Implementation of Biometric Verification of a Fingerprint Whose Image is Taken from a Glass Surface

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***Abstract* - Biometric systems often use the comparison of fingerprint characteristics for authentication and identification of persons, especially in mobile devices. This paper presents the procedures, devices, tools and algorithms that, with the use of non-forensic specialized devices, successfully capture a fingerprint from a curved glass surface using a mobile phone's digital camera and create a 3D model of the fingerprint that successfully unlocks a Samsung Android mobile device.**

Keywords - biometric system, fingerprint biometrics, fingerprint sensor, fingerprints, bypassing fingerprint biometric system

I. Introduction

The practical purpose of this paper is to create a fake fingerprint from a latent fingerprint left on a surface. There are papers available that prove that fake fingerprints capable of bypassing biometric systems can be created using commercially available tools and products, however, most of them collect fingerprint data directly from the finger which requires cooperation from the host. [1] Publicly available research shows various fingerprint image extraction techniques [2] as well as methods of creating a fake fingerprint on different types of sensors such as capacitive, optical, and ultrasonic sensors.[3] Available research in this area shows that it is possible to fabricate a fingerprint using the printing technique in 3D format by creating the so-called golden finger [4]. Extensive insights into the morphogenesis of the fingerprint give us a very good explanation of why this part of the human body is relevant for authentication mechanisms (methods) [5].

This paper will focus on indirect methods of collection, more precisely from the picture of a fingerprint left on a surface, and ways to improve and digitally alter the collected data to be able to create a realistic 3D model from the picture. After the 3D model with enough details is created focus will be on identifying the 3D printing technologies capable of printing fake fingerprints and utilizing the same. The practical part will be divided into four parts. Collection – where the collection of the fingerprint data will be conducted and explained. Digital processing – where software tools needed for the optimization of collected data and creation of 3D objects will be identified and used. Creation – where 3D printing technologies needed will be identified, selected, and used to create a realistic fake 3D fingerprint. Testing - where a short test on a smartphone device will be performed to make sure we have created a fake fingerprint capable of bypassing the fingerprint biometric system used for security.

The guiding idea is to use only off-the-shelf commercially available tools and products to make working fake fingerprints at „home“ conditions.

II. Collection of the Fingerprint Data

When it comes to the collection of fingerprint data as mentioned before it can be done using one of the different types of sensors, it can also be done by using ink and paper, the oldest technique available. However, for all those types of collection, the host or holder of fingerprint data must be compliant to give his fingerprint. This practical experiment focuses on indirect methods of collection without the knowledge of the host. This means latent fingerprint is collected and processed.

A. *Size of the minutiae*

The average size of the fingerprint is 1.27cm x 1.77cm it is of course different in males, females, and children. The size of the ridge differs from 100μm (0.1mm) in width for smaller fingerprints in children or women to 300μm (0.3mm) in width for larger fingerprints in grown-up males. Ridge and valley together are usually around 500μm (0.5mm) wide. The depth of the ridges varies from 20μm (0.02mm) to 50μm (0.05mm). In essence, we are working with really small sizes that need to be accurately collected. The FBI standard for fingerprint collection is a resolution of 500 dpi, which means there are 500 dots of data in a line along one inch or 2.54cm. We have to take into consideration that the FBI takes fingerprint data with a direct method using ink and paper which produces perfect contrast and ideal scanning conditions. In a matter of collecting latent fingerprints where is expected to collect a certain amount of visual noise inside the fingerprint pattern, we would need to raise the amount of data collected so visual noise could be digitally removed. Because of this, we would need a camera that can take a picture of a standard fingerprint size in a resolution of 2000x2000 pixels [6].

B. *Different surfaces*

Professional forensic investigators can lift latent fingerprints from a wide range of surfaces, however, surfaces that are smooth, non-porous, and reflective are recognized as the best source of quality fingerprint data. In the experiment, the focus will be exactly on these kinds of surfaces because forensic investigators have at their disposal special tools and equipment while the experiment will be conducted using regular household items. Furthermore, the idea is to find the most suitable surfaces which are used every day. The three types of objects are selected from everyday life: wine glass, ceramic plate, and cutlery.

C. *The collection*

Initially, there were two ideas for the collection of fingerprints. The first was to take a photo of fingerprints left on the mentioned surfaces, the photo had to be excellent capturing all minutiae details with good contrast. The second idea was to dust the fingerprint with baby powder, collect it using transparent tape, paste it on dark background and try to scan it using the all-in-one printer. While the first method was successful the second method failed, because it was performed with a white baby powder which did not collect enough minutiae details when transported with transparent tape to the black surface. The experiment was continued using the first method.

Tools used for the collection are the iPhone 12 pro max - smartphone camera, as a camera for taking fingerprints, baby powder as a dusting powder, a make-up brush for dusting, and a simple standing lamp as a light source. The most important tool in this experiment, is the smartphone camera, with 12 megapixels and a resolution of 3024x4032 pixels. All mentioned tools can be found in a regular household.

Original idea was to collect the fingerprints from a wine glass, cutlery, and a ceramic plate. Collection from the wine glass and cutlery was successful while collecting from the white ceramic plate yielded no results because no matter what set up the light source, the fingerprint would be visible with the naked eye but not with the camera. In the case of a wine glass, the surface was transparent and allowed to focus of the source of light at an angle that made the fingerprint visible to the camera, in the case of cutlery the surface was reflective with a darker background which also made fingerprint details visible at specific lighting. In the case of the white ceramic plate, the surface was smooth and non-porous but not necessarily reflective with a white background which made the fingerprint not visible to the camera. The experiment was continued with wine glass and cutlery as surfaces to collect the fingerprint.

The first assumption was that fingerprints had to be dusted to be visible to the naked eye and camera (Figure 3, Figure 4). However, in a dark environment with the light source carefully positioned it is possible to make good photographs with a satisfying number of minutiae details without dusting the fingerprints (Figure 1, Figure 2).

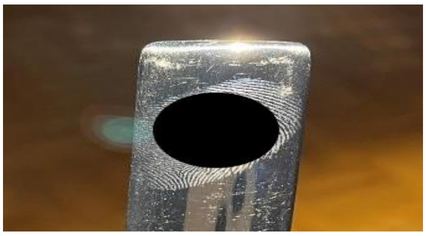

Figure 1. Fingerprint on cutlery without using the dusting powder

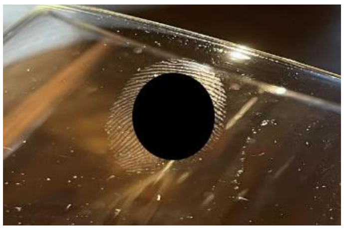

Figure 2. Fingerprint on wine glass without using the dusting powder

In the second round of fingerprint collection, baby powder was used with a makeup brush to highlight the ridges and valleys of the minutiae. The skin on the fingertips leaves small amounts of oil and sweat when pressed against smooths surfaces, fine powders like baby powder stick to the oils and sweat and enhance the fingerprint visually.

Figure 3. Fingerprint on cutlery using the dusting powder

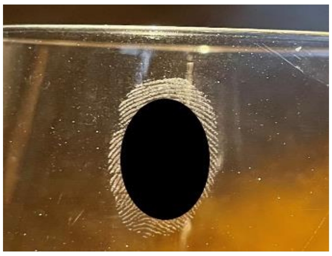

Figure 4. Fingerprint on a wine glass using the dusting powder

One thing that is important to do while taking a picture of a fingerprint is to measure the exact size of the fingerprint (Figure 5). The length and width of the fingerprint should be measured precisely because those are the only measurements that can be taken and based on that ratio the correct minutiae size will be replicated later in the process. It is not possible to measure the depth of the valleys or the height of the ridge.

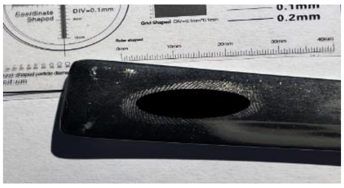

Figure 5. Taking fingerprint measurements

III. DIGITAL PROCESSING

After the fingerprint is collected with a satisfying number of minutiae details visible, the fingerprint picture will be optimized for crating a 3D fingerprint model.

A. *Photograph optimisation*

When fingerprints are collected by the police black or blue ink and white paper are used to produce an image of the fingerprint with great contrast so even the smallest details are distinguished. Considering this, the first thing to do in a latent fingerprint image is to enhance the contrast to make the ridge details more distinctive. For this task, photoshop software Adobe Photoshop

version 23.1.1. was used. In the case of latent fingerprint photographs, there is a lot of visual noise available and it should be reduced to the minimum. Because of this, the fingerprint image is converted to grayscale, and cropped for all excess image areas that are not representing information about fingerprint ridges or valleys (Figure 6, Figure 7, Figure 8). Also, Adobe Photoshop offers an option of image upscaling with a help of AI, this is making the picture clearer with a help of one of the offered resampling algorithms.

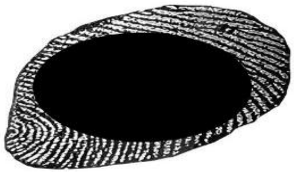

Figure 6. Latent fingerprint image in grayscale with enhanced contrast

It is really important not to bend the image while resizing because if there is a change in the proportions of the image, the most important data which makes fingerprints unique is lost. The scaling should be done by maintaining the aspect ratio regardless of the image size or shape.

Concerning digital optimization, it made little to no difference if a photograph taken using the baby powder or without it is used. This is mainly because photographed oils from skin ridges stand out in white color which when converted to grayscale produces the same contrast as photographs where the baby powder is used for enhancement.

Similar to this a fingerprint picture can be further enhanced using filters available in Photoshop which create a fingerprint picture with clear ridges and valleys without shadows, however, when this picture is used to mesh to a 3D model a lot of data about the depth of valleys is lost. This makes the 3D model have steep distinctions between ridges and valleys. Nevertheless, this kind of picture could be used to store and represent fingerprint data in 2D format.

Figure 7. Fingerprint picture with just minutiae data

B. *Creating a digital 3D model*

The next step in creating a fake fingerprint is to create a 3D model from a 2D photograph. There are existing research papers that describe a process of successful creation of the fake fingerprint when a real fingerprint is used for mold creation [7] and according to the Encyclopedia of Biometrics [8], there are three different methods and detection levels for fingerprint spoofing. Having that in mind it was decided to create a 3D mold for the fingerprint rather than printing the fingerprint itself. This is mainly because flexible materials like liquid latex or fabric glue can be used to create a fake fingerprint that can be attached to the real finger, for a more realistic representation of the fingerprint in a sense of temperature and conductivity.

Many different software solutions have been tested to create a satisfying 3D model of the molds. In Photoshop adobes 3D extrusion, the option works in a way that on a grayscale image, it makes ridges from white parts of the image and indentations from dark parts of the image. This in theory is exactly what we need but the final result was a model of the fingerprint which consisted of spikes where minutiae should be while valleys details were visible. Nevertheless, we have saved the file ready for 3D printing to see the final product when it is printed with a 3D printer.

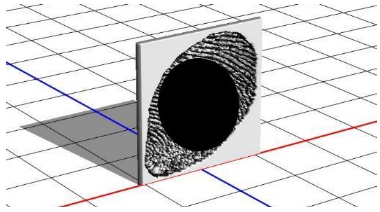

Figure 8. 3D model of the fingerprint made in Adobe Photoshop

After having experimented with other software like Blender and Meshroom it was decided to use a simple software initially developed to create a 3D relief on surfaces from a photograph (Figure 9). The software mentioned is "Photo ToMesh" by Ransen Software. Although its main purpose is to make personalized coffee mugs and medals it has served the purpose of creating a fingerprint mold perfectly. The software also offers an invert option which was used to invert ridges and valleys which made the creation of 3D printed mold from fingerprint pictures much easier. Photo ToMesh automatically converts the image to grayscale while preserving a lot of fine detail information about minutiae.

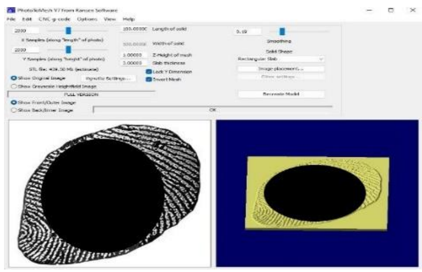

Figure 9. Photo ToMesh software - creating a 3D fingerprint mold

After the 3D object is created in Photo ToMesh it can be saved as an STL file which can be used by the majority of slicing software in a preparation for 3D printing.

Throughout the process of digitally optimizing the picture and creating a 3D model, it was important to preserve the correct size ratios because the biggest obstacle to tackle in the process was creating a fake fingerprint of the same size as a real fingerprint. Even when the photograph was upscaled and the resolution was enlarged two times the ratios remained the same. All this was done to scale the fingerprint mold to the correct size just before printing to preserve the greatest amount of detail possible.

C. Creating the fingerprint – 3D printing

The final phase in fingerprint creation is 3D printing the fingerprint mold. To do this we had to identify the 3D printer with the capability of printing small minutiae size dimensions accurately.

IV. Introduction to 3D printers

Generally, there are three biggest groups of 3D printers available commercially: FDM, SLA, and SLS printers. Each of these groups has its specific usage, advantages, and disadvantages according to what we have selected as the best printer for printing fingerprint mold. Layer thickness plays a big role in 3D printing precision, because of this every 3D object has to be sliced using the slicer software to a specific layer height just before printing.

Fuzed Deposition Modeling or FDM printers rely on heating a filament and creating a thin layer of material which immediately hardens to create layers. The filament is loaded in a form of a coil that goes through the nozzle which heats it and positions it carefully to create an object. These kinds of printers are affordable but are not precise with the best ones having a layer thickness of 0.1mm. Also, the surface of the objects printed with FDM printers is jagged and rough because of the way the layers of hot filament are placed on top of each other. Because of the low precision and rough final product surface, it was concluded that an FDM printer would not be able to print a fake fingerprint mold with a satisfying level of detail.

Selective Laser Sintering or SLS printers use high voltage laser to heat a powder-like material into solid layers. Each new layer is a new layer of powder glued to the previous one by applying heat with a laser. This enables SLS printers to work with harder materials like metal which is also the main advantage of SLS 3D printers. The surface of the final product from these kinds of printers is jagged and rough but can be polished after the material is completely cured. Precision is very good ranging from 0.08mm to 0.1mm layer thickness having in mind that products are cured after printing in a high-temperature oven which completely binds the layers. The main disadvantage here is price and size because of what SLS 3D printers are primarily used for industrial purposes. Rough final product surface and high costs are the main reasons SLS printers are not being used for printing fingerprint molds in this case.

Stereolithography or SLA 3D printers create the layers of a 3D object by curing the material in a form of liquid using UV light. These kinds of printers are the most precise with a layer height of 0.01m to 0.05mm. The main disadvantages of SLA printers are small working areas and the brittleness of printed objects while the main advantages are precision and price. Being that the width of the fingerprint ridges and valley range from 0.1mm to 0.3mm and the depth of valleys is from 0.02m to 0.05mm the SLA 3D printer is selected as the best option to print the fingerprint mold. [9]

A. Selecting the SLA 3D printer and resin

Stereolithographic printers are in the 3D printing community usually called resin printers because they are creating objects from a liquid similar to resin. Although this group of printers is known for precision one of the main characteristics by which the price of the printer is determined is the size of the working area. Because fingerprints are small in size, it was decided to select the printer with a small working area but with the best precision possible. For these reasons, Phrozen Sonic Mini 8K was selected as the printer of choice (Figure 10). The print volume of this printer is 16.5 x 7.2 x 18 cm which is more than enough to print multiple fingerprint molds. A field in which this printer is superior to all other commercially available SLA 3D printers is precision. With a layer thickness starting from 0.01mm and XY resolution of 0.022m m, this is one of the most precise 3D printers available. The precision is achieved by LCD type screen which is 16.5 x 7.2 cm in size and has a resolution of 7500 x 3240 pixels. The LCD screen emits UV light and cures the resin to create layers of an object.

Figure 10. Phrozen Sonic Mini 8K 3D printer [10]

When talking about 3D resin printing it is important to mention that there are many different kinds of resin, some are specially made to be flexible, others to be strong and there are a few resins that are made for high-precision printing. While it was possible to get the 3D printer with 8K resolution it was not possible to acquire an 8K resin for this experiment. For printing all of the fingerprint molds, the Creality Standard Rigid Resin Plus was used, this is an affordable resin capable of achieving standard levels of precision.

B. 3D printing the molds

Just before the printing, a 3D object has to be prepared with slicer software, this type of software creates layers from the 3D object and saves it as instruction for the 3D printer. The software that has been used in the experiment is called Chitubox and it comes with a Phrozen Sonic Mini 8K printer. Many instruction properties like exposure time and layer height have to be set correctly for a successful 3D print. Among many others, two of the most important features that Chitubox offers are scaling and mirroring 3D objects.

With measurements taken while photographing the fingerprint, it is easy to scale the fingerprint to the correct size. In this example, the length measured on one of the fingerprints is 25mm. When loaded in the Chitubox, the program showed the size of the 3D model much larger when measured in millimeters. The length of the fingerprint is presented as a Y axis, and scaling it to the correct measurement with a locked ratio provides the correct size of the fingerprint including the width of the minutiae (Figur 11).

Another important feature mentioned above is mirroring, to get the correct fingerprint shape after molding the initial shape has to be mirrored. This happens because a picture of the fingerprint is taken from the front and from that picture, the mold is printed rather than the fingerprint itself.

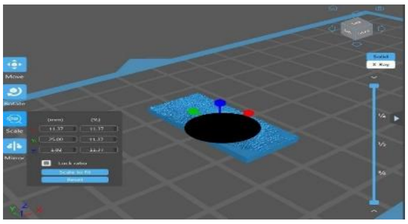

Figure 11. Scaling the model to the correct size in Chitubox

The one thing that was not possible to measure is the depth of the valleys, in the 3D model this measurement was adjusted by changing the mesh height. Experiments were done with different mesh heights to find appropriate valley depths which will define the height of the ridges once the molds are cast.

After a few failed attempts to print, mainly because of the wrong exposure time settings for a very small layer height, it was possible to successfully print the 3D model of the mold. Even though it is not visible from the pictures, the level of detail in these molds is very high (Figure 12, Figure 13). The layer height of the print was set to 0.02mm with an exposure time of 3.4 seconds per layer which made the print time 5 hours and 12 minutes long.

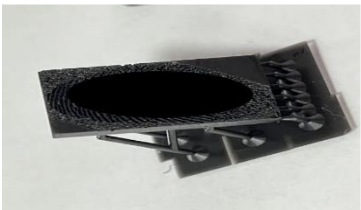

Figure 12. 3D printed fingerprint mold 1

Figure 13. 3D printed fingerprint mold 2

C. Casting the molds and adjusting

After the molds have been printed, support was removed, and cast the molds using liquid latex. Figure 22. shows four different fingerprint molds cast with liquid latex. Numbers one and two are molds of the same fingerprint with a difference in mesh height or valley depth, the same is true for numbers three and four. Mesh height in molds one and three is scaled to 1.0 being that it differs from minutiae to minutiae and it would not be correct to set a fixed value for all minutiae. Number 1.0 on a scale represents values software for 3D extrusion has made based on photograph shadows. Molds number two and four have mesh height scaled to 1.5 which means they have 50% higher ridges (Figure 14). This was done to detect perfect mesh height in future casts easier.

Figure 14. 3D printed fingerprint molds cast with liquid latex

Fake fingerprint minutiae were clearly visible, however, due to the sharp mold edges, the latex did not shape very well. Also, a mesh height of 1.5 or 50% bigger was a clear failure because the ridges were too big, and due to the sticky nature of latex, they ripped off while disassembling. A mesh height of 1.0 was good but the ridges were still too sharp to mold the latex perfectly.

To fix the problems mentioned above the smoothing option in Photo ToMesh software was used. This option created rounded edges and combined with the antialiasing option in Chitubox resulted in smoother layer transitions while printing.

After the second set of molds was printed, it was filled half of them with liquid latex and half of the with fabric glue. Drying the fingerprints lasted 12 hours after the molds were separated from the casts. There was no tearing and ripping while disassembling fake fingerprints from molds and the details on the fingerprints were of much better quality (Figure 15). Also, fabric glue molds have an overall better quality of detail for what reason they were selected for testing.

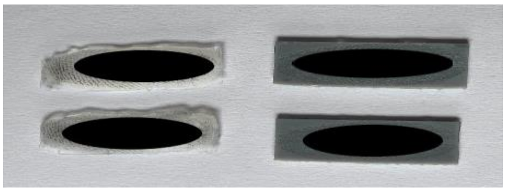

Figure 15. Molds and fabric glue fake fingerprints that were successful in unlocking the smartphone

D. Testing the fake fingerprints

Fake fingerprints were tested on a Samsung Galaxy A32 5G which uses a capacitive fingerprint scanner for fingerprint authorization. The success rate was 23% measured by 100 attempts to unlock the phone. It is important to mention that the success rate on a real fingerprint enrolled into the security system was only 54% which made fingerprint authentication with a real fingerprint fail almost every other attempt on this device. Also, during the tests, it was noticed that marginal parts of fake fingerprints work much better than the center of the fingerprint. We have figured that this is connected to the angle of taking the picture of the fingerprint. It happens because we cannot take picture of the fingerprint from the perfect 90-degree angle, we have to adjust the angle of taking a picture to the visibility of the latent fingerprint. As a result, we usually take pictures from angles around 60 to 70 degrees which makes the final picture just like a fingerprint mold slightly out of proportion. That is why parts of the fingerprint whose picture has been taken from an angle closer to 90 degrees work better.

The whole process of creating a fake fingerprint lasted about 17 hours, where most of the time was consumed on drying the molded fingerprints (around 12 hours) and printing the molds (4 hours). Taking the picture of the fingerprint, digitally optimizing it, and creating a 3D object ready for printing takes less than an hour.

Extensive testing on all types of fingerprint sensors is needed to further adjust and enhance this method of creating fake fingerprints.

V. CONCLUSION

The experiment aimed at collecting fake fingerprints using commercially available tools and products was conducted. The focus of the experiment was to collect fingerprints from everyday objects such as a wine glass, ceramic plate, and cutlery. The experiment used a smartphone camera, baby powder, a make-up brush, and a standing lamp as a light source. The results showed that the collection of fingerprints from a wine glass and cutlery was successful, but from the ceramic plate was not. The optimization process involved using baby powder and Adobe Photoshop to enhance the details of the fingerprint and create a clear 2D representation.

To create a digital 3D model of a fingerprint, the experiment used Photo ToMesh software and an SLA 3D printer. The Phrozen Sonic Mini 8K was selected as the printer due to its small size and precision, while the Creality Standard Rigid Resin Plus was used for printing the molds. The fingerprint was scaled and mirrored in Chitubox slicer software to get the correct size and shape. However, the final molds had issues with sharp edges and high ridges, which were addressed using smoothing and antialiasing options in the software.

In conclusion, the experiment demonstrated that commercially available tools and products can be used to collect and create fake fingerprints, but preserving the correct size ratios and preserving detail was a challenge. The optimization process and 3D printing process required careful consideration of the tools and techniques used to achieve the best results.

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