Impact of 3D Printing on Fingerprint Spoofing

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1 · INTRODUCTION

2 · APPLICATIONS OF 3D SCANNING AND PRINTING IN BIOMETRIC SYSTEMS

2 · EXPERIMENTAL METHODS

3 · RESULTS: FIRST ITERATION OF THE 3D PRINTED MOLD

4 · RESULTS: SECOND ITERATION OF THE 3D PRINTED MOLD

5 · DISCUSSION: 3D PRINTING OPTIMIZATION

7 · CONCLUSIONS AND IMPLICATIONS

9 · ABOUT NOVETTA
INTRODUCTION

Vulnerability testing is one of many ways in which Novetta evaluates biometric system performance. Performing vulnerability testing, especially as it relates to sophisticated biometric artefacts, requires continuous evaluation of emerging technologies. The objective of vulnerability testing is to facilitate the development of robust biometric systems resistant to physical attacks using impostor biometrics, or artefacts.

This study investigates whether currently available commercial 3D printers can produce artefacts comparable to traditional cooperative spoofing fabrication methods and whether current commercial 3D printers prompt a new approach to vulnerability testing of biometric fingerprint systems. In this study, artefacts fabricated from 3D printed molds were evaluated for viability as attack vectors.
APPLICATIONS OF 3D SCANNING AND PRINTING IN BIOMETRIC SYSTEMS

The rapid prototyping industry has grown in the past three decades [1] to encompass new technology and methods while meeting its objectives of:

• Creating objects difficult or impossible to make with traditional machining techniques.

• Assisting in delivering tangible and intangible goods on demand.

One of these new technologies is 3D printing, a layer-by-layer additive method, which enables fabrication of intricate parts without costly molds or dies. 3D fabrication techniques have expanded to include methods for 3D printing metals, ceramics, cell sustaining bio-tissues, and food [2]. Developments in methodology have influenced the advancement of 2-photon stereolithography (SLA) [3] allowing fabrication of micron-sized small parts with never-before encountered resolution. The models printed in each technique can be computer generated or derive from scanning methods.

The first application of 3D scanning in fingerprint biometrics was specialized hardware used to record a 3D image of the finger, gathering fingerprint data without contact or deformation. One such sensor is AIRprint from Advanced Optical Systems Inc. which can capture fingerprint data from up to 6 feet away. This technology has been applied for timekeeping and access control as seen in applications by Touchless Biometric Systems [4]. Algorithms have met the need to convert the acquired data to 2D presentations [5] [6], thereby making the 3D data backwards compatible with legacy flat and rolled fingerprint data.

Using 3D printing and 3D scanning for fabricating biometrically viable fingerprint molds or physical artefacts has not been reported in the literature, although researchers have experimented with 3D printing for other biometric modalities. Experiments using 3D printed masks for spoofing facial recognition have been completed, often with the goal of developing advanced software to distinguish between genuine and artefact presentations [7].

EXPERIMENTAL METHODS

Raw data on fingerprint 3D structure was captured using the David Structured Light Scanning (SLS) system and David 3 software. The relative position of the camera, object, and scanner, as used in this study, is show in Figure 1.

Figure 1: Schematic of SLS setup.
3D scanning curved objects with micron sized features presented challenges related to camera resolution and field of focus. Also, scanning a finger requires multiple individual scans as only a fraction of the surface can be captured in a single one. David 3 software was used to merge collected scans and create a single 3D mesh. This 3D mesh was then used to generate the digital file for 3D printing, including editing for quality and format.

Solid Concepts, a rapid prototyping service, was selected primarily due to printer availability. The PolyJet™ HD from Objet was chosen as the target printer for its small z-layer thickness (16µm) and tight x-y plane tolerance (±127 µm) [8]. This printer uses a process similar to inkjet printing: Micron-sized droplets of a photopolymer are deposited by a motor then cured in position with a UV light [9]. Any support material used to print complex parts is washed away following printing.

In the course of this study, two iterations of 3D printed molds were produced. Both were used to fabricate biometric artefacts using methods described in the literature for cooperative molds. Biometric presentations from fabricated artefacts were captured using an FBI Appendix F certified optical fingerprint scanner.

RESULTS: FIRST ITERATION OF THE 3D PRINTED MOLD

The first iteration 3D printed mold was printed at a 1:1 (life size) scale. The 3D mesh file used for printing was based directly on the 3D scanned finger data. The resulting mold (Figure 2) effectively replicated the overall finger size and shape; however, fingerprint ridges were absent from ~80% of the fingerprint area.

Figure 2: First iteration 3D printed mold, locally contrast enhanced using CLAHE to better show surface details.

Ridges and valleys that were present in the mold and its corresponding artefact were reproduced at the correct scale. However, due to introduced topology from the 3D printing process, the first iteration 3D mold was unable to produce artefacts of a sufficient quality for spoofing applications.

Figure 3 shows the effect of printer motor movement on droplet deposition in greater detail. The topology introduced by the motor movement obscured the faint appearance of ridges and valleys across the few areas of the fingerprint surface in which they appeared.

Figure 3: Macro image of mold showing introduced vertical topology, due to printer movement (illustrated in red), and true horizontal topology, representing captured and printed ridges/valleys (illustrated in blue).
Figure 4 shows the biometric presentation of an artefact created from the first iteration 3D mold. The few ridge and valley features identifiable in the presentation are near the top or sides of the print area. The core fingerprint section is missing level 2 fingerprint features. The ridge and valley structures that are present have continuous, introduced, intersecting features making genuine minutiae points difficult to detect. Artefacts fabricated from this mold are not viable for spoofing attacks.

This presentation neither passed the quality check nor matched the genuine biometric reference. Additional examination of the biometric presentation and mold confirmed that ridge and valley structures presented were replicated accurately.

RESULTS: SECOND ITERATION OF THE 3D PRINTED MOLD

The first printed mold yielded insight into the feasibility of printing such small features. This insight was used to redesign a second mold with more fingerprint features. The second printing included both an increased ridge to valley height difference throughout the biometrically important fingerprint area and an increase in scale from life sized (1:1 scale) to 1.4:1.

The second iteration 3D printed mold is shown in Figure 5. The mold exhibited increased feature size and had significantly more ridges and valleys present compared to the first iteration printing. Although the ridge flow could be easily detected within the second iteration mold, minutiae from ridge endings and bifurcations were more difficult to identify through visual inspection.

As in the first iteration printing, the second iteration of the 3D printed mold was used to...
fabricate an artefact for biometric testing. A rolled biometric presentation of the resulting artefact is shown in Figure 6.

Most biometric presentations from this artefact failed the quality check. Those that passed did not match the genuine presentation. This was attributed to missing genuine minutiae from the presentation and increased false minutiae attributed to defects.

A flat presentation and its corresponding detected minutiae are shown in Figure 7. Areas of unclear ridge flow appear as empty spaces. Most of the detected minutiae points do not correspond to genuine minutiae points and were likely introduced during the printing process.

A visual inspection of the second iteration 3D printed mold and the resulting artefact revealed that unlike the first iteration printing, the size and shape of reproduced ridges and valleys were inaccurate. In particular the ridge width is too narrow throughout most of the sample.

**DISCUSSION: 3D PRINTING OPTIMIZATION**

Current commercial 3D printers have reached a resolution and accuracy point where it is beneficial to experimentally determine their capability of reproducing a fingerprint on a 1:1 scale. The 3D printing specifications for the tested printer are shown in Figure 8 alongside the range of expected feature sizes within the population. The x-y tolerance is significantly smaller than average valley to valley distance [10] and the z-layer thickness is a fraction of the ridge to valley depth.

Both iterations of the 3D printed molds were examined to identify possible root causes for the lack of features present (first iteration) and the inaccuracy of features present (second iteration). It was determined that the main limiting factor is likely the x-y plane tolerance of ±127 µm. This resulted in the introduced topology overriding the ridge structures in the first iteration 3D printed mold and the inaccurately reproduced ridge and valley structures in the second iteration. The
inaccuracy of the second iteration 3D printed mold is likely due to the increased ridge to valley height providing a greater number of z-layers over which the x-y plane tolerance limits were amplified.

The challenge of producing a successful 3D printed mold, and thus artefacts, includes several restricting parameters. There is a minimum ridge height required to 3D print ridge flow within the mold. However, increasing ridge to valley height without substantially increasing ridge/valley width exasperates, rather than mitigates these issues.

The second iteration 3D printed mold, although optimized to overcome one restriction, did not result in an accurate artefact. A 3D printed fingerprint mold is the negative of the artefact features, i.e. the features that appear to be ridges in the mold are valleys in the artefact. As a result, the following were determined:

- Optimizing the mold design with the current state of commercial 3D printers has limitations.
- Tolerance in the x-y plane has a significant impact on ridge shape and minutiae points.
- Currently available commercial 3D printers cannot, at this time, fabricate a mold comparable to cooperative fingerprint molds.
- Modification of the mold to a flat presentation and modifying the printing direction to diminish x-y tolerance effects can potentially create a biometrically viable mold.

A topographically accurate mold is a complex structure with a global overall shape and fine structure. The problem can be simplified by using a flat representation of a fingerprint presentation. A flat representation could be better adjusted in the x, y, and z plans to minimize the impact of the x-y plane tolerance on mold accuracy. A mold produced in this manner would not be comparable to a cooperative fingerprint mold, nor contain enough features to perform rolled presentations on the sensor. However, this type of mold would be comparable to those derived from lifted latent fingerprints.

FINGERPRINT REPRESENTATION

FINGERPRINT RIDGE TO VALLEY DEPTH

Figure 8: Schematic of fingerprint ridge in relation to 3D printing technique specifications.
CONCLUSIONS AND IMPLICATIONS

The viability of fabricating a topographically accurate mold using 3D printing was investigated resulting in two iterative 3D printed molds. The first iteration 3D printed mold included some areas with accurately reproduced ridge and valley structures, but otherwise lacked fingerprint features. To address this issue the ridge to valley height difference was increased and a second 3D printed mold was produced.

The second iteration 3D printed mold contained significantly more ridges and valleys than the first; however the features were reproduced less accurately. Biometric presentations of an artefact produced using the second iteration 3D printed mold confirmed the presence of few accurate minutiae and a significant number of false minutiae introduced in the printing process.

The PolyJet™ HD printer chosen for use in this study has one of the smallest x-y plane tolerances among available commercial 3D printers; however accurate replication of ridge and valley structure at this scale is difficult. This study shows that commercially available 3D printers cannot print at the resolution necessary to fabricate fingerprint molds comparable to those made through cooperative methods.

It may be possible to print more accurate 3D molds than those produced in this study by using:

- Fingerprints with greater valley-to-valley width.
- Fingerprints with less ridge flow variation, such as those exhibiting arches rather than whorls.

However, such cases would not be representative of the general population and were therefore not explored in this study. Further evaluation of those cases may show that in select circumstances 3D printing can introduce novel vulnerabilities into biometric fingerprint systems.

Conducting biometric fingerprint system vulnerability testing remains a priority despite the non-viability of this artefact fabrication method. Advancing technology is a constant reminder that novel physical attacks are not a question of if, but a question of when. Consistent and timely testing allows for deployment of biometric systems that mitigate these potential risks.

KEY POINTS

- Using 3D printing for mold fabrication did not result in a mold comparable to cooperative molds described in the literature.
- Current 3D printing process specifications contributed to the quality and extent of minutiae replication.
- Commercially available 3D printers cannot currently print non-flat fingerprint molds.
References


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