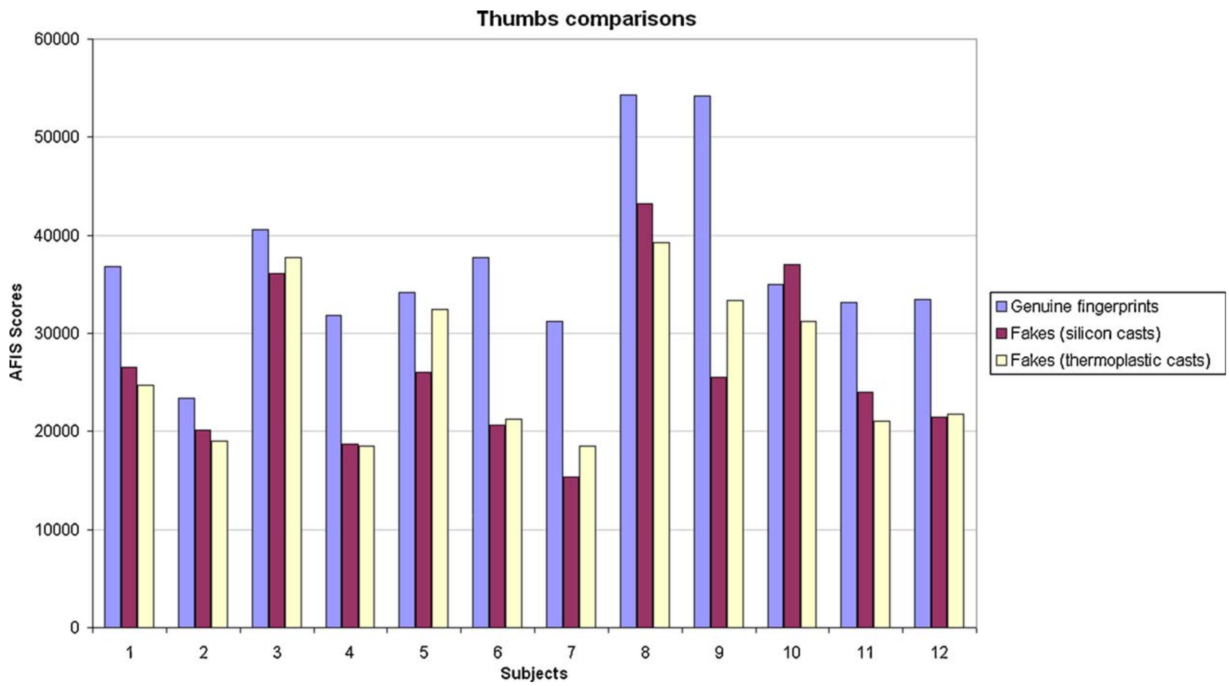

Fig. 6. Illustration of 'matching' scores computed for right thumbs and fake fingerprints elaborated from direct casts.

selected is Siligum, a silicon moulding paste produced by Gedeo®. Two equal parts of reactants are mixed and a ball is formed with the mixture. The finger is then pressed against it for a few seconds until it hardens.

Only one procedure has been used for the production of indirect casts. First, latent fingermarks left on a piece of glass have been photographed using a low-angled light. Second, the digital images were processed using Adobe Photoshop® CS2 software in order to optimize the contrast between the mark and the background, to manually remove artifacts and to convert grey levels images into binary ones (Fig. 1). Finally, these corrected images have been printed on acetate sheet with a Lexmark® T632 laser printer. That output was used as a 3D matrix (due to the elevation of the toner deposit) ready to be used for the second cast. That production method was initially proposed on an Internet website (http://www.ccc.de/biometrie/fingerabdruck_kopieren.xml?language=en). It has been optimized by trial and error to find the appropriate combination of products. Compared to other techniques dedicated to the production of fake fingerprints without cooperation (such as the use of photogravure or the elaboration of stamps) [11,12], the above method led to the best results in terms of reproduction of the three levels of details (up to the pores) from the donor's fingerprints.

Latex (produced by Gedeo®) was retained as pouring material for all kinds of casts (direct and indirect). White glue (produced by Geistlich®) has also been used with indirect casts. The drying time is about 24 h.

2.2. Production of fake fingers

Fake fingerprints were produced with and without the cooperation of 12 subjects, six men and six women [1]. The right index and the right thumb of each

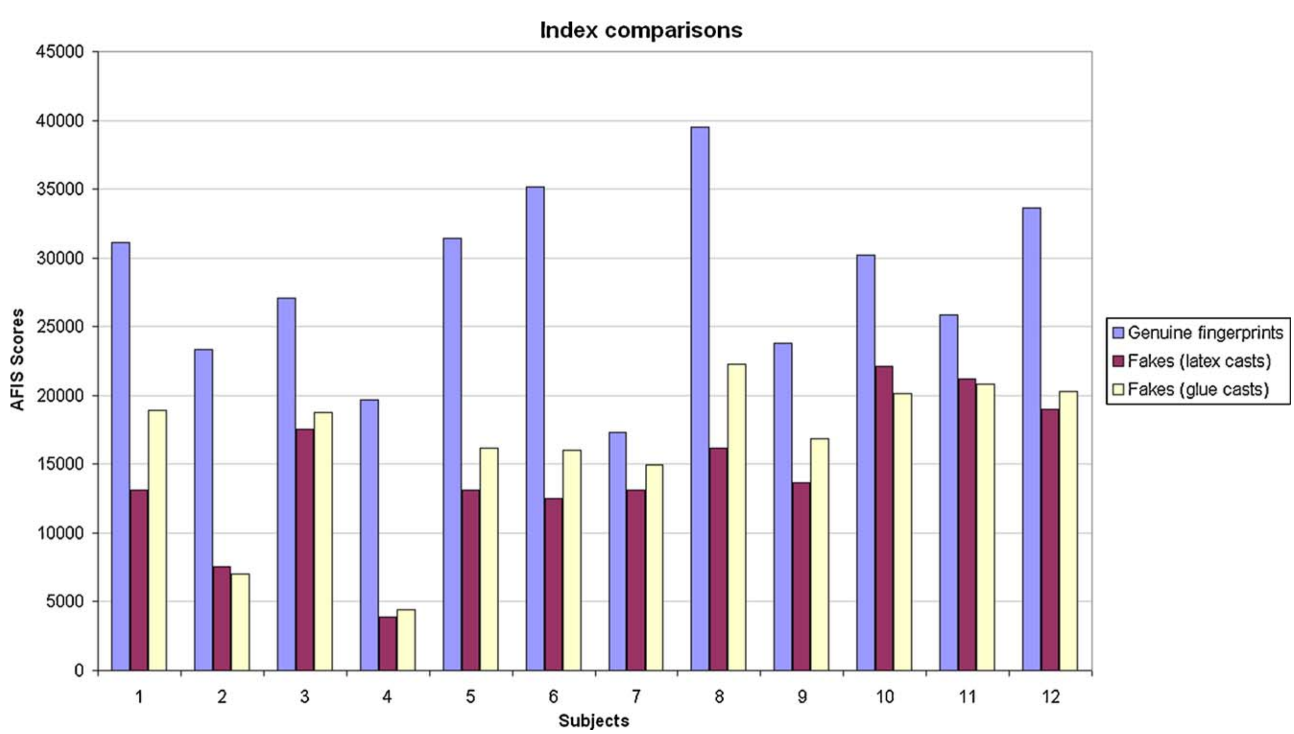

Fig. 7. Illustration of 'matching' scores computed for right indexes and fake fingerprints elaborated from indirect casts.

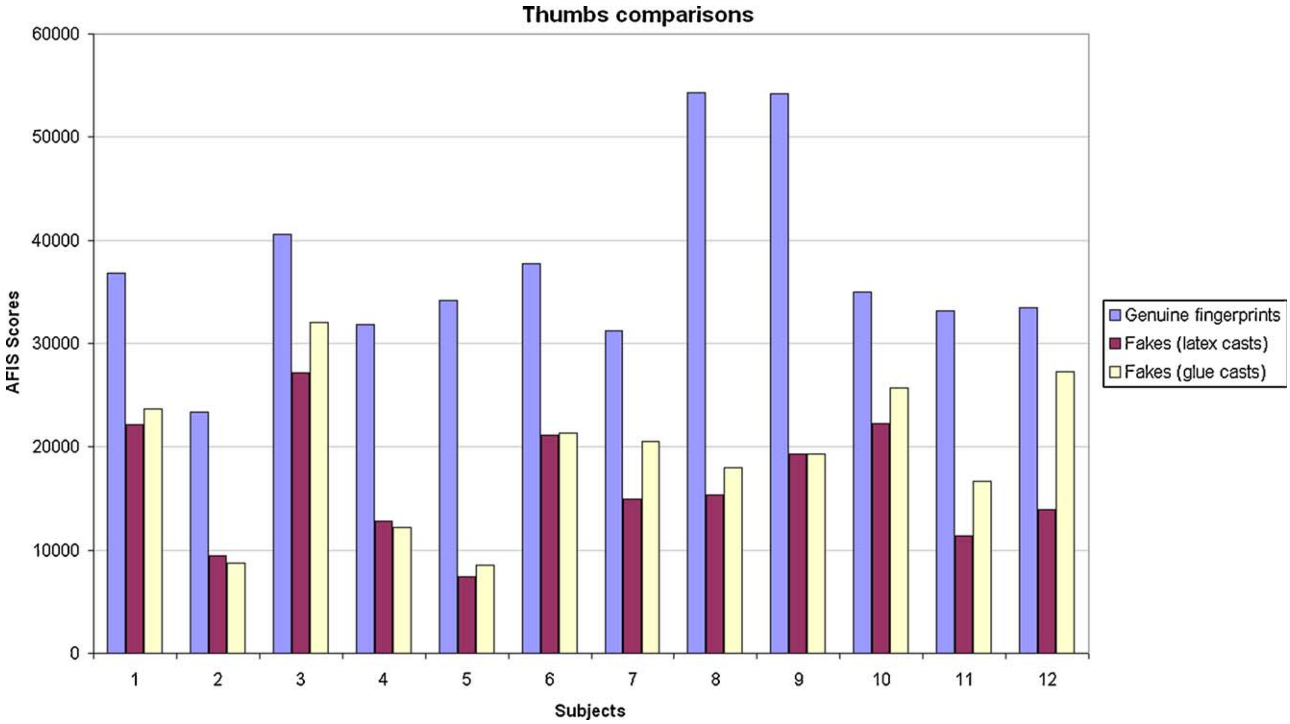

Fig. 8. Illustration of 'matching' scores computed for right thumbs and fake fingerprints elaborated from indirect casts.

subject have been chosen to produce fake fingerprints. The production of direct casts has been supervised by one of the authors (corresponding author) having produced around 200 casts. Once the cast is elaborated, it was examined to detect possible defects. If a defect was observed, the procedure was repeated until a cast of sufficient quality is obtained. For indirect casts, a latent mark is deposited by the subject on glass and then photographed with a digital Canon EOS 20D camera and a Canon 60 mm macro-lens. For each cast, a fake fingerprint was produced with latex or glue (depending on the method) (Fig. 2) and then examined by a qualified examiner to assess its quality. Fake fingerprints of insufficient quality have been excluded and the procedure was repeated. Cases of failure to produce quality moulds remained negligible, about 7%. Failures were caused by the difficulty to predict the drying time of the latex or glue mould that depends essentially on temperature, airflow and humidity. If a separation of the final mould is attempted before it is dry, the quality of the production will lower.

2.3. Fingerprint reader and comparison

Fingerprint images were captured (flat impressions and not rolled "nail to nail" impressions) using an optical sensor CrossMatch Technologies LScan 1000T at a resolution of 1000 dpi. Five images were captured for each fake fingerprint and six genuine captures were acquired for each finger, one used for the enrolment procedure and the other five to be used as genuine transactions. Once captured, fingerprint images were introduced in an automatic fingerprint identification system Desktop Morpho AFIS developed by SAGEM (3.1.2b.micro.7a Version) to perform comparisons. "Identification" is the authentication mode which was selected for this experiment. It consists in comparing the tested fingerprint to all reference prints enrolled in the system (12 pairs right index/thumb fingers from 12 subjects). After each comparison, the AFIS system returns a list of candidates of the closest matches according to a scoring metric, which is arbitrary and dependent of the technology used. Note that the computation of the scores on our AFIS system does not depend on the size of the background database. The DMA system has been modified in order to return the same score between a query and a template regardless of the background database size. Ranks are essentially irrelevant in this study.

3. Results

624 images have been captured and inserted in the AFIS. 24 images of genuine fingers have been used as references and the other 600 images (480 captures from fake fingers and 120 from genuine fingers) have been used as query transactions. For each transaction, the comparison scores associated to each reference enrolled in the system have been computed. For each transaction, the system returned:

- One 'matching' score, which represents the score computed for the comparison between a query impression and the corresponding fingerprint coming from the same source.

ANOVA					
Scores					
	Sum of Squares	df	Mean Square	F	Significance
Inter-groups	1.592E10	1	1.592E10	216.971	.000
Intra-groups	4.387E10	598	7.336E7		
Total	5.979E10	599			

Fig. 9. Illustration of the statistical test (ANOVA) performed to study the differences among scores according to the samples.

- 23 ‘non-matching’ scores, which represents the scores obtained for the comparison between the query impression and the reference images coming from different sources.

The ‘matching’ scores (regardless of the nature of the query, genuine or fake) were systematically higher than the ‘non-matching’ scores when considering each subject, except for some extreme values observed for subjects #1, 2, 4, 5, 11 and 12 (Fig. 3). The scores used for this experiment have been computed for each comparison between the 600 query impressions and the 24 reference fingerprints regardless of the background database. Nevertheless, in order to verify that the size of the database does not influence this tendency, the size of the reference database has been increased to our operational database (comprising of 650,000 rolled impressions). When the scores are computed again on the whole database, the same tendency is observed. In addition ‘non-matching’ scores are not significantly affected by the status (genuine versus fake) of the query.

The results showed that ‘matching’ scores computed for real fingers were in majority higher than those computed for fake fingerprints from the same source (Fig. 4). The effect is larger when indirect cast is used compared to direct cast. The results also showed that thumbs presented ‘matching’ scores usually higher than those computed for index fingers.

Results for each individual are presented for direct and indirect casts in Figs. 5 and 6 and 7 and 8 respectively. It can be seen that for

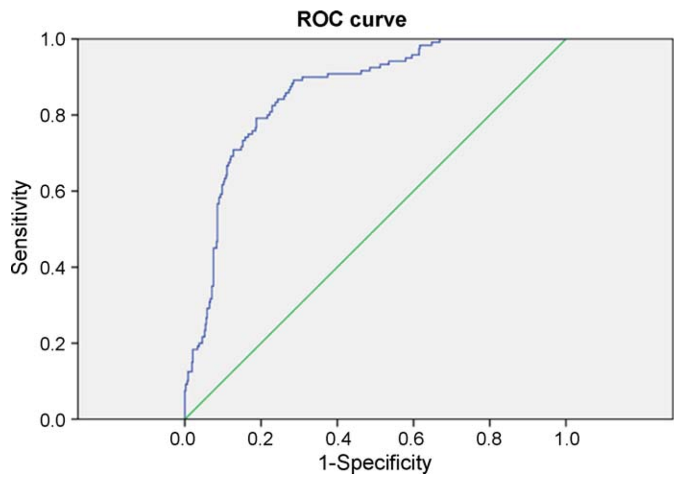

Fig. 10. The receiver operating characteristic (ROC) curve plotting the fraction of true positives (sensitivity) versus the fraction of false positives (1-specificity).

some individuals the scores obtained for fake fingers are higher than for real fingers. It is the case for the index of subjects #8 and 10, with fake fingerprints elaborated from thermoplastic and silicon casts respectively. The observation that the scores produced for direct casts are higher than those produced for indirect casts can also be generally observed in these four figures. It has also to be

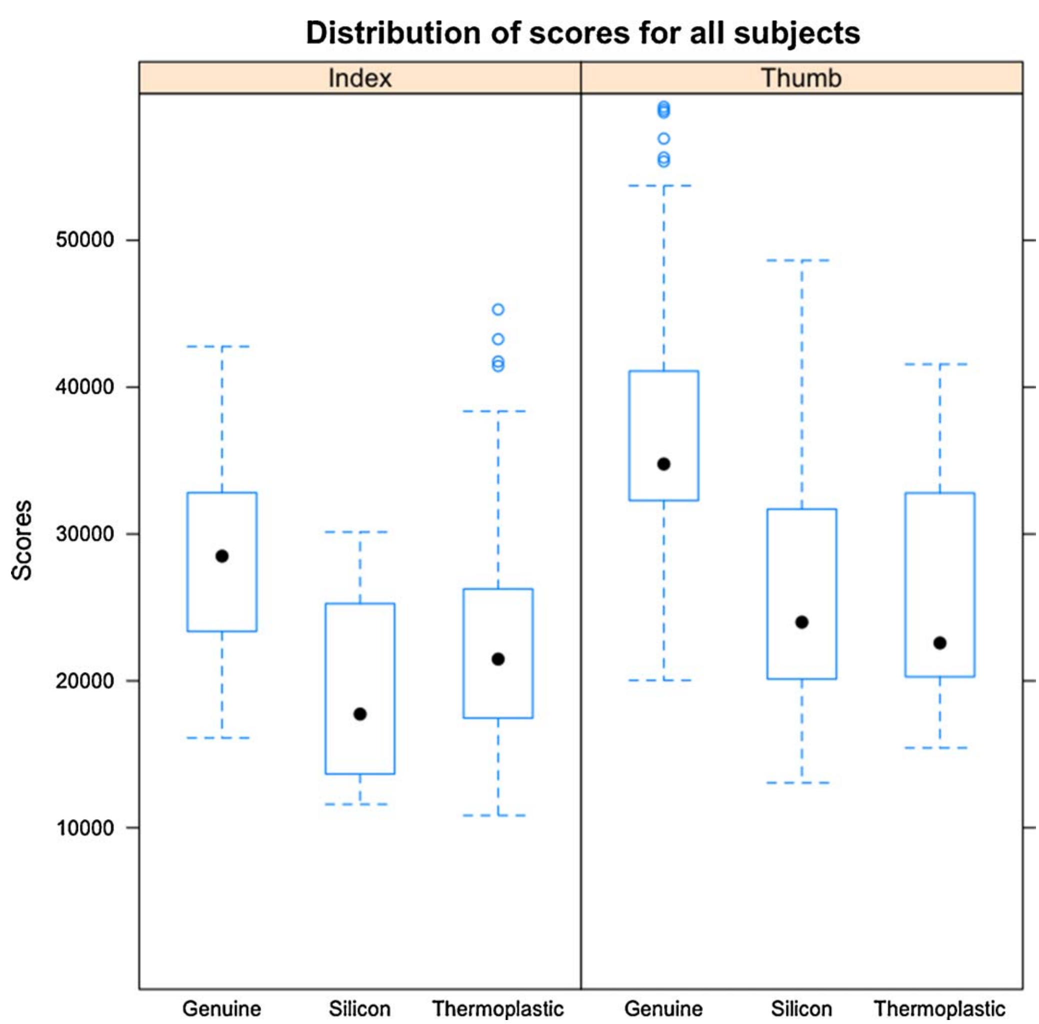

Fig. 11. Distribution of scores for all subjects, for genuine index and thumb (columns 1 and 4), for fake index and thumb from silicon casts (columns 2 and 5) and for fake index and thumb from thermoplastic casts (columns 3 and 6).

noted that, among all the fake fingerprints from indirect casts, those elaborated with glue produced scores generally higher than those in latex (Figs. 7 and 8).

When proceeding to an analysis of the variance (ANOVA), the test demonstrated that the differences observed between the samples (real and fake fingerprints) are significant (Fig. 9). The *F* value tests the null hypothesis that there is no difference between means of the different groups tested. To be significant, the test must have a significance value inferior or equal to 5%. As shown in Fig. 9, this value is 0 for this experiment. Although scores could be used as a decision metric between genuine and fake fingers, the ROC curve illustrated in Fig. 10 shows how difficult it is to classify samples on the basis of this single information alone. For example, in order to obtain an optimum correct acceptance rate (close to 100%), the system has to deal with a false acceptance rate above 60%.

Fig. 11 illustrates the distribution of scores computed for genuine and fake fingerprints elaborated from direct casts. The distribution of scores computed for genuine fingerprints was higher than the one computed for fake fingerprints and the distribution of scores computed for fake fingerprints elaborated from thermoplastic casts was on average higher than the one computed for fake fingerprints elaborated from silicon casts (Figs. 11 and 12).

Regarding 'non-matching' scores, it appeared that this information did not allow to differentiate genuine from fake fingerprints. Indeed, for all kind of samples, the 'non-matching' scores varied usually between 1000 and 4000 (arbitrary unit) even if they have also reached a threshold of ~6500 for some subjects (subjects #1, 3, 8–11) and that scores exceptionally high have been observed for the thumbs of the subjects #1 and 9 (7125 for subject #1 and 7208 and 8014 for subject #9).

4. Discussion

The different steps involved in the production of fake fingers elaborated from indirect casts can reduce the quality of the final information. First, the quality of the latent mark is decisive. If the mark is too partial, the final information is reduced and the score decreases. In addition, if the mark is too loaded with secretions for example, section of the friction ridge skin impression may not be legible. During the manual processing of the images, these areas lacking legibility will be extrapolated by the production forger and erroneous characteristics points can be generated on the pattern of the fake fingerprint. Moreover, the manual processing applied to the ridges edges can introduced modifications in the position and orientation of the characteristic points, that can greatly influenced the automatic encoding (Fig. 1). Second, once the image is processed, a tri-dimensional matrix will be produced from this image by the laser impression on acetate foil. Due to the production mode, the depth of this matrix is very limited and the ridges and furrows thickness can greatly influence the quality of the fake fingerprints. For example, if the ridges are too thin, details will be very difficult to observe in the capture due to the small area of contact. Moreover, if the pressure applied on the fake fingerprint is too strong, furrows can be put in contact with the capture due to the weak thickness and then produce a loss of information in the area concerned. That laser impression method was chosen because of the ease of access to such devices compared to other methods of production. That could explain why genuine fingerprints, when submitted for a transaction on this AFIS system, produced scores higher than fake fingerprints. This tendency is corroborated when considering each subject separately.

The production of fake fingers elaborated from direct casts allows obtaining information in three dimensions. For this

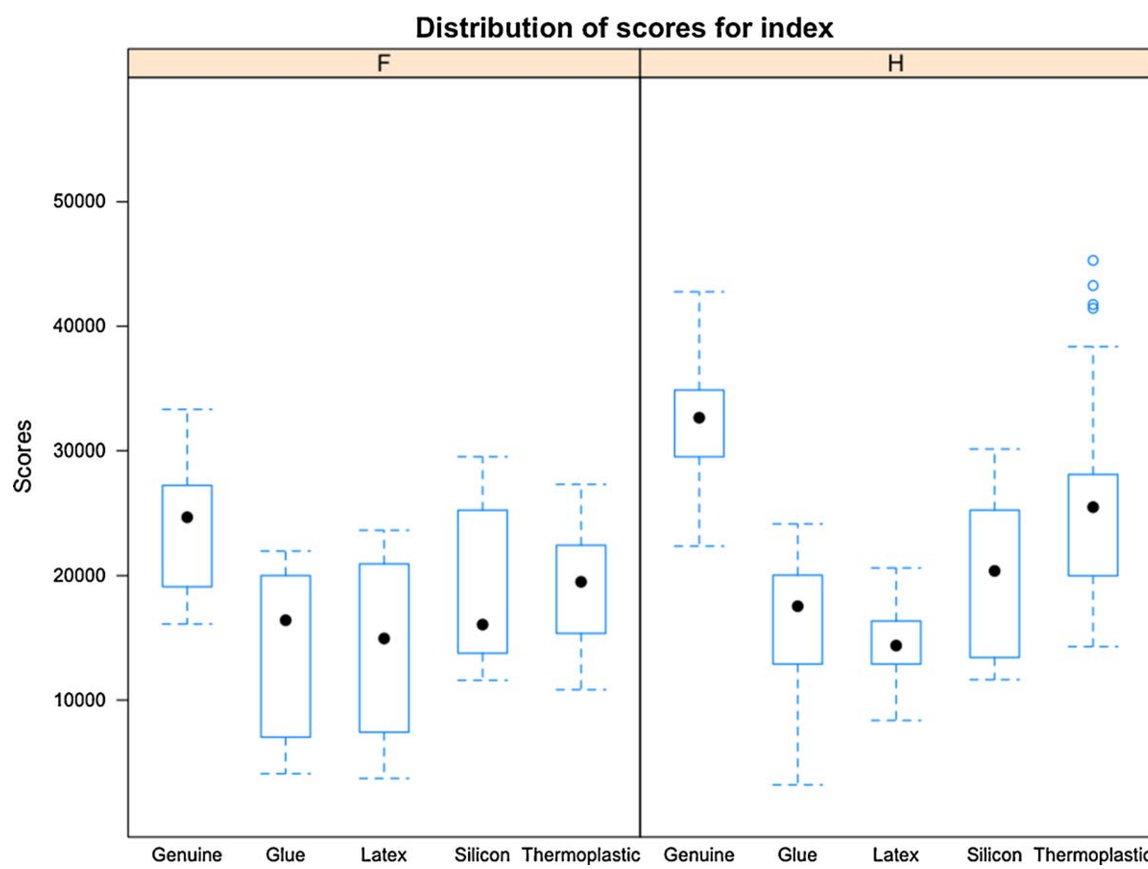

Fig. 12. Distribution of scores for genuine index, for fake index indirect casts (glue and latex) and for fake index from direct casts (silicon and thermoplastic) for female (columns 1–5) and male (columns 6–10) subjects respectively.

reason, scores produced by this type of fake fingerprints are higher than those produced by fake fingerprints elaborated from indirect casts. Moreover, the number of steps involved in their elaboration is lower; it reduces thus the risks of loss or modification of the information relative to the print. However, fake fingerprints present scores that are still lower than those produced by real fingerprints. The moulding step and the removal of the finger from the moulding material can indeed introduce modifications on small portions of the pattern, like constraints produced by involuntary movements of the finger or a too premature removal, or even loss of information, such as wrenching on the side of the mould during the removal step. This modification or loss of information can then reduce the scores associated to the print.

The materials used for mould fabrication influence the quality of the reproduction too. The use of silicon increases the apparition of small bubbles and inter-ridges across furrows of the mould. The production of thermoplastic mould requires a cooling step. During this step, some constraints can appear on the mould, such as grooves. All these details are then reproduced on the ridges of the fake fingers and can modify the final information and therefore reduce the scores associated to the print.

The subject and the impostor can have an influence on the score. Men present higher scores than women. The positioning of the finger during the live capture, the way of the mark was deposited and the moulding produce can also influence the score. For some subjects, like the subjects #5–8, the area of the fingerprint can considerably vary depending on the situation. In this case, the images captured from fake fingers can represent an area of the print very different from the one enrolled in the system. The shared area between the reference and transaction prints being reduced, the score is automatically lowered. Even if this phenomenon can also be observed with comparisons between real fingerprint impressions, it is more pronounced when considering comparisons between fake and real fingerprints. During the production of the fake fingerprints, the wrinkles (if present) on the print are considerably reinforced when considering fake fingerprints elaborated from direct casts. This phenomenon can influence the score as well. When considering fake fingerprints elaborated from indirect casts, this phenomenon does not occur because of the manual processing of the image during which eventual wrinkles are removed. An additional factor is the fact that all fake fingers were used by a woman. Their fingers are smaller than the fingers of the male subjects used for the fake fingerprint production. If the area of contact with the captor is smaller than the area of the genuine finger, then the score computed for the fake fingerprint is inferior to the score computed for the real finger. This observation can explain the fact that the scores decline in a more pronounced way for men than women among samples.

Despite the fact that a transaction involving a fake finger leads to a reduction of the scores produced by the print, the ROC curve demonstrates that it is not possible to systematically differentiate all types of samples on the basis of the scores only (Fig. 10). Regarding 'non-matching' scores, it also appeared that this information did not allow to differentiate genuine from fake fingerprints (Fig. 3).

This experiment showed that the scores computed for each transaction of a same subject and finger are quite stable, in particular considering fake fingerprints. Fake fingerprints are reproductions of original prints. There is no physiological activity and the texture is not identical to skin texture, it is thus normal that transactions show little variations. Regarding the stability of difference observed among samples, it has to be noted that the pattern, the quality of the print and the subject to personify have an influence on the quality of the fake fingerprints.

5. Conclusion

This experiment led to three major observations: First, real fingerprints produced scores higher than fake fingerprints and this tendency is more easily observed when considering each subject separately. Secondly, scores are not sufficient to differentiate these samples especially considering all subjects taken together (even when considering 'non-matching' scores). That explains why livescan without liveness detection can be spoofed. Thirdly, production methods and subjects can greatly influence the scores computed for fake fingerprints. Moreover, training and the fact that several attempts can be performed are two factors that increase the scores.

The results also showed that fake fingerprints elaborated from indirect casts led to lower scores than fake fingerprints elaborated from direct casts. This can be explained by the amount of steps involved in the production of fake fingerprints from indirect casts, which can reduce or affect the quality of the final information. The subject can also influence the score, since the width of the furrows and the presence of wrinkles on the original print can influence the quality of the fake fingers.

Acknowledgments

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