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High- Resolution Latent Fingerprint Time Series for Short- and Long-Term Print Age Estimation

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ABSTRACT: Estimating the time a latent fingerprint has remained at a crime scene is in an important challenge to forensic experts, which could not be solved for 80 years. Potential suspects often admit to have been at the scene of a crime, but claim to have done so at a time before or after the crime has happened, significantly reducing the evidentiary value of latent prints. Furthermore, the age of a fingerprint might provide important information about the sequence of events and even the sequence of over- lapped prints. Research conducted on this issue in the last decades has failed to provide reliable results, partially due to the invasiveness of used fingerprint lifting techniques (e.g. alteration of the trace during development) as well as the lack of using digital processing methods. However, the improvement of non-invasive capturing devices in the last decades has enabled significant potential for transferring fingerprint age estimation to the digital domain.Even though the work of this thesis cannot provide a final and highly accurate age estimation scheme, it demonstrates the potential of applying non-invasive capturing devices in combination with a digital processing pipeline towards this challenge. Furthermore, additional benefits from the here investigated age estimation approach are identified, such as the potential to enhance data privacy in daily police work by a preselection of prints based on their age (computed from very small areas, insufficient for identification). Also, fingerprint age estimation might be used in preventive application scenarios, which has so far been prohibited by data protection laws.

KEYWORDS: Latent fingerprints, public research collection, age estimation, digitized forensics, computer forensics, fingerprint processing pipeline, baseline performance.

I. INTRODUCTION

Age estimation of latent fingerprints is an important issue to forensic investigations, which has not been adequately addressed for 80 years. It is a very important issue in crime scene forensics. In contrast to biometrics, where age is often referred to as the biological age of an enrolled human, the age of crime scene traces refers to the time which has passed between placement of a trace and its capture by the authorities. It is vital for forensic investigators to determine such age, linking a trace to the time of a crime. Especially for latent fingerprints, which are widely used as evidence in criminal investigations, suspects often claim to have been at a crime scene prior to or after the crime [1]. Only if a latent print is able to link an individual to the time of a crime in addition to linking it to the place of the crime, the evidentiary value of the print can be considered strong in court. This challenge of latent print age estimation has been known to forensic investigators for more than 80 years but could not be adequately addressed so far. Recently, non-invasive, high-resolution capturing devices have been introduced to the domain of capturing crime scene traces. In contrast to the classical process of physical or chemical print enhancement and lifting, these techniques do not alter a latent print, therefore allowing for the first time to consecutively capture a single print in regular time intervals and to observe the morphological changes as well as changes in chemical composition and other properties occurring over time. These changes include (among others) the drying of the print (evaporation of water and short-chained fatty acid) as well as a loss in height and structure during degradation (summaries of studies on these degradation processes can be found in [2] and [3]).

Non-invasive, high-resolution capturing devices include Fourier-transform Infrared Spectroscopes capturing chemical print properties, Electric Potential Sensors capturing electrostatic properties as well as optical devices capturing

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morphological properties such as Coherence Tomography, Chromatic White Light (CWL) sensors and Confocal Laser Scanning Microscopes (CLSM) [2]. However, such non-invasiveness and increased resolution evoke high purchase costs (often higher than €100,000 per device), requiring an intense exchange of datasets between scientific experts to ensure reproducibility and scientific progress. Furthermore, data privacy is an important factor to be considered because the devices can provide very high-resolution print images, which are considered person-related data in most European countries and therefore are subject to specific data protection regulations [4]
.This paper organized VII sections. The subsequent section explain literature survey. Section III focuses the important aspect of age estimation. Section IV explain the system architecture and methodology. Section V consider the algorithm used for age estimation. Section VI explains the important results and discussion and a conclusion is presented in the last section.

II. LITERATURE SURVEY

According to [1] Ronny Merkel proposed Estimating the time a latent fingerprint has remained at a crime scene is in an important challenge to forensic experts, which could not be solved for 80 years. Potential suspects often admit to have been at the scene of a crime, but claim to have done so at a time before or after the crime has happened, significantly reducing the evidentiary value of latent prints. Furthermore, the age of a fingerprint might provide important information about the sequence of events and even the sequence of overlapped prints. Research conducted on this issue in the last decades has failed to provide reliable results, partially due to the invasiveness of used fingerprint lifting techniques (e.g. alteration of the trace duringdevelopment) as well as the lack of using digital processing methods. However, theimprovementof non-invasive capturing devices in the last decades has enabled significant potential fortransferring fingerprint age estimation to the digital domain.

According to [2] Haiying Guan, Paul Lee et.alproposed system Latent fingerprints obtained from crime scenes are rarely immediately suitable for identification purposes. Instead, most latent fingerprint images must be pre-processed to enhance the fingerprint information held within the digital image, while suppressing interference arising from noise and otherwise unwanted image features. In the following we present results of our ongoing research to assess this critical step in the forensicworkflow. Previously we discussed the creation of a new database of latent fingerprint images to support such research. The new contributions of this paper are twofold. First, we implement a study in which a group of trained Latent Print Examiners provide Extended Feature Set mark-ups of all images. We discuss the experimental design of this study, and its execution. Next, we propose metrics for measuring the increase of fingerprint information provided by latent fingerprint image pre-processing, and we present preliminary analysis of these metrics when applied to the images in our database1. We consider formally defined quality scales (Good, Bad, Ugly), and minutiae identifications of latent fingerprint images before and after pre-processing. All analyses show that latent fingerprint image pre-processing results in a statistically significant increase in fingerprint information and quality.

According to [3] CarstenGottschlich, Benjamin Tams et.al.proposed system Fingerprint recognition is widely used for verification and identification in many commercial, governmental and forensic applications. The orientation field (OF) plays an important role at various processing stages in fingerprint recognition systems. OFs are used for imageenhancement, fingerprint alignment, for fingerprint liveness detection, fingerprint alteration detection and fingerprint matching. In this paper,a novel approach is presented to globally model an OF combinedwith locally adaptive methods. We show that this model adapts perfectlyto the 'true OF' in the limit. This perfect OF is described bya small number of parameters with straightforward geometric interpretation.Applications are manifold: Quick expert marking of verypoor quality (for instance latent) OFs, high fidelity low parameter OFcompression and a direct road to ground truth OFs markings for largedatabases, say. In this contribution we describe an algorithm to perfectlyestimate OF parameters automatically or semi-automatically,depending on image quality, and we establish the main underlying claim of high fidelity low parameter OF compression.

According to[4] Josep De Alcaraz-Fossoul, CarmeBarrotet. al.proposed system elaboratesfor over a century, law enforcement agencies, forensic laboratories, and penal courts worldwide have usedfingerprint impressions as reliable and conclusive evidenceto identify perpetrators of criminal activity. Although fingerprintidentification has been

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repeatedly proven as one ofthe most robust and definite forensic techniques, a measureof the rate at which latent fingerprints degrade over time hasnot been established effectively. Ideally, criminal investigatorsshould be able not only to place any given individual at

a crime scene but also be able to date the moment any latentfingerprints were deposited at the location. The presenter port aims to determine particular visual patterns of degradationof latent fingerprints exposed to certain monitored laboratory conditions simulating those in the field. Factorsconsidered include temperature, relative humidity, air currents,composition of fingerprintdepositions, various exposures to daylight (direct, penumbra,and darkness), and type of physical substrate (glass andplastic) over a period of 6 months. The study employs atitanium dioxide-based powder as developer. Our results indicatethat, contrary to common belief, certain latent fingerprintsexposed to direct sunlight indoors degrade similarly tothose in the dark where environmental conditions are moreconstant. While all sebaceous latent fingerprints on glass arestill useful for identification after 6 months, diverse results areobtained with impressions on plastic; these demonstrate a much higher and faster degree of decay, making identification difficult or impossible, especially for echini depositions.

According to [5] Girod A., Ramotowski R. et. al.proposed system elaborate the question of the age of fingermarks is often raised in investigations and trials when suspects admit that they have left their fingemarks at a crime scene but allege that the contact occurred at a different time than the crime and for legal reasons. In the first part of this review article, examples from American appellate court cases will be used to demonstrate that there is a lack of consensus among American courts regarding the admissibility and weight of testimony from expertwitnesses who provide opinions about the age of fingermarks. Of course, these issues are not only encountered in America but have also been reported elsewhere, for example in Europe. The disparity in the way finger mark dating cases were managed in these examples is probably due to the fact that no methodology has been validated and accepted by the forensic science community so far. The second part of this review article summarizes the studies reported on finger mark dating in the literature and highlights the fact that most proposed methodologies still suffer from limitations preventing their use in practice. Nevertheless, several approaches based on the evolution of aging parameters detected in fingermark residue over time appear to show promise for thefingermark dating field. Based on these approaches, the definition of a formal methodologicalframework for fingermark dating cases is proposed in order to produce relevant temporal information. This framework identifies which type of information could and should beobtained about fingermark aging and what developments are still required to scientifically address dating issues.

Author and Year	**Title**	**Approach**	**Advantages**	**Disadvantages**
Girod, A., et al 2012 [5]	Finger mark age determinations: legal considerations, review of the literature and practical propositions	system describes the composition of finger mark residue as being a complex system with numerous compounds coming from different sources and evolving over time from the initial composition (corresponding to the composition right after deposition) to the aged composition(corresponding to the evolution of the initial composition over time)	1 : Improve the Image pixel strength as well as quality. 2 : Improve the PSNR for all type of images.	**1 :** Sometime can be increased the time complexity for extraction.
Kiltz, Stefan, et al [7] 2012	Challenges in contact-less latent fingerprint processing in crime scenes: Review of sensors and image processing	System define the elaborate the contact-less acquisition of untreated latent fingerprint traces with various sensing and image processing techniques is an upcoming opportunity in crime scene forensics	**1 :** Define different techniques for insertion of fingerprint.	**1**: There is no implementation scenario as well as real time result for synthetic and real time data.

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	investigations			
Merkel, Ronny, Jana Dittmann, and Claus Vielhauer [8] 2012	Novel fingerprint aging features using binary pixel sub-tendencies: A comparison of contactless CLSM and CWL sensors	system Age determination of latent fingerprints from crime scenes is an open challenge to forensic experts since several decades. In recent publications it was shown that a feature called binary pixel in combination with a contactless and non-invasive Chromatic White Light (CWL) image sensor is able to distinguish between fingerprints younger as or older than five hours with an accuracy of about 70-80%.	**1 :** Best approach for insert fingerprint insert into pixel level without affecting the histogram values. 2: Easy to recovered from defined pixels in 2D array.	**1:** It can work for binary pixels only like 0 or 1.
Merkel, Ronny, et al. [9] 2012	General fusion approaches for the age determination of latent fingerprint traces: results for 2D and 3D binary pixel feature fusion	proposed system determining the age of latent fingerprint traces found at crime scenes is an unresolved research issue since decades. Solving this issue could provide criminal investigators with the specific time a fingerprint trace was left on a surface, and therefore would enable them to link potential suspects to the time a crime took place as well as to reconstruct the sequence of events or eliminate irrelevant fingerprints to ensure privacy constraints.	**1 :** method provide the easy recognition of crime fingerprints. 2:System can have ability to eliminate the irrelevant fingerprints during the detection.	**1 :** It can work for 2D and 3D pixel version only.
Merkel, Ronny, et al. [10] 2013	First investigation of latent fingerprints long-term aging using chromatic white light sensors	It proposed Non-invasive high-resolution Chromatic White Light (CWL) measurement devices offer great potential for solving the challenge of latent fingerprints age determination. In this paper, it place 40 prints from different subjects on hard disk platters and capture them from three different indoor locations every week over 1.5 years, acquiring high-resolution time series	**1 :** Approach has used luminance and chrominance factors and features. **2 :** It can extract the around 40 different features for identification which will provide best accuracy.	**1 :** Sometime generate the false negative ration when generate probability factors.

III. IMPARTANT ASPECT OF AGE ESTIMATION

Age estimation is divided into morphological,substance-specific and statistical approaches.Methods mainly aiming at the shape and size of the fingerprint (e.g. ridge lines, pores and particles) are referred to as morphological approaches and their features as morphological features. Approaches explicitly targeting certain chemical substances or substance groups (e.g. the qualitative and quantitative composition of a print) are referred to as substance-specific methods and their features as substance-specific features. Approaches calculating statistical, pixel-based measures of captured fingerprint images (e.g. mean, variance, contrast, roughness and coherence) are referred to as statistical methods and their features as statistical features. This distinction is made for a better categorization of different age estimation techniques. However, it is to note that this separation is not always trivial and that intersections may occur.

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Contact-Based Morphological Approaches

Most approaches are based on the visual inspection of developed fingerprints and the subjective opinion of an expert on how long a print has remained on a certain surface under specific conditions. Such approaches often focus on the quality of the ridges or minutiae and are therefore considered to be morphology based. A numerous amount of case-related experiments has been conducted in the field of forensic crime scene investigation, mainly focusing on the controlled aging of fingerprints under reconstructed crime scene conditions to prove or disprove a suspects version of being at the crime scene at a certain time.Early morphology based age estimation approaches include the usage of an Electrostatic Detection Apparatus (ESDA) in 1980 and the healing stage of wounds on a finger. Such approaches have a very narrow application area and are limited in their prospects. ESDA is destructive, possibly preventing identification after age estimation and can only visualize prints younger than 24 hours. Using the healing state of wounds can only be applied if wounds are indeed present. Both experiments do neither provide specific rules for age estimation, nor objective quality measures or error rates. Their practical application therefore remains doubtful.

Contact-Based Substance-Specific Approaches

Contact-based substance-specific investigations have provided many details about the different chemical substances present in latent fingerprints, which can be over 300. Although the different studies have successfully investigated the degradation process of certain substances, substance groups, or ratios between substances, they have also shown the great variability of such degradation, mainly influenced by the chemical composition of the prints as well as environmental influences. Therefore, no research beyond the presentation of degradation tendencies is known from the field, such as specific age estimation approaches, possible age classes or objective measures of performance and error. The lack of capturing consecutive images of a specific fingerprint as well as the lack of digital processing and evaluation methods seems to be a major disadvantage of these schemes, similar to the contact-based morphological approaches.

Contactless Morphological Approaches

An important unknown factor for most age estimation approaches can be seen in the uncertainty of the initial state of the investigated characteristic. Watson et al. claim that the initial amount of charge seems to be dependent mainly on the surface material and the fingerprint application and therefore can possibly be estimated. Whether the initial state of the charge can indeed be obtained has yet to be shown and remains a crucial aspects for the feasibility of the scheme. However, the application influence of contact pressure and -time seems to be significant. Furthermore, the method is limited to insulating surfaces. The decay of the surface charge is dependent on the surface characteristics and environmental influences, according to the authors. A time period of days or weeks is given for common plastics, before the charge has dropped below measureable levels. The method is therefore only suitable for comparatively short aging periods. Despite the mentioned drawbacks, the method seems to be promising, if the reported findings can be confirmed by quantitative tests. Summarizing the two introduced morphological approaches, the use of non-invasively captured, consecutive fingerprint images for the evaluation of aging properties seems to be promising, yet barely explored.

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IV. SYSTEM ARCHITECTURE AND METHODOLOGY

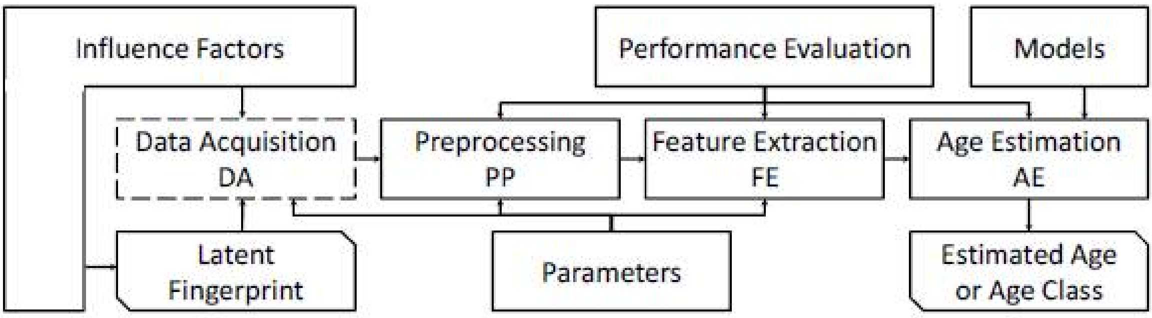

Figure.1 digital processing pipeline for fingerprint age estimation and performance evaluation

As the main methodological foundation, a digital processing pipeline for the age estimation of latent fingerprints and its performance evaluation is designed. It is based on the general biometric processing pipeline. The detailed structure of its four main steps of data acquisition, pre-processing, feature extraction and classification is designed and implemented for the age estimation of latent fingerprints (Figure 1)

In the data acquisition step (DA), the designed processing pipeline captures a latent fingerprint image in regular time intervals, hence creating a digital time series. The print as well as the capturing process can be subject to different influences from the environment, the fingerprint application, thecapturing device, sweat composition or surface material (section 2.4). Such influences can lead tocertain distortions in the captured time series, which need to be addressed in later processing steps.In this thesis, data acquisition is not of interest beyond the identification of basic sensor settings aswell as the identification of potential distortions, which later need to be reduced in the scope of image pre-processing. It is therefore marked in dashed lines in Figure 1. In future work, also optimizations of the hardware should be conducted, including researchers from the fields of sensor manufacturing.

After the capture of an aging time series is completed, all additional processing steps are conductedon the digitized data. The original fingerprint, which has not been altered by the capturing process, isnot required anymore and can be used for other investigation methods, such as DNA analysis. Fordesigning the three following processing steps of time series pre-processing (PP), feature extraction
(FE) and age estimation (AE), existing processing techniques can be transferred and adapted fromother application areas (such as algorithms for live fingerprints from biometrics or classification algorithmsfrom machine-learning, section 2.3). However, also new methods need to be designed inmany cases from basic image processing operations.

In the pre-processing step (PP) of the pipeline, images need to be transferred into a comparable form, by spatial alignment (long-term aging), reduction of various influences from the capturing devices and the environment as well as the segmentation of relevant fingerprint structures. The digital pre-processing of time series is regarded as especially challenging, because fluctuations of the capturing devices (e.g. changes of the overall image brightness over time) as well as changes from the environmental conditions (e.g. accumulating dust) need to be digitally reduced for the creation of reliable time series.

Various features are implemented and evaluated in the feature extraction step (FE), where different statistical, image-based features are applied for the first time to the challenge of age estimation.Furthermore, morphological features are designed and evaluated in the scope of long-term aging. Features are computed from pre-processed print time series, which results in a sequence of featureValues, representing the aging curve of such feature in respect to the investigated fingerprint. In the age estimation step (AE), formula-based age computation as well as machine-learning based classification into well-defined age classes is investigated. For the first time, automated latent print age

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estimation is performed, resulting in objective performance measures, which might be used as abenchmark for future age estimation approaches.

Initial Dataset

Previously we created a database of latent fingerprintimages isolating several steps within the pre-processingworkflow. This database includes 89 latent fingerprintimage pairs that were developed using a cross-section of forensic field work techniques including: ninhydrin, silvermagnesium powder, white powder, bi-chromatic powder,bi-chromatic mag powder, and black ink. The original images were scanned by high-resolution flatbed scannersand subsequently pre-processed within Adobe Photoshop,the primary image analysis tool used by latent examiners practicing today. The image transformations in thepre-processing workflow were recorded in AdobePhotoshop and saved in an accompanying metadata file asper existing best-practice guidelines. The result was acollection of triplets consisting of original image,processed image, and metadata file. This database hasproven to be an invaluable source of controlled data fordeveloping scientific analyses of forensic imagepre-processing.

V. ALGORITHM

BOZORTHAlgorithm

BOZORTH3 is an algorithm and utility that matches two minutiae patterns with each other and produces a match score. Matching between the fingerprint can be one-to one verification or one-to-many identification. Bozorth algorithm includes three steps for fingerprint matching:

Step 1: Construction of Intra-Fingerprint Minutiae Comparison Tables

Step 2: Construction of Inter-Fingerprint Compatibility Table

Step 3: Traverse Inter-Fingerprint Compatibility Table constructed in second step

In step 1 probe fingerprint comparison table and gallery fingerprint comparison table are constructed. Table construction for both galley and probe fingerprint mainly depends on position and orientation of minutiae. Relative measurements from each minutiae to all other minutiae are computed in a fingerprint and tabulated in the table known as minutiae comparison table. Relative measurements of minutiae in a fingerprint to find the distance between the minutiae and orientation of the fingerprint.

Consider approach in which k and j represents minutiae points on fingerprint. Consider point k where k (x_k, y_k) represents location of minutiae k on the fingerprint and $\beta 1$ represents the orientation θ_k of minutiae. All the minutiae of the fingerprint are represented in this style. In $d(pm)$ represents the distance between two minutiae's k,j as distance between two minutiae's will remain constant regardless of how much shifting and rotation may exist between two points. β_k, β_j are computed relative to the intervening line as shown by incorporating θ_kj and each minutiae's orientation t.
For each comparison between minutiae all the entries mentioned below are made
$\{d\_kj, \beta\_k, \beta\_j, \theta\_kj\}$ Where β 1 = (β_k, β_j) andβ 2 = $ma(\beta\_k, \beta\_j)$ in the illustration above $\beta 1 = \beta\_k and \beta 2 = \beta\_j$. Entries made in the table are stored in order of increasing distance and the table is trimmed at the point when the maximum distance threshold is reached. Same procedure is followed for each fingerprint while constructing Intra-Fingerprint Minutiae Comparison Table.

In step 2 compatible table is constructed from two separate fingerprint comparison tables. All vales of probe fingerprint comparison table are pair-wise computed with measurements stored in comparison table P. All the measurements are stored as mt□ entry in table P, denoted as pm and (pm) represents the measurements corresponding to minutiae k. Distence between two minutiae is also store in table as d(Pm). The same procedure is done for gallery fingerprint and is stored in table entry Gn. Following tests are performed on table entries Pm and Gn to form a compatible table. These

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tests checks if the corresponding distances and angles are in specified tolerance. Where Δ() and Δ*d*() represents the difference function.

Step 3 determines how well two fingerprints match each other based on the compatibility table designed in step 2.

VI. RESULTS AND DISCUSSION

performance of the proposed sets of latent print time seriesare presented. In the first part, the correlation coefficientsvagranth(|r|≥0.8) are used to analyze the general feasibility of the features by evaluation of the characteristic progression of their aging curves. In the second part, machinelearningbased age estimation is applied using two-class problemsto evaluate the practical age estimation performance ofthe features. For classification, the 19 features F1 - F19 areapplied, leading to 36 feature combinations for S1, S2 andS6 as well as 37 feature combinations for S3 - S5 andS7 - S10

Short-Term Age Estimation PerformanceUsing Machine-Learning

For short-term aging periods of up to 24 hours, the mainhypothesis suggests that features F1 and F2 perform best.Features are interdependent to a certain degree but someperformance increase is expected for the combination ofall features (F'38). The results for the short-term age estimationperformance for sets S1 (CWL) and S2 (CLSM)are depicted in Fig. 12 in respect to different time thresholdstt= {1, 2, .., 23h}. Together with the results of allcombined features (F'38), the five best-performing singlefeatures are depicted (the results of all features are givenn Supplementary VII). It can be seen from the figure thatthe combined performance of all features performs slightlybetter than the performance of the best single feature forboth devices (with a kappa improvement of about +0.1).Furthermore, a general trend can be seen in that intensitybasedfeatures mostly perform better than topography-basedoneand that Benford's Law features mostly perform worsethan other features (please also refer to Supplementary VII foradditional feature curves).Furthermore, the CWL sensor (leftfigure) achieves a lower total performance than the CLSMdevice (right figure). However, in future studies it also hasto be investigated to what extent certain influences of the capturing devices are systematically impacting the observedprint intensity (e.g. a very strong decrease of light sourcelaser intensity during the measurement period of half a yearwas observed for the CLSM device, leading to a significantdecrease in overall image brightness, which is corrected bytemporal normalization). When studying the performances inrespect to different time thresholds tt, both devices exhibitthe best performance for thresholds between tt= 4 hand tt= 8 h (highest performance for both devices isachieved using F'38 and tt= 5h: κ_max(CWL) = 0.51,κ_max(CLSM) = 0.70) with decreasing performance forhigh thresholds and a certain performance fluctuation for lowthresholds which can peak very high in a few cases of theCLSM device (however, these peaks are not considered for thehighest performance determination since their cause is unclearat this point). The continuous decrease in age estimationperformance for higher time thresholds appears to be mainlycaused by the drying process of the prints, where aging speedsbecome more and more undistinguishable the dryer a printbecomes. Concluding from these findings, the age estimationperformance is highest for time thresholds between fourand eight hours and is decreased with continuous print age.In general, the single features F1 and F2 perform best for bothdevices, achieving a performance close to the combination ofall features F'38 (with an average kappa decrease of about-0.1). Therefore, the investigated features appear to be highlyinterdependent and very few (if not a single) intensity-basedstatistical feature(s) might be sufficient for achieving the bestoverall observed age estimation performance.

Long-Term Age Estimation PerformanceUsing Machine-Learning

According to the main hypothesis, long-term aging periodsshould exhibit worse age estimation results for thefeatures F1 - F18 than the short-term aging periods sincethe prints have largely dried and less degradation behaviour can be observed. However, the capture intervals have alsobecome larger, potentially countering such trend. The dustfeature F19 should perform particularly well since dust isexpected to continuously accumulate on the print over time.The results for CWL long-term aging periods of up to threeyears (with time thresholds tt= {1,2,..,29m}) are depictedin Fig. 13 for all combined features (F'38) as well as the fivebest-performing single features (the results for all features

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aregiven in Supplementary VIII). They show a similar trend withregard to the short-term aging of Fig. 12 in respect to intensitybasedfeatures performing better than topography-based ones,Benford's Law featuresperforming comparatively bad and acombined classification using all features performing betterthan most single features. However, a big difference can be

seen in the dust feature F'37 computed from intensity images,which performs extraordinary well and can alone achievea similarly good performance than combining all featuresin F'38. Therefore, the improved dust feature is very promising,performing much better than any other feature. For the setsS3 and S4 (with a higher resolution than S5), the dust featureachieves very goodclassification results for a comparativelybroad range of time thresholds(between 5 and 20 months; bestperformance of S3 is achieved for tt= 11m with $\kappa = 0.85$, bestperformance of S4 is achieved for tt= 14m with $\kappa = 0.82$).For set S5 exhibiting a slightly lower resolution), a similartrend is present, however less strong, best results are achievedfor time thresholds between 2 and 8months (best performancefor tt= 6m with $\kappa = 0.71$). However, only between17 and 20differing time series are available for sets S3 - S7, leading onlytofirst qualitative performance indications. The general trendof decreasing age estimation performance for increasing printage can also be observed here, yet not as fast and clear as forthe earlier discussed short-term aging.

VII. CONCLUSION

Friction ridge skin on fingers and palms has been purportedly known to be a unique physical characteristic of an individual that does not change over time and can be used as a person's "seal" or "signature" since ancient times. In this work, we have reported on experiments carried out using the first publicly available database of highresolutionlatent print time series has been presented. The three systems implement different approaches for feature extraction, fingerprint alignment, and matching. Furthermore, several combinations of the systems using simple fusion schemes have been reported.A number of experimental findings can be put forward as a result.We can confirm that minutiae have discriminative power but that complementary information, such as second and higher order minutiae constellation, local orientation, frequency, ridge shape or texture information encoding alternative features, improves the performance, in particular in low-quality fingerprints. The minutiae-based algorithm that results in the best performance (HH) exploits both a minutiae-based correspondence and a correlation-based matching, instead of using only either of them. Moreover, the HH algorithm extracts minutiae by means of complex filtering, instead of using the classical approach based on binarization, which is known to result in loss of information and spurious minutiae . When combining only two systems.

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