CHALLENGES IN CONTACT-LESS LATENT FINGERPRINT PROCESSING IN CRIME SCENES: REVIEW OF SENSORS AND IMAGE PROCESSING INVESTIGATIONS

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ABSTRACT

The contact-less acquisition of untreated latent fingerprint traces with various sensing and image processing techniques is an upcoming opportunity in crime scene forensics. Current analyses of imaging sensor systems show the applicability but dependence on several factors e.g. substrate type, latent trace structure and scanning technology. Also, spectroscopy might be used on fingerprints to determine their chemical composition. Multi-sensor devices might cover huge ranges of different application scenarios. Beside single-sensor tuning and multi-sensor fusion approaches for quality improvement of 3D scan data for localisation (coarse scan), acquisition (detailed scan) and analysis of fingerprint traces, new challenges arise. In this article we review and summarise the current state of the art of applicable sensing and pre-processing techniques and identify 7 challenges: the need for the integration of different process models, the determination of sensor parameters, the choice of sensor types for different surfaces, the challenge posed by non-planar surfaces, the influence of dust and dirt, the age detection and separation of overlapping fingerprints and the ongoing extension of an existing benchmarking scheme [1]. Based on experiments described in this article we suggest adding the sub properties of exploited characteristic and angle tolerance to the input sensory technology property *I*. We show that contact-less sensors open new opportunities but also require a lot of further research for forensic usage.

***Index Terms*—**Signal processing applications, Design and implementation of signal processing systems, Image and video processing, Dactyloscopy, Pattern Recognition

1. INTRODUCTION

Latent fingerprints are mostly invisible to the naked eye and require processing to render them visible. They can be grouped into difficult-to-avoid traces, making them very valuable in forensics as proof of contact between an individual and the surface containing the fingerprint residue; at some point in time. Exemplary fingerprints are taken directly off a finger and are widely used (e.g. biometric authentication systems). Research in contact-less latent fingerprint localisation (coarse scan), acquisition (detailed scan) and processing in crime scenes has increased significantly recently to overcome disadvantages of traditional dactyloscopic techniques. Most importantly, alterations from contact-based physical or chemical fingerprint processing can hinder or even rule out further investigations from other perspectives (e.g. drugs, DNA). Contact-based methods are often well researched and many procedures and best-practice guides [2] exist. With new possibilities offered by contact-less localisation, acquisition and digital fingerprint investigation, including the use of 3D topography data potentially allowing for new features, new challenges arise. A fundamental change in procedures is the conversion of physical trace evidence into digital objects, requiring new means to ensure the comprehensibility of fully digital investigations. Authenticity and integrity ensuring mechanisms need also be applied to the chain of custody for digital objects. The localisation and acquisition process and all transformations applied to digital trace evidence and their results need to be explained to non-technicians, persuading a judge to allow the evidence in court. In some countries the Daubert factors [2] are used, which must be met by contact-less latent fingerprint processing in crime scenes. Benchmarking with technical properties, application-related aspects, input sensory technologies, pre-processing algorithms, tested objects and materials, and forensic legal requirements is a means to address some factors [1]. This article is structured as follows: In Section 2 the state of the art in contact-less acquisition sensor technologies is summarised. In Section 3 seven selected challenges for the application of contact-less latent fingerprint localisation, acquisition and analysis are discussed. In Section 4 tests using selected contact-less sensors for challenges of different surfaces are described, followed by a discussion of results. The article ends with a conclusion in Section 5.

2. STATE OF THE ART IN CONTACT-LESS FINGERPRINT ACQUSITION

Contact-less sensors are currently researched for the acquisition of latent and exemplary fingerprints for forensics (dactyloscopy) and biometric systems for user authentication. Generally, fingerprint acquisition can be divided into techniques exploiting chemical or physical characteristics of the fingerprint and substrate, leading to a proposal of a new benchmarking sub property of exploited characteristic in the Input Sensory Technology *I* as introduced in [1]. A 3D acquisition is desirable, potentially yielding more fingerprint information. Although some approaches, e.g. chemical force microscopy or RAMAN spectroscopy, acquire the data contact-less, they rely on the use of exciter particles [3], rendering the technique contact-based. Other techniques remove fingerprint residue to analyse the result of its interaction with (usually metallic) surfaces [3]. In the following an overview on selected promising existing, exclusively contact-less acquisition sensors and technologies based on chemical or physical characteristics of fingerprint and/or substrate is given. Exploiting *physical characteristics* of fingerprint residue and/or substrate, the approach from [4] uses linear polarisation filters and digital cameras to acquire 2D images of latent fingerprints from non-porous surfaces. But resulting images are distorted due to the needed camera angle (Section 4.3). Gloss measurement [3] produces 2D latent fingerprint images according to the surface's ability to reflect light differently in the presence of fingerprint residue. Using a diffractive glossmeter [5], latent fingerprints from curved smooth surfaces are acquired, requiring the placement of the object on a rotary table. Swept Source Optical Coherence Tomography [6] offers options to acquire 3D topography and tomography data including latent fingerprints under layers of dust on light dispersing materials. It was only tested on glass surfaces and the resulting data only vaguely resemble traditional fingerprint images. Approaches using structured light [7] acquire 3D topographic data by projecting a constantly refined interference fringe onto a surface and record the reflected light distorted by surface anomalies e.g. fingerprint residue. They might be used to acquire latent fingerprints but, to our knowledge, currently the resolution is too low to be used in dactyloscopy. Confocal microscopy [3] using point illumination and excluding non-focused light with a rotating pinhole drum produces 3D images reach the needed resolution to acquire fingerprint data, first tests show its general applicability. Atomic force microscopy in its full contact-less variants is generally suited to produce very high-resolution 3D images. But, as stated in [3], it needs substrates to be put in a vacuum, reducing potential application fields. Exploiting *chemical characteristics*, the approach using 2D infrared spectroscopic imaging by Fourier transform infrared microscopy [8] was tested on latent fingerprints on non-porous (e.g. litterbags, cans) and porous surfaces (e.g. copier paper, postcard). This expensive technology needs active infrared light sources to be cooled to emit the needed frequencies, for now ruling out the use in mobile crime scene devices. Other spectrography-based approaches using the UV or visible part of the spectrum are currently researched [3].

3. SELECTED CHALLENGES IN CONTACTLESS LATENT FINGERPRINT PROCESSING

Using new contact-less acquisition sensors enables a more detailed investigation of a trace, e.g. using multiple sensors. With contact-less sensors and fully digital processing, an automatic detection of potential latent fingerprints, an automatic feature extraction and a classification (e.g. into fingerprint residue and substrate surface) based on the generic model of a biometric system [9] could be achievable (Fig. 1). It can potentially provide approaches unanswered by traditional dactyloscopic techniques, e.g. separation of overlapping fingerprints [13] that are typically dismissed today or an age determination of fingerprints [3]. The latter could potentially drastically reduce the amount of fingerprints that need to be processed and exclude fingerprints of innocent persons according to the time of the crime. With those techniques new challenges arise: at first potential fingerprint traces must be localised and identified on various substrates within a short period of time, followed by the detailed acquisition of each trace [12]. Depending on the substrate characteristics different image processing or pattern recognition techniques must be utilised to detect a trace or to visualise the ridge pattern for an investigation by dactyloscopic experts. Especially the pattern recognition requires the design and evaluation of suitable features for a classifier. Afterwards, models must be trained for each class of similar substrates using those features and reference data. The selection of the appropriate model is a new challenge for a potential forensic investigation. A challenge for all those steps is to determine how reliable the results are. The digitised trace can be investigated as digital data, avoiding the media discontinuity of printing the fingerprint to trace cards. But the security aspects and the chain of custody must be maintained for the physical and digital trace. An additional challenge is to retain a comprehensive link between all representations of a trace.

3.1. Need for integration of different models

Traditional forensic methods and procedures for IT-forensics need to be integrated into one approach for contact-less localisation, acquisition and subsequent analysis of fingerprints. Our proposal is to study and combine 3 models to integrate the relevant aspects: biometric pipeline, ACE-V methodology and IT-forensic process models. When using contact-less sensors and digital processing, the model of the *biometric pipeline* [9] can be applied. It describes the signal processing chain as data acquisition, pre-processing, feature extraction and storage of reference data in *enrolment* mode and is re-run to add comparison/classification in *identification/authentication* mode. For forensics it needs to be adapted (Fig. 1).

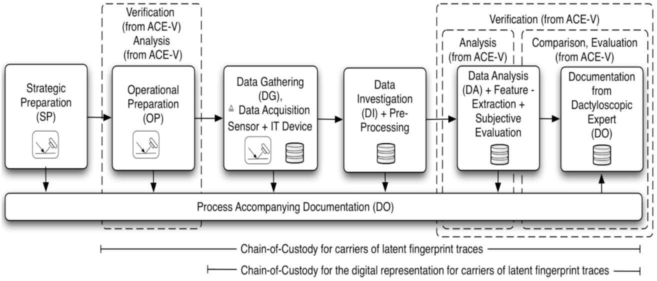

Figure 1: Biometric system (modified from [9])

There is no (direct) enrolment and latent fingerprints left unintentionally and without cooperation by the originator are used, under less-than-ideal circumstances (e.g. smeared, incomplete, overlapping). The *ACE-V methodology*, part of the fingerprint identification process [2], is long used in dactyloscopy. It requires a dactyloscopic expert to *analyse* fingerprint and substrate to conclude whether dactyloscopic material is present and assess the degree of detail. He then *compares* the latent fingerprint systematically on all three levels of detail with a reference sample (latent or exemplar). Then he *evaluates* all information, reaching a conclusion of match, mismatch or inconclusiveness. The whole process is executed again by an independent forensic expert at the *verify* stage. The identification process and ACE-V need to be adapted for contact-less fingerprint acquisition, requiring a digital chain of custody and comprehensible pre-processing transformations to enhance and annotate trace data. In *IT-forensics* various process models exist to help ensuring a proper conduct of the investigation (e.g. [10]). They often group procedures in phases of the investigation process, require proper documentation and ask for measures to ensure authenticity and integrity of traces, thus rendering the investigation comprehensible. The model from [11] adds a classification of forensic data types and forensic methods.

3.2. Determination of sensor parameters

From our experiences, determining appropriate sensor parameters is a challenge for the contact-less fingerprint trace acquisition. But a major advantage is the possibility of multiple trace acquisition, even with different sensors. Parameters usually depend on substrate characteristics. Smooth, non-textured, reflective surfaces usually require other acquisition parameters as structured, textured, diffuse reflecting substrates. For instance, the sampling frequency between 100 and 2000Hz for the Chromatic White Light sensor (CWL) or the illumination intensity (0 to 100 %) are substrate-dependent. An appropriate sensor positioning (Z axis setting) is very important for non-planar surfaces due to the limited measuring interval of 660µm. Also, other lighting and camera angles might be needed in [4].

3.3. Sensor types for different surfaces

Different substrates might require different acquisition techniques. From our observations, especially *porous surfaces* absorb fingerprint residue, rendering the fingerprint invisible for many surface measurement techniques. Here, different sensors are needed and in an optimal case chemical-imaging techniques might detect the residue [8]. Such techniques might provide more information for fingerprint age determination. For *non-porous surfaces* various sensors can be used to acquire the trace and surface properties (e.g. structure, texture) might help determining appropriate sensors. Single sensor fusion approaches [3] extended towards multi-sensor fusion seem promising.

3.4. Non-planar surfaces

From our two year's experience, non-planar surfaces are challenging for contact-less acquisition, especially for (semi-) automated approaches, due to two effects: the distortion during the *acquisition process* and the distortion during the *deposition of the fingerprint*. Also, shadowing effects can influence scan results. To conquer the distortion during the acquisition process, additional knowledge about the surface's topology is needed. With such information the distortion might be eliminated or at least reduced. Determining the distortion during the deposition of the fingerprint is more challenging. Usually no or limited information of the deposition circumstances is known. Hence, the distortion should be estimated during the investigation process.

3.5. Influence of dust and dirt

Generally, dust and dirt can have a significant influence on the fingerprint acquisition. In traditional forensics dust and dirt usually provide the noise backdrop, from which enhancement methods have to contrast against the visible fingerprint information [2]. Using *contact-less acquisition and digital processing*, it can degrade the automatic localisation of fingerprint traces on some materials (e.g. brushed steel) whilst enhancing the process on other surfaces (e.g. silver metallic painted metal) as first results show using CWL sensors [12]. On a tested glass surface, Swept Source Optical Coherence Tomography showed potential as a sensor [6].

3.6. Age detection of fingerprints and separation of overlapping fingerprints

As of now, the age determination has roughly been evaluated for the CWL sensor, indicating positive tendencies [3]. The age detection mostly requires consecutive high-resolution scans of the fingerprints to detect the degrading of the residue, which can be provided by the CWL sensor. First attempts to (semi-) automatically separate overlapping fingerprints show positive tendencies [13] but rely on the selection of suited sensors, e.g. limited depth of focus and thus partially blurred image of the camera-based approach can interfere with the separation attempts (see Section 4.3).

3.7. Extension of the benchmarking scheme

The benchmarking scheme from [1] needs to be extended to describe a sensor in more detail. The *angle tolerance* of a sensor is an important sub property for non-planar surfaces. Further, the sub property of *exploited characteristics* of fingerprint residue (e.g. physical or chemical) is a valuable scheme extension.

4. EXPERIMENTS

In this section, 3 selected contact-less sensor approaches are used to exemplary examine cooperative substrates to show the general suitability for either localisation and/or detailed fingerprint acquisition and identify challenging substrates for the chosen approaches, motivating further research.

4.1. Test setup and execution

Our test setup for this article is shown in Table 1. It includes the exemplary CWL sensor s_1 (FRT MicroProf 200 CWL 600) and the Camera-based approach s_2 (Canon EOS 550d with EF 50mm f/2.5 macro lens and a linear polarisation filter), using the approach from [4]. As sensor s_3 we use UV imaging (JAI CM-140 GE UV camera with a UV-sensitive Baader-Venus filter [16] and a super-actinic UV-lighting source Sylvania Blacklight F40W/2FT/350BL, 300-460nm). We consider a surface *cooperative* if the fingerprint is visible directly after acquisition. A *challenging surface* needs digital pre-processing to show the fingerprint. From *very challenging surfaces*, fingerprints cannot be visualised, yet. We distinguish the tests into coarse and detailed scans. The first surface m_1 is a smooth non-textured white furniture surface, which can be considered as an almost ideal surface for the CWL sensor and the camera-based approach. The second surface m_2, matte metallic paint is challenging for s_1 (extensive pre-processing needed) and very challenging for s_2 due to the low contrast between fingerprint and surface. The third surface m_3, a curved power outlet cover is challenging due to its non-planarity. The fourth surface m_4, copying paper is even more challenging due to its porosity.

Table 1: Selected sensors and material with tendency for the result quality (5 samples each)

Sensor Material	s_1: FRT MircoProf 200 CWL 600		s_2: Canon EOS 550d DSLR + linear polariser		s_3: UV-Imaging JAI CM-140 GE UV + Baader-Venus filter
	Coarse scan	detailed scan	coarse scan	Detailed scan	Detailed scan
m_1: Furniture surface	Co-operative	Co-operative	Co-operative	Co-operative	Challenging
m_2: Matte metallic paint	Co-operative	Challenging	Co-operative	Very challenging	Challenging
m_3: Curved power outlet cover	Challenging	Challenging	Challenging	Challenging	Challenging
m_4: Copying paper	Very Challenging	Very challenging	Very challenging	Very challenging	Cooperative

4.2. Results for the CWL Sensor [1,3,12,15]

The FRT MicroProf 200 device with a CWL 600 sensor can acquire latent fingerprints from many non-porous substrates (e.g. m_1, m_2). Non-planar surfaces e.g. m_3 pose a challenge due to the actual measuring angle of actual 90°±30° [14], limiting the steepness of slopes, thus restricting the ascertainable shape and surface characteristics of the substrates today. Thus, we propose to add the *angle tolerance* sub property to the benchmarking scheme [1] in the "Input Sensory Technology *I*" property. Further, for the CWL sensor non-planar surfaces with multiple semi-transparent layers are very challenging. Such surface characteristics increase the non-deterministic sensor noise, affecting the acquisition [1]. But on many surfaces a differential image approach renders the fingerprint visible as introduced in [1], indicating that the residue is recognised. Without a differential image additional pre-processing methods are required to visualise the fingerprint residue. Smooth, non-textured surfaces, e.g. m_1 demonstrate the superior detail of fingerprint intensity images captured by the CWL sensor with lateral resolutions of up to 12700 ppi. On some structured surfaces, e.g. m_3 the fingerprint pattern is readily visible (Fig. 2).

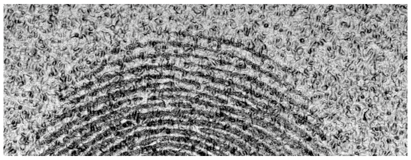

Figure 2: Fingerprint Intensity image on structured, curved power outlet cover (m_3) acquired with CWL (s_1)

But even for those surfaces the 3D topography of the residue is faintly or not all visible. Especially porous surfaces are very challenging for the CWL. Here, the differential image approach can only visualise a faint ridge pattern of fresh fingerprints on paper (m_4) with extensive pre-processing. The visibility decreases very fast within a few hours due to absorption. CWL sensors can be readily used to locate (coarse scan) for m_1 and m_2 and to acquire (detailed scan) fingerprints for m_1 [12]. Our first results show that resulting data can be used to separate overlapping fingerprints [15] and for age detection [3].

4.3. Results for the Camera with Polariser [4]

The approach of [4] is suitable to visualise latent prints from smooth surfaces m_1 (Fig. 3, left). However, especially structured surfaces m_2 are very challenging (Fig. 3, right).

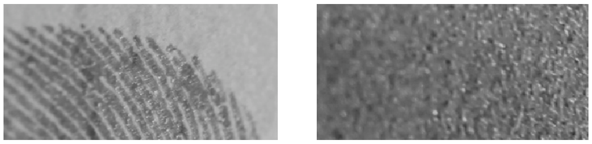

Figure 3: Camera with Polariser (s_2) on cooperating surface (m_1, left) and non-cooperating surface (m_2, right)

Further, a shading effect might occur on very structured or non-planar surfaces (m_3) due to the required angles of the camera and the light source. Porous surfaces (m_4) are very challenging due to the absorption of the fingerprint residue and the resulting decrease of the differences between the reflection behaviour of the surface and residue. Our actual pre-processing based on [4] consists of the combination of multiple images that are captured with different polarisation filter angles, exploiting the enhancement options of the contrast between fingerprint and surface. Macro lenses enhance the resolution but reduce depth of focus. The achievable resolution depends on the camera, lens and working distance (approx. 1200ppi in our setup).

4.4. Results for the UV-imaging [16]

UV-Imaging [16] uses fingerprint residue characteristics. It enables the acquisition of fingerprints from porous surfaces m_4 (Fig. 4). Fingerprints on non-porous surfaces m_{1-3} are not or barely visible with UV-imaging. A combination with the approach of [4] from section 4.3 might improve the results.

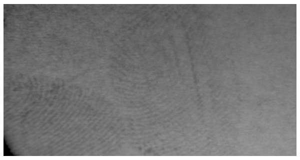

Figure 4: Fingerprints on copying paper (m_4) acquired with UV imaging (s_3)

UV light sources must be operated with caution, as short wavelength UV radiation can endanger the operator's safety and potentially alter fingerprint information (e.g. DNA).

4.5. Discussion of results

As these exemplary selected tests show, different substrates can be cooperative with some contact-less acquisition techniques whilst providing challenges for others. While the CWL sensor seems to be applicable for fingerprints on some non-absorbing surfaces it still requires digital pre-processing techniques to render the fingerprint visible. Notably the differential image approach from [1] shows that fingerprint residue is recognised by the sensor. The camera-based approach is applicable for fingerprints on some smooth, non-absorbing surfaces. But since it is relying on differences between the surfaces' specular reflection and the fingerprints' diffuse reflection, especially structured and thus diffusely reflecting surfaces are very challenging. Furthermore, the depth of focus limits might pose a problem depending of the camera-lens-combination. The UV-camera approach uses different light spectra to acquire images, being very challenging on our tested non-absorbing surfaces. But it is suitable to visualise the fingerprint on porous surfaces, e.g. paper, even after several days. The spatial resolution needs improvement to achieve a sufficient resolution for the subjective assessment by forensic experts. All sensors seem appropriate for the localisation of the fingerprint unless the surface is very challenging for the used sensing technique. But especially for the detailed scan the limited depth of focus and the distortion of the camera-based approach need to be eliminated. The UV-imaging approach requires a higher spatial resolution for the detailed acquisition. This can be achieved with higher sensor resolutions or by using different lenses with higher magnification. The latter would require combining multiple images to acquire a full fingerprint.

5. CONCLUSION

Contact-less sensors open novel opportunities such as the detection and separation of overlapping fingerprints and the age detection of fingerprints, but several challenges have to be addressed. To gain acceptance in legal proceedings, different models from biometrics, IT-forensics but also existing ones in dactyloscopy need to be integrated into a new process model. Another challenge is to select best-suited sensor parameters for coarse and detailed scan, which are very dependent on the substrate and sensor setup. Also, the determination which sensor to use on which surface, remains a challenge. On porous surfaces UV-imaging showed positive tendencies in our experiments. On a number of non-porous substrates, contact-less 3D surface measurement sensors can be used according to our experiments. Some sensor techniques are only usable for coarse scans due to low resolution, others rely on fingerprints being localised with a different technique. A further challenge is posed by non-planar surfaces distorting the fingerprint where topology information needs to be integrated. Another challenge we identified is that with the contact-less acquisition, dust and dirt can degrade and in rare cases enhance (semi-) automated processes. A further challenge is the age detection of fingerprints and the separation of overlapping fingerprints. For the latter a first (semi-) automatic approach shows positive tendencies whilst relying on distortion free and high-resolution fingerprint scans. Using repetitive high-resolution scans, measuring the degrading of fingerprints shows first positive tendencies. To establish and maintain a benchmarking scheme vital to the acceptance of contact-less fingerprint acquisition and digital processing, its constant extension also is challenging as new sensor technologies can require the addition of new properties.

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