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Case study of the acquisition of contactless fingerprints in a real police setting

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Abstract: Biometric recognition systems integrated into mobile devices have gained acceptance during recent years. Developments in fingerprint acquisition technology have resulted in touchless mobile devices that acquire high quality fingerprints. While authorities are particular interested on mobile solutions, they have databases containing fingerprint data mainly acquired using contact-based devices. Therefore, they are interested in the accuracy of cross-sensor fingerprint recognition. We present a case study of a comprehensive matching comparison on real fingerprint data acquired by national police officers. The objective of this study is: (i) to analyse the feasibility when comparing data acquired using a typical contact-based fingerprint device against data acquired using a new contactless device, and (ii) the feedback of the end user (i.e. national police officers) regarding the acquisition process. Obtained results are promising and the current prototype shows its feasibility for operational police use. The end users expressed their satisfaction with the developed prototype and they suggested extra functionalities towards a practical solution for police officers.

Keywords: fingerprint, contactless devices, mobile devices, police use case.

1 Introduction

1.1 Previous work

Biometric technologies are being used for many security applications such as border control, forensics, criminal identification or e-business. One of the most reliable approaches for human identification is fingerprint recognition [Ma09, Al09]. While in the past a lot of fingerprint-based systems used integrated contact-based sensors, contactless devices have gained attention in recent years becoming feasible as well. Traditional contact-based fingerprint systems have some limitations such as latent impression on the surface of the sensor and internal reflections [RJ04, WW04]. To address them, contactless fingerprint identification systems have been introduced. Some advantages of contactless acquisition methods are: the more unconstrained capturing environment, almost no skin condition side effects, better hygienic settings and no presence of latent fingerprints on the sensor. During the contactless acquisition process, intra-class differences and deformations such as perspective distortion are introduced by the high degree of freedom of the fingers, the involuntary finger motion and the inherently variations during the acquisition. On the other

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hand, elastic deformation of the fingers are often present during the contact-based acquisition process. Such differences pose challenges such as extract the features accurately and match them in the corresponding images during the comparison between fingerprints acquired using these sensors. The comparison between contactless fingerprint images against contact-based fingerprint images is named sensor interoperability and it is an active area of research [RJ04, Al06, Ch06, MEK09, La16]. It is well known that the performance of fingerprint comparison decreases when matching fingerprints acquired with different types of devices [RN06, RN08, Zh14, Mi19]. The development of advanced capabilities to accurately match both types of data contactless and contact-based is of great interest because in the past many official databases were generated using contact-based devices. Lin and Kumar noted the importance of matching fingerprints present in legacy databases against fingerprints acquired using contactless devices [LK18]. Ericson and Shine [ES15] investigated the matching performance and the interoperability of contact-based fingerprint sensors compared with contactless ones. The authors used data that was acquired in a controlled environment at different time-separated sessions over 4 months achieving true matching rates greater than 90%. Labati et al. [La16] employed a four-step finger segmentation procedure using touchless fingerprint data. Under laboratory conditions they achieved equal error rates (EER) as low as 0.22% when they evaluate the interoperability of both technologies touch-based and touchless. Lin and Kumar [LK19] presented a CNN-based framework for matching fingerprints. The authors evaluated their approach on two databases containing contact-based fingerprints and the respective contactless fingerprints. Libert et al. [Li20] investigated the interoperability of both modalities contactless and contact-based using an in-house dataset of 200 people. Their results showed that multiple finger matching significantly improves the performance of contactless devices.

1.2 Motivation

In this work we used data acquired by police officers in different sessions. This data is stored in an official database and it will be further used by local authorities. It is well known, access to such data is not easy due to legal reasons; therefore it is not easy to carry out comparison using this kind of data. Data acquisition was carried out by the officers at a national police refugee registration center under real-world conditions (Fig. 1). Up to our knowledge, the used dataset is the largest used for a comparison of real data. National authorities are interested in contactless technologies due to different reasons: the acquisition process is faster than using contact-based technologies, it is not necessary to clean the device after acquiring data and many times the officers need to identify people while they are on duty. The focus of this paper is not on proposing a new method that outperforms existing methods. This paper deals with the issue of how reliably two fingerprints can be compared in a real police scenario. To do that, we analyse the recognition performance using real data recorded by national police officers. We present a comparison study of matching real data, which will be later officially used, acquired with a new contactless prototype and a contact-based fingerprint device. Moreover, the usability of the contactless device is investigated by summarizing their feedback. The contact-less device is an own developed sensor using a liquid lens. Up to our knowledge, this is the first study presenting fingerprint matching results of a contactless device using a liquid lens. The rest of the

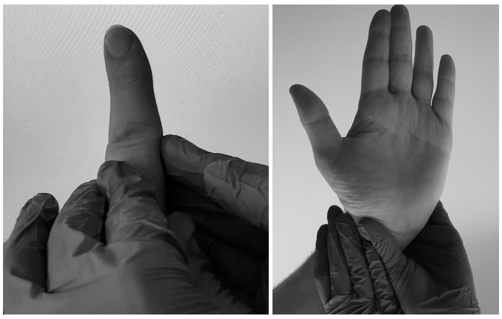

Fig. 1: Capturing process of fingerprints by the police (re-enacted). Left image: contact-based case. Right image: contactless case.

paper is organized as follows: Section 2 gives a description of the developed prototype, the acquisition process and an overview of the captured data. A discussion of the results and user's feedback are presented in Section 3. Section 4 outlines our concluding remarks and summarises planned improvements.

2 Capture Process

2.1 Capture device

The own developed scanner is a contactless fingerprint sensor that uses a liquid lens integrated with a Time-of-Flight (TOF) sensor. The liquid lens achieves a new focal plane within 5 ms and the TOF sensor measures the distance of the fingers to the sensor. The device acquires grey-scale images of 3052×2015 pixels at a frame rate of 10 fps. The developed scanner captures a stack of fingerphotos of the subject to ensure high quality fingerprints. The processing pipeline is very similar to the work of [Pr22, Wi19] and consists of multiple steps to extract the fingerprints from the original fingerphoto. In a first step, the fingertips are segmented. Instead of using a color-based segmentation as in [Wi19] we apply a trained CNN for segmentation. Afterwards the fingers are cropped as well as rotated to an upright position and scaled to 500 PPI, so that we are compliant to FBI-standards [Am11]. Especially a precise scaling is of great importance for the matching performance. During the recording of contactless fingerprints, many blurred images of the fingertips are also captured. Therefore, it is very important to check whether the captured finger images have sufficient sharpness [CG02]. Fingerphotos with sufficient sharpness are enhanced to increase the contrast between ridges and valleys, and to mimic the appearance of contact-based fingerprints. For this, the contrast is increased using histogram equalization [Re04] and the image is mirrored to correspond to touch-based fingerprints. In Fig. 2 the results of the different enhancement methods are displayed on a sample fingerphoto. The enhancement method has a strong influence on actual appearance of the fingerprint. Enhancement 1 is based on Wild et al. [Wi19] and they applied among others Gaussian blurring, a brightness normalisation and morphological operations. Enhancement

2 is based on [Ka21], who applied a grey-value inversion, followed by horizontal flipping and a contrast-limited adaptive histogram equalization (CLAHE). Enhancement 3 is based on the work of Priesnitz et al. [Pr22] and they apply different kernel sizes on the cascaded filters of CLAHE.

Fig. 2: Sample fingerprints generated by different enhancements.

2.2 Acquired dataset

For acquiring the data two devices were used, a contact-based device and a contact-less one. In case of the contact-based acquisition, the Law Enforcement Agency (LEA) used the optical fingerprint scanner IDEMIA TP 5300 scanner with 1000 DPI[3]. To capture contact-less fingerprints, our own device was used by the LEA, which captures the images with a single image sensor and without any 3D data. The number of human subjects who provided contactless fingerprints is 613. Of this group, 481 persons also submitted contact-based fingerprints. The contact-based fingerprints were rolled fingerprints with 10 prints (corresponding to 10 fingers) per person. Police officers often had to help with the capturing by guiding the person's fingers or hand (see Fig. 1), because many persons were not able to follow the instructions - intentionally or unintentionally. For hygienic reasons, the police officers wore gloves during the recording process All 10 fingers were captured for each subject. No chemical substance was used to clean the participant's fingers prior to data acquisition. Many images (between 50 and 80) per finger were acquired and best 6 images were selected based on the sharpness value (at least 0.2) [Ka21]. Each session took place indoors without any changes in the environmental conditions. Acquisition took place in different sessions over 6 months (between June 2021 and December 2021). In case of the contact-based device the average acquisition time per subject is ≈ 45 seconds to acquire ≈ 10 flat fingerprints and almost 120 seconds if rolled fingerprints are acquired. In case of the contactless device the acquisition time is ≈ 10 seconds for either 4 fingers left hand, 4 fingers right hand or both thumbs. Due to the recording in a refugee registration center, where refugees are registered, a very diverse dataset was obtained. Gender distribution for each ethnic group is given in Table 1, while Table 2 groups the age distribution of the participants.

[3] https://www.idemia.com/palmprint-scanner

Ethnic group	M.	F.	N.I.
Africa	75	18	1
Asia	273	153	0
Europe	59	13	0
Central America	2	1	0
South America	4	3	0
Unknown	7	4	0
Total	420	192	1

Tab. 1: Gender distribution of the participants. M., F. and N.I. mean male, female and not indicated, respectively.

Age group	M.	F.	N.I.
< 20	49	24	1
[20, 30)	167	64	0
[30, 40)	119	59	0
[40, 50)	52	24	0
[50, 60)	25	15	0
> 60	8	6	0
Total	420	192	1

Tab. 2: Age distribution of the participants. M., F. and N.I. mean male, female and not indicated, respectively.

3 Results

3.1 Comparison performance

The biometric performance is evaluated employing the IDKit SDK 8.0.1.50 and the equal error rates (EER) as well as the True Acceptance Rates (TAR) are calculated. To evaluate the matching performance, we have conducted three groups of testing: (i) contactless (CL) versus CL fingerprints, (ii) CL versus contact-based (CB), and (iii) warped CL versus CB. The matching results are summarized in Tab. 3. The total number of fingerprints used for the evaluation are 28,182 contactless and 5,657 contact-based fingerprints. We also plot the false non match rate (i.e. miss-categorization of two recordings from the same person as being from different people) versus the false match rate (i.e. mismatch of two recordings from two different people as coming from the same person) of both comparison cases, CL against CL and CL against CB. Obtained curves are depicted in Fig. 3. These curves show evidence of real performance difference between both types of match. This difference is remarkable in the FMR range between 10^{-6} element and 10^{-2}. We have also performed three image enhancement methods (see Section 2.1) to check the impact on the matching process. The best EERs are obtained based on the method of Priesnitz et al. [Pr22] and the lowest values are obtained when using thumb fingers.

Matches	LL	LB	L*B	LB [Wi19]	LB [Pr22]
EER (single)	0.37%	1.40%	1.10%	2.40%	1.10%
TAR †	99.49	94.87	96.65	-	-
EER (thumbs)	0.09%	0.23%	0.46%	0.85%	0.30%
TAR †	99.91	99.47	99.02	-	-
EER (little)	1.10%	2.90%	2.40%	4.20%	2.10%
TAR †	98.55	87.79	90.84	-	-

Tab. 3: Left side: Equal error rate (EER) and True Acceptance Rate (TAR) of single fingers, thumbs and little fingers. LL, LB and L*B mean contactless against contactless, contactless against contact-based and warped contactless against contact-based, respectively. The enhancement is based on [Ka21]. TAR † is TAR@FAR=0.01%). Right side: EER of fingerprints generated by different enhancements.

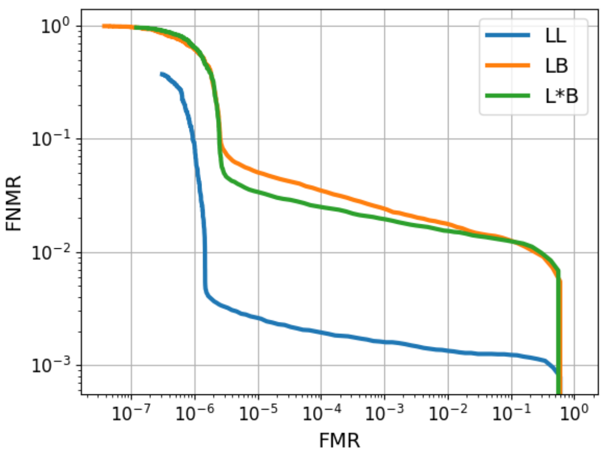

Fig. 3: False non match rate (FNMR) vs. false match rate (FMR) curves. LL = contactless against contactless, LB = contactless against contact-based, and L*B = warped contactless against contact-based.

3.2 User's feedback

In case of contact-based acquisition, police officers instructed participants how to place their fingers and in many cases they had to help the participants to place their fingers correctly. In case of the contactless device, sometimes staff members had to provide instructions how to correct the shots and in many cases participants figured out by themselves how to improve the acquisition process. During the recording sessions and after collecting all data police officers were asked about the performance of the prototype and its usability. Feedback concerning handling the device, its response and possibilities to improve it, was collected. In general, the responses of the police officers were very positive and comments such as the following were received:

- The solution is very simple, the scanner turns on automatically when the hand is held over it.
- By presenting once the scanner to the user, he/she can easily carry out the recording process by himself/herself without any further indications. Furthermore, the automatic hand recognition process (left hand or right hand) is extremely practical and works very well.
- Few cases did not work. Such cases can easily be overwritten manually.
- The outside light has no influence on the detection speed.
- Capturing prints from people with very wet or very dry fingers is better than flat bed scanner devices.
- An extension towards PIV certification or an extension towards rolled fingerprints will be very useful.

As we can see, collected feedback reveals that the end user was very satisfied with the prototype. Besides, additional functionalities were suggested.

4 Conclusion

In this paper, we presented a comparison between two devices on real fingerprint data acquired by national police officers. The objective of this study was to analyse the feasibility when comparing data acquired using a contactless fingerprint device against data acquired a contact-based one and collect user's feedback regarding the acquisition process. The fully functional contactless prototype is a mobile FP capturing tool for police use which aims to optimize the process carried out by national police officers. This prototype uses a liquid lens and up to our knowledge this is the first study presenting fingerprint matching results of a contactless device using a liquid lens against data of an official database. Obtained results are promising and the current prototype shows its feasibility for operational police use. Furthermore, it turns out that from the user's point of view, the contactless device has been very practical and useful. The insights and valuable user's feedback gained throughout this study serve as guidance for future work towards a practical solution for police officers.

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References

[Al06] Alonso-Fernandez, F.; Veldhuis, R. N. J.; Bazen, A. M.; Fierrez-Aguilar, J.; Ortega-Garcia, J.: Sensor interoperability and fusion in fingerprint verification: A case study using minutiae-and ridge-based matchers. In: Proceedings of 9th International Conference on Control, Automation, Robotics and Vision. 2006.

[Al09] Alonso-Fernandez, D.; Bigun, J.; Fierrez, J.; Fronthaler, H.; Kollreider, K.; Ortega-Garcia, J.: Guide to Biometric Reference Systems and Performance Evaluation. Springer-Verlag, London, UK, 2009.

[Am11] American National Standard for Information Systems: NIST Special Publication 500-290: Data Format for the Interchange of Fingerprint, Facial & Other Biometric Information. Technical report, US Department of Commerce, Technology Administration, National Institute of Standards, and Technology, 2011.

[CG02] Caviedes, Jorge; Gurbuz, Sabri: No-reference sharpness metric based on local edge kurtosis. In: ICIP. volume 3. IEEE, pp. III–III, 2002.

[Ch06] Chen, Yi; Parziale, Geppy; Diaz-Santana, Eva; Jain, Anil K: 3D touchless fingerprints: Compatibility with legacy rolled images. In: Proceedings of 2006 Biometrics Symposium: Special Session on Research at the Biometric Consortium Conference. 2006.

[ES15] Ericson, Lars; Shine, Stephen: Evaluation of contactless versus contact fingerprint data phase 2 (version 1.1). Technical report, DOJ Office Justice Programs, I. ManTech Adv. Syst. Int, Tech. Rep, May 2015.

[Ka21] Kauba, Christof; Söllinger, Dominik; Kirchgasser, Simon; Weissenfeld, Axel; Fernández Domínguez, Gustavo; Strobl, Bernhard; Uhl, Andreas: Towards using police officers' business smartphones for contactless fingerprint acquisition and enabling fingerprint comparison against contact-based datasets. Sensors, 21(7):2248, 2021.

[La16] Labati, Ruggero Donida; Genovese, Angelo; Piuri, Vincenzo; Scotti, Fabio: Toward unconstrained fingerprint recognition: A fully touchless 3-D system based on two views on the move. IEEE Trans. Systems, Man, and Cybernetics: Systems, 46(2):202–219, 2016.

[Li20] Libert, John; Grantham, John; Bandini, Bruce; Ko, Kenneth; Orandi, Shahram; Watson, Craig: NISTIR 8307 Interoperability Assessment 2019: Contactless-to-Contact Fingerprint Capture. Technical report, NIST National Institute of Standards and Technology, 2020.

[LK18] Lin, C.; Kumar, A.: Matching Contactless and Contact-based Conventional Fingerprint Images for Biometrics Identification. In: Proceedings of XXX. pp. 2008–2021, 2018.

[LK19] Lin, Chenhao; Kumar, Ajay: A CNN-based Framework for Comparison of Contactless to Contact-based Fingerprints. IEEE Transactions on Information Forensics and Security, 14(3):662–676, 2019.

[Ma09] Maltoni, Davide; Maio, Dario; Jain, Anil K.; Prabhakar, Salil: Handbook of fingerprint recognition. Springer-Verlag, London, UK, 2009.

[MEK09] Modi, Shimon K.; Elliott, Stephen J.; Kim, Hale: Statistical analysis of fingerprint sensor interoperability performance. In: Proceedings of IEEE 3rd International Conference on Biometrics: Theory, Applications, and Systems. 2009.

[Mi19] Minaee, Shervin; Abdolrashidi, Amirali; Su, Hang; Bennamoun, Mohammed; Zhang, David: Biometric Recognition Using Deep Learning: A Survey. CoRR, abs/1912.00271, 2019.

[Pr22] Priesnitz, Jannis; Huesmann, Rolf; Rathgeb, Christian; Buchmann, Nicolas; Busch, Christoph: Mobile contactless fingerprint recognition: implementation, performance and usability aspects. Sensors, 22(3):792, 2022.

[Re04] Reza, Ali M: Realization of the contrast limited adaptive histogram equalization (CLAHE) for real-time image enhancement. Journal of VLSI signal processing systems for signal, image and video technology, 38(1):35–44, 2004.

[RJ04] Ross, Arun; Jain, Anil: Biometric sensor interoperability: A case study in fingerprints. Biometric Authentication (Lecture Notes in Computer Science), 3087:134–145, 2004.

[RN06] Ross, A.; Nadgir, R.: A calibration model for fingerprint sensor interoperability. In: Proceedings of SPIE Conference on Biometric Technology for Human Identification III. volume 62020B, pp. 1–12, 2006.

[RN08] Ross, A.; Nadgir, R.: A thin-plate spline calibration model for fingerprint sensor interoperability. IEEE Transactions on Knowledge Data Engineering, 20(8):1097–1110, 2008.

[Wi19] Wild, Peter; Daubner, Franz; Penz, Harald; Domínguez, Gustavo Fernández: Comparative test of smartphone finger photo vs. touch-based cross-sensor fingerprint recognition. In: 2019 7th International Workshop on Biometrics and Forensics. IEEE, pp. 1–6, 2019.

[WW04] Wood, S. S.; Wilson, C. L.: Studies of plain-to-rolled fingerprint matching using the NIST algorithmic test bed (ATB). Technical report, US Department of Commerce, Technology Administration, National Institute of Standards, and Technology, 2004.

[Zh14] Zhou, Wei; Hu, Jiankun; Wang, Song; Petersen, Ian; Bennamoun, Mohammed: Performance evaluation of large 3d fingerprint databases. Electronics Letters, 50(15):1060–1061, 2014.