Inkjet printing of artificial latent fingermarks for improved quality assurance and research efficiency

A thesis submitted for the Degree of Doctor of Philosophy (Science)

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Certificate of original authorship

I, Romain Steiner declare that this thesis, is submitted in fulfilment of the requirements for the award of Doctor of Philosophy, in the Faculty of Science at the University of Technology Sydney.

This thesis is wholly my own work unless otherwise referenced or acknowledged. In addition, I certify that all information sources and literature used are indicated in the thesis.

This document has not been submitted for qualifications at any other academic institution.

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Research communication

Peer-Reviewed Publications

Steiner, R., Moret, S. and Roux, C., *Evaluation of the use of chemical pads to mimic latent fingermarks for research purposes*. Forensic Science International, 2020. 314.

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Conference Presentations

Oral presentation at the 5th Crossing Forensic Borders seminar held by the University of Technology Sydney, Australia; 10 February 2021.

Oral presentation at the 8th Doctoral School of the Ecole des Sciences Criminelles (ESC), University of Lausanne held in Les Diablerets, Switzerland; 26-29 August 2019.

Oral presentation at the WSU-UTS Symposium held in Sydney, Australia; 11 July 2019.

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Abstract

Research in fingermark detection is a constantly evolving field where detection techniques are frequently improved or discovered to be able to detect as many fingermarks as possible in any given case. Quality control in fingermark detection is paramount to ensuring detection techniques meet a scientifically accepted standard, but this control is hindered by the intrinsic variability of natural fingermarks. The chemical composition of fingermark secretions, as well as deposition parameters such as the pressure applied or the amount of residue deposited on a substrate, can considerably vary between individuals and even for a same individual at different times. Because of this variability, it is challenging to unambiguously attribute any failure to detect fingermarks to the detection technique used rather than to a poor quality of the latent mark. The International Fingerprint Research Group (IFRG) guidelines aim at providing a standardised framework for researchers to reduce the effect of fingermark variability. However, due to its unpredictable nature, this variability can never be completely controlled, and new detection techniques need to go through many different stages of experimentation (and peer-review) before being approved for use into standard operating procedures.

This thesis aimed at developing a method to reproducibly produce artificial fingermarks using an inkjet printer. Firstly, a standard solution mimicking real human secretions was developed and was shown to be reactive towards a range of commonly used detection techniques. Fingermark patterns were then printed using an everyday inkjet printer by replacing the black ink with the synthetic secretions. Artificial fingermarks were printed on a porous and a non-porous substrate and were processed with some of the most used detection techniques on these kinds of surfaces. The artificial fingermarks were shown to be reactive towards most of the detection techniques tested. To validate the process, two different practical applications were examined: the production of proficiency tests for the assessment of laboratories methods and detection techniques, and an inter-laboratory comparison focussed on the physical developer technique. Both experiments showed very good potential for the use of artificial fingermark for quality assessment and research.

The proposed method has potential to alleviate the effects of fingermark variability by providing a way to reproducibly produced controllable fingermarks with a known and fixed composition. Further research is imperative to improve the method but the results found showed that artificial fingermarks are the right way to go for a better research and quality assessment.

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I warmly address a special acknowledgement to the fingermark donors who took some of their time (and I know it is precious!) to put their hands in latex gloves, rub their fingers on their forehead before pressing them against different substrates. This may not sound as a big deal, but this research would not have been the same without their availability.

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Abbreviations

Abbreviation	Word
ATR	Attenuated Total Reflection
CA	Cyanoacrylate
CAST	Centre for Applied Science and Technology
DCM	Dichloromethane
DFO	1,8-Diazafluoren-9-one
DI	Deionised
DOD	Drop on demand
DPI	Dots per inch
Emulsion$_{conc}$	Emulsion prepared with sebum$_{conc}$ (de la Hunty's formulation)
Emulsion$_{D}$	Emulsion (de la Hunty's formulation)
Emulsion$_{S}$	Emulsion (Sisco *et al.* formulation)
ESC	Ecole des Sciences Criminelles
FTIR	Fourier-Transform Infrared
Gsm	Grams per square meter
H/I	Hexane/isopropanol (50:50, v/v)
HCl	Hydrogen chloride
HLB	Hydrophilic-lipophilic balance
IFRG	International Fingerprint Research Group
Ind/Zn	1,2-indanedione/zinc
LOD	Limit of detection
MDPI	Max dots per inch (resolution)
MMD	Multi Metal Deposition
NaCl	Sodium chloride
NaOH	Sodium hydroxide
NFI	Netherlands Forensic Institute
Nin	Ninhydrin
o/w	Oil-in-water
ORO	Oil Red O
PD	Physical developer
pH	Potential of hydrogen
PT	Proficiency test/testing
R6G	Rhodamine 6G
SDPI	Standard dots per inch (resolution)
Sebum$_{conc}$	Concentrated synthetic sebum (de la Hunty's formulation)
Sebum$_{D}$	Synthetic sebum (de la Hunty's formulation)
Sebum$_{S}$	Synthetic sebum (Sisco *et al.* formulation)
SMD	Single Metal Deposition
Sol-gel	Solution-gelation

$Sweat_D$	Synthetic sweat (de la Hunty's formulation)
$Sweat_S$	Synthetic sweat (Sisco *et al.* formulation)
TRL	Technology Readiness Level
UC	University of Canberra
$VMD_{Au/Zn}$	Gold/zinc vacuum metal deposition
w/o	Water-in-oil

Overview

Research in fingermark detection is a constantly evolving field where new detection techniques are frequently discovered, and existing ones are continuously improved in order to optimise the detection in any given case. Given the high number of laboratories developing and testing fingermark detection techniques, research must be standardised in some way for the results to be comparable. The International Fingerprint Research Group (IFRG) Guidelines were published to set the framework in which fingermark detection research has to be undertaken to guarantee valid results throughout the different phases of research and development in fingerprint research.

This need for standardisation arises from one specific characteristic of fingermarks: their inherent variability. Fingermark variability is the result of two main parameters: the chemical composition of the secretions and the deposition factors. These two parameters have been studied and efforts have been reported to try to control fingermark variability by developing standard solutions or by presenting methods to reproducibly deposit latent fingermarks. However, no real attempt at creating realistic artificial fingermarks, with a known chemical composition and a controllable deposition method, has been reported. Standard solutions are usually limited to simplistic mixtures that are reactive towards very few detection techniques. More complex solutions have been reported but their reactivity towards a large range of techniques has never been assessed. Moreover, a reproducible way to deposit fingermark simulants has never been extensively studied nevertheless some promising results were obtained by using an inkjet printer.

This thesis aimed at developing a method to reproducibly produce artificial fingermarks with a known, controllable, and realistic composition using an inkjet printer. A simulant is considered as realistic if its reactivity towards an extended range of detection technique mimics real fingermarks. It should also allow for detection sequences to be assessed on different types of substrates. To achieve this goal, the research was divided into four main parts: (i) the evaluation of commercially available chemical pads to produce latent fingermarks, (ii) the development of artificial secretions, (iii) the presentation and optimisation of the inkjet printing method, and (iv) the demonstration of two different practical applications that could benefit from the use of artificial fingermarks.

The primary objective of the study in relation to the chemical pads was to evaluate their reliability to mimic real fingermarks when deposited on different substrates and processed with different detection techniques. The results obtained showed that, even if those pads can give a better control on the quality in some cases, they are too unreliable and cannot be recommended for use in research or practice. The deposition method using a rubber stamp was also shown to be unreproducible as it was impossible to precisely control the amount of simulant loaded on the stamps and deposited on the substrate. These results further highlighted the need for a more realistic simulant, combined with a better deposition method.

The second part of the thesis was dedicated to the choice of the most optimal synthetic solutions for the purpose of the research. Different synthetic sweat and sebum formulations found in the literature were tested and their reactivity towards common detection techniques was compared. Emulsions formed by mixing the sweat and sebum solutions were tested with the same detection techniques applied individually and in sequence, and the results confirmed the presence of both eccrine and sebaceous compounds within the emulsions. The choice was conclusively made to keep the formulations with the most optimal properties for inkjet printing.

The third, and fundamental part of the research, aimed at presenting and optimising the inkjet printing method to controllably print artificial fingermarks with the synthetic solutions developed. Two different printers were compared: a commercially available consumer inkjet printer (HP Printer), and a chemical printer (Fujifilm Printer). The high reproducibility of the HP Printer was first demonstrated by printing a consequent number of pages with the synthetic sweat solution. Artificial fingermarks were then printed with the different synthetic solutions (sweat, sebum, and emulsion) on a porous (paper) and a non-porous (acetate) substrate. The artificial fingermarks were processed with a range of detection techniques compatible with each of the substrates: 1,2-indanedione/zinc, ninhydrin, Oil Red O, and physical developer on paper; cyanoacrylate fuming, rhodamine 6G, gold/zinc vacuum metal deposition, and silver-black powder on acetate. The techniques were applied individually, as well as in sequence, and the results assessed. The best results were obtained on the fingermarks printed with the emulsion, which not only had a very similar quality and contrast compared to real fingermarks but could also be processed with detection sequences on paper and acetate. Two main shortcomings were identified that were directly related to the use of the HP Printer: the impossibility to print on rigid or thick substrates and to print solutions that are too viscous. The Fujifilm Printer was used to try to overcome those issues, but the results showed that the printer suffered from an important lack of reproducibility and that the emulsion could not be printed without clogging the cartridge nozzles. Overall, inkjet printing was shown to be a very efficient, easy to apply, and a quick method to produce realistic artificial fingermarks. The quality of the results was highly reproducible and comparable to those obtained when real fingermarks were processed with the same detection techniques. For those reasons, the inkjet printing method could start being implemented by laboratories as positive control tests that would lead to an important gain of time and improved quality assurance in research and practice.

Finally, the last part of the research presented how the use of artificial fingermarks could be applied to the production of proficiency tests (PTs) and to inter-laboratory comparisons of detection techniques. PTs currently suffer from the intrinsic variability of fingermarks as two different forensic laboratories will never receive the exact same fingermark, thus making laboratory detection success comparisons challenging. A collaboration with Forensic Foundations (a PTs providing company) was undertaken where the fingermarks sent to the participants were printed with artificial secretions on a paper substrate. Pre-testing of the samples showed that all the fingermarks were properly printed and detected by correctly prepared working solutions of 1,2-indanedione/zinc and ninhydrin. It was demonstrated that the fingermarks sent to the participants were all consistent, which will conclusively contribute to a better review of their methods. The inter-laboratory study was undertaken in collaboration with the Ecole des Sciences Criminelles in Switzerland and focused on physical developer (PD) performance. Different patterns printed with the Fujifilm Printer were processed in Australia and Switzerland with two similar PD working solutions. However, because the poor reproducibility of the Fujifilm Printer, no definitive conclusions could be drawn regarding any advantage in the efficiency of the PD technique applied in Switzerland or Australia. Despite these results, the potential of artificial fingermarks to compare different working solutions used by different laboratories remains very promising. Using reproducible printers such as the HP might resolve some of the shortcomings highlighted. Finally, artificial fingermarks have the potential to have an important impact in the way research is undertaken. It is hoped that this thesis will lay the foundation of future developments to optimise the process even further.