Reduced Contact Lifting of Latent Fingerprint

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***Abstract*—Fingerprint is the most well-known and successfully deployed biometric modality due to its ease of acquisition, established use, acceptance and high recognition rate (i.e., robustness). One form of fingerprint is called latent fingerprint. Despite its subtle appearance, latent fingerprint is commonly left all over the place unintentionally, including water tap, door knob, elevator button, and cup. To lift these latent fingerprints, the conventional approach involving the process of powdering and taping may physically damage the latent fingerprint. Therefore, a reduced contact method is desirable. This study focuses on latent fingerprints left on curved surfaces, such as water tap, door knob, and water flasks. The latent fingerprint is uncovered (i.e., made visible) by means of fuming, and the end product is captured by a camera. A geometrical compensation method, which takes the curvature of the surface as input, is formulated to geometrically correct (i.e., flatten) the image. The corrected image is further enhanced and sent for matching purpose. Experiments show that the application of the proposed geometrical compensation method is able to flatten the fingerprint image uncovered from a single directional curved surface and improve its matching score.**

I. Introduction

A latent fingerprint is the print left from a finger on a surface which is not visible to the naked eye. Making latent fingerprints visible and subsequently lifting it has an important role in crime scene investigation. There are some conventional methods for doing this such as powdering the print and lifting the revealed print with tape. The problem of powdering and taping is that once lifting failed, the process cannot be repeated. In a more conservative method, instead of using tape, lifting can be done in a contact-less manner, such as photographing the revealed print using a camera. However, this solution is not directly applicable for prints left on curved surfaces due to the distortions caused by the curved surface in the areas far from the center of the captured image.

This paper proposes a method to compensate for the geometrical distortion in a fingerprint image taken from a print left on a single directional curved surface. As a requisite to do so, we also propose a method to calculate the curvature of the curved surface. By first obtaining the radius, the fingerprint image can then be non-linearly stretched. For evaluation purpose, a fingerprint matching algorithm is deployed to examine the improvement in matching capability of the processed image with its rolled print counterpart.

The rest of this paper is structured as follows: Section 2 briefly reviews a latent-to-rolled fingerprint matching algorithm. Section 3 describes the latent print lifting method used in our experiment which is to minimize the physical interactions with a latent print. Section 4 proposes a geometrical compensation method to stretch the latent print image. Section 5 details the experimental setup as well as the results. Finally, discussions are presented in Section 6 and conclusions are drawn in Section 7.

II. Fingerprint Matching Algorithm

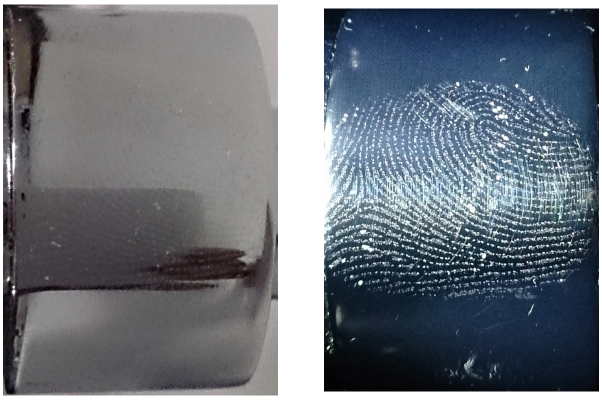
In this work, we consider the minutia cylinder-code (MCC) proposed by Cappelli et al. [1] to match latent fingerprint to rolled fingerprint, which is very relevant to the scenario we consider in this paper, i.e., crime scene fingerprint recognition. MCC uses minutiae attributes of a fingerprint, including minutiae distances (x, y) and direction θ, to make a three dimensional feature (i.e., cylinder) for representing each minutiae. The cylinder for each minutiae is constructed and compared to calculate the matching score between two fingerprints. The number of blocks and layers of cylinders, and its validity are based on the threshold and parameters used. For the detailed descriptions, interested readers are referred to [1]–[4].

III. Reduced Contact Latent Print Lifting

This section describes the method used to reveal and lift a latent print from curved surfaces. Since revealing and lifting processes can cause distortion in the pattern of a fingerprint, our aim is to lift a print with minimum physical interaction with the print to suppress the distortion caused.

A. Revealing print

The purpose of this step is to maximize the contrast between ridges and valleys of the print left on a curved surface in order to prepare it for lifting. Here, we use cyanoacrylate to reveal the latent print. The area with a print mark on the curved surface needs to be in touch with vapored super glue. To maximize the polymerization speed of print residue with cyanoacrylate, the target area will be enclosed as small as possible by using a cardboard or plastic bag containing a few drops of super glue inside the chamber. The print will be revealed in 1 to 2 hours. To further shorten the time, we can expose the closed box to some external heat which can be achieved by attaching an iron rod to one of the sides of the enclosed surface or blowing hot air over the box using hair dryer.



(a) Image captured under ambient light

(b) Image captured with flashlight

Fig. 1: Images captured from a fume-developed fingerprint on a curved surface shown in (a), under ambient light, and (b), under flashlight's light. In (b), the surface is surrounded with a uniformly colored paper to eliminate the shadows exist in the center of (a).

Fig. 2: Cardboard box and flashlight utilized in this study for revealing and enhancing fingerprints.

B. Lifting print

The developed print can be lifted by a camera. Since the developed print is white, depending on the color of the surface, the contrast between ridges and valleys in the captured image might be insufficient under the ambient lightning condition. As such, the application of a flashlight with proper lighting angle during photo capturing can improve the contrast. Fig. 1 shows images taken from a developed print, each lifted under ambient light (see Fig. 1(a)), and flashlight's light (see Fig. 1(b)). Fig. 2 shows the cardboard and flashlight used in revealing the latent print.

IV. Geometrical compensation

The image captured from a curved surface has distorted print pattern especially in the areas far from the center of the image. This section details the steps in flattening this distorted image by stretching the image. To do so, first the radius of the curved surface needs to be estimated. The image is then stretched in the direction of the curvature to be flattened.

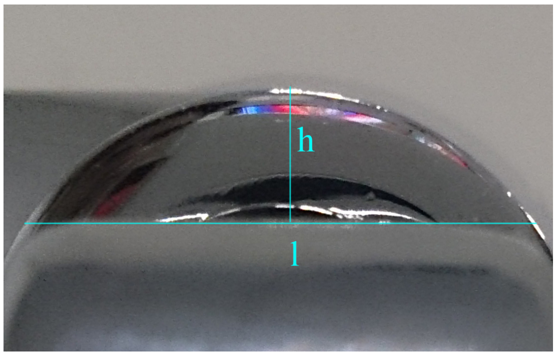


Fig. 3: Image captured from the side of a water tap with cord length l and arch height h.

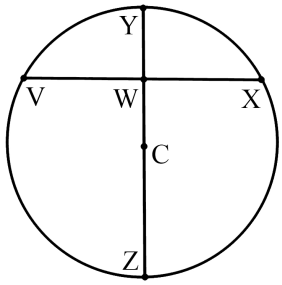


Fig. 4: A circle centered at C with intersecting chords. VX, YW and CZ represent chord length, arch height, and radius, respectively.

A. Curvature estimation

In most cases, the full diameter of the curved surface is accessible and can be measured directly by a ruler, e.g., water glass. For the case where the full diameter cannot be measured, an image from the side of the curved surface is captured. Fig. 3 shows the sample of an image captured from the side of a water tap. The chord length is labeled by l, and the arch height is labeled by h. By having cord length and arch hight, the radius can be calculated. Fig. 4 shows a circle with intersecting chords similar to the image captured from the side of a curved surface shown in Fig. 3. Here, $VX = l$, and $WY = h$. Based on the intersecting chords theorem [5], $WV \times WX = WY \times WZ$. By having $WV = WX = l/2$ and $WY = h$, we can substitute l and h into the theorem and obtain $WZ = l^2/4h$. The diameter of the circle becomes $WY + WZ = h + WZ$. Therefore, the radius of the circle r is computed as:

$$r = \frac{4h^2 + l^2}{8h}. \tag{1}$$

B. Non-linear stretching

By using the radius of the curved surface, the image captured from the curved surface can be stretched and flattened. Fig. 5 shows the representation of the curved surface with radius r. Here, c is a section of this curved surface, and f is the image of this section that will be captured by camera. Since $f = r\sin(\theta)$, therefore $\theta = \arcsin f/r$. On the other hand, $c = r\theta$. Hence, for f, $c(f)$ can be defined as:

Data: $s_{i-1} = \sum_{i-1} f_i,$ and$f_i = 1$
Result: The optimum size for segment f_i, and the size that it needs to be stretched to (i.e., c_i)

```
c_i = c(s_{i-1} + f_i) - c(s_{i-1})
while c_i - f_i < 1 do
    f_i = f_i + 1;
    c_i = c(s_{i-1} + f_i) - c(s_{i-1})
end
return f_i, c_i;
```

Algorithm 1: Calculation of f_i, and c_i

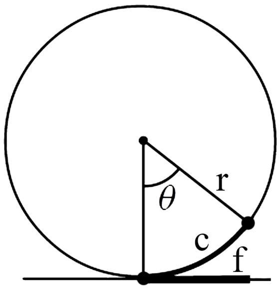


Fig. 5: Representation of a section of a curved surface with radius r, by c, image of this section, by f.

$$c(f) = r \arcsin \frac{f}{r}. \tag{2}$$

When moving away from the center of the image, θ increases which leads to an increase in the required stretch, c. Hence, the area far from the center of the image needs to be stretched more, and vice versa. In other words, a non-linear stretch is applied, and the amount to be stretched depends on distance from the center of the image. Therefore, to improve this method, the image is split into several segments and stretched separately. For an image with multiple segments (indexed by i), let f_i denote the width of each segment, and let c_i denote the width to be stretched for f_i. Specifically, c_i is computed as:

$$c_i = c(\sum_i f_i) - c(\sum_{i-1} f_i). \tag{3}$$

To further improve this method, the segment's size has to be in relevance to the required stretching size. Therefore, by moving away from the center, the image needs to be segmented into smaller segments. This helps in minimizing the required stretching size for all the segments and as a result, minimizes the quality loss. To do so, non-linear stretching will be used. At first, we split the image into two halves, i.e., F1 and F2. Each half starts from the center with no distortion, and gradually moving to the edge where maximum distortion is observed. Next, the first half will be segmented. Starting from the non-distorted edge, f_1 with the width of 1 pixel is selected, and c_1 will be calculated. The size of segment f_1 will be increased until the inequality below is satisfied for $i = 1$:

$$c_i - f_i \geq 1 \tag{4}$$

Algorithm 1 summarizes the aforementioned procedures. Basically, after the first segment f_1 is stretched to c_1, the pixel immediately after f_1 is selected as f_2, and the the value of c_2 is computed using Algorithm 1. f_2 is then stretched by c_2, and the process continues for f_i using c_i until the entire half image is processed. The stretched segments is merged together to make the flattened half, $F1$:

$$F_1 = \bigcup_i c_i \tag{5}$$

The flattened image of the second half, i.e., $F2$ is obtained in a similar manner. Eventually both flattened halves are merged to make the flattened image F:

$$F = F_1 \bigcup F_2 \tag{6}$$

V. Experiments

This section details the setup of tools, evaluation of the matching scores, as well as quality analysis of the prints.

VI. Setup and Tools

Our fingerprint revealing tools include super glue, a card board box and a flash light (see Fig. 2). Sony Xperia ZR mobile phone is used for lifting the prints by capturing images of the prints. Magnetic powder, and a magnetic wand, (see Fig. 6) are used for lifting the rolled fingerprints, which are the counterparts of the latent prints. HP DeskJet F4185 is used for scanning the lifted rolled fingerprints. Sony VAIO VPCS125FG Core i3 with Microsoft Windows 8.1 and Adobe Photoshop CS6 are used for photo editing. Microsoft Visual Studio is used for running the fingerprint matching tests.

In our experiments, rolled and latent prints are sourced from the thumb and middle finger of four volunteers. A rolled fingerprint is an impression of a finger on a flat surface by rolling the finger. We used three curved surfaces with different curvatures, including water tap, jam jar and medicine bottle (see Fig. 7), to conduct our experiments. Four volunteers participated to supply fingerprint impressions on these surfaces. 9 unique thumbs and 1 middle fingerprint samples were collected. After leaving the impression on the curved surface, each print was developed and lifted as we previously described. The lifted image was flattened with the proposed geometrical compensation method. Since the ridges in the developed prints are in white color, all the images are inverted, i.e., a negation process. For each fingerprint, a rolled print impression were also made on a paper. Magnetic powder was applied on the impression to reveal the fingerprint, with the aid of a wand to evenly distribute the powder. The developed fingerprint is scanned at 4800 dpi. All the prints were resized to 1000 dpi by Photoshop for further evaluation.

Fig. 6: Magnetic powder and magnetic wand utilized for capturing rolled fingerprint impressions.

Fig. 7: Medicine bottle, water tap, and jam jar utilized in experiments as a curved-surface object respectively from left to right.

Specifically, we compute the matching score between the lifted image and its rolled counterpart. To perform the matching, first we automatically extract the minutia feature template of the prints using VeriFinger [6]. Then we use MCC SDK to obtain the matching score. This is to evaluate the effectiveness of proposed method when the processed image is directly fed into the Automatic Fingerprint Identification Systems (AFISs). The experiment results are reported and discussed in the following subsections.

A. *Matching Curved and Flattened Fingerprints [1]*

MCC SDK v1.4 [8] which implements minutia cylinder-code (MCC) [1] for fingerprint matching is deployed to match the curved and flattened fingerprints to their rolled counterparts. The purpose of this step is to verify the feasibility of the proposed geometrical compensation method, and to evaluate the improvement of matching scores after the application of the proposed method.

Here, we examine the changes in matching scores. First, minutia features of both curved and flattened prints are marked automatically and extracted by using the VeriFinger SDK [6]. Matching scores of these prints with their rolled fingerprint counterparts are calculated and compared. Minutiae of rolled fingerprints are manually marked. Fig. 8 shows four samples with their auto-marked minutia and the obtained matching score. The matching scores for all samples are recorded in Table I. Nine out of ten samples show an improvement in the matching score of the flattened fingerprint. The improvement in the matching score is similar across all three curved surfaces (each with different curvatures). It is because, for an image taken from a surface with higher curvature, less fingerprint pattern is available but more stretching is required. On the other hand, for a low curvature surface, less stretching is required but more fingerprint pattern is available, which will be corrected. These results suggest that the proposed method can be utilized to flatten the images taken from fingerprints left on a curved surface and help to improve matching scores.

VII. Discussions

Many of the surfaces that are prone to have latent fingerprints are not flat. For example, water taps, water glasses, cups, bottles and door knobs are some of the sources to find latent fingerprints. In forensics, in lifting a latent print, the concern is to minimize the damage on the print during lifting in order not to destroy the evidence. Being able to repeat the lifting is another goal. While capturing an image from a developed latent satisfies these goals, distortions of fingerprint pattern caused by the curvature of a non-flat surface is an obstacle for the implementation of these lifting techniques.

The proposed method lifts fingerprint image from non-flat surface with the aim to minimize the aforementioned distortions.

Application of super glue and flashlight for lifting contributed in reducing the contact to the surface while non-linear stretching minimizes the quality loss during the processing of the image. Specifically, non-linear stretching is achieved by segmenting the image into small units (down to the granularity of 1 pixel) for fine stretching purpose.

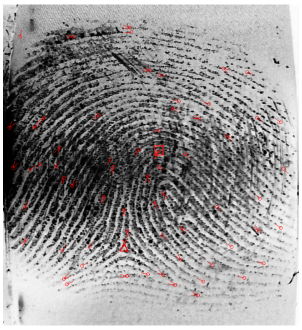
VIII. Conclusions

In this paper, a reduced contact method for lifting latent fingerprints is proposed, where non-linear stretching is performed to an image captured from a curved surface.

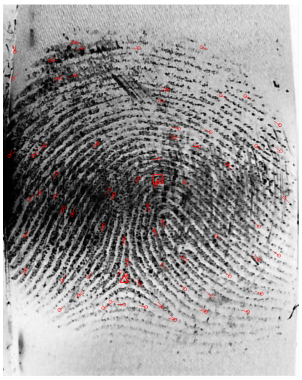
Experimental results show that, in general, verification of the flattened images using the current state-of-the-art fingerprint matching algorithm (viz., MCC) can be improved by applying the proposed method.

TABLE I: Matching Score of the camera-captured latent fingerprints with no correction, (i.e., before flattening), and with correction, (i.e., after flattening).

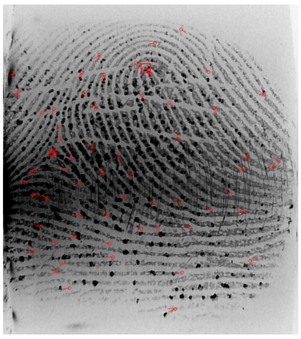
Matching Scores			
Sample	Camera-captured (no correction)	Camera-captured (with correction)	Radius (mm)
S01	**0.0122**	**0.0132**	13
S02	**0.0227**	**0.0229**	13
S03	**0.0164**	**0.0272**	13
S04	**0.0460**	**0.0499**	13
S05	**0.0899**	**0.0880**	13
S06	**0.0150**	**0.0168**	26
S07	**0.0373**	**0.0409**	26
S08	**0.0218**	**0.0257**	26
S09	**0.0299**	**0.0351**	23
S10	**0.0647**	**0.0793**	23



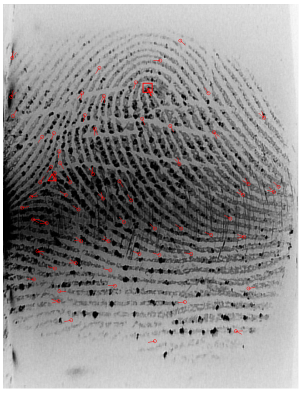
(a) S03
Score: 0.0164



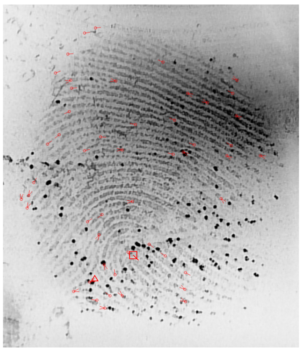
(e) S03 Flattened
Score: 0.0272



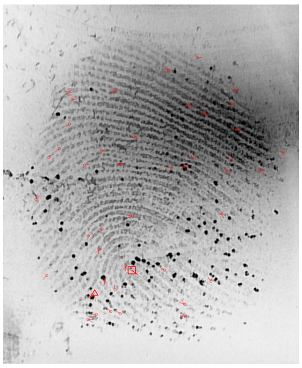
(b) S04
Score: 0.0460



(f) S04 Flattened
Score: 0.0499



(c) S08
Score: 0.0218



(g) S08 Flattened
Score: 0.0257

(d) S09
Score: 0.0299

(h) S09 Flattened
Score: 0.0351

Fig. 8: Lifted latents from tap, shown in (a), (b), from jam jar, shown in (c), and from medicine bottle, shown in (d), as well as their corresponding flattened image shown in (e), (f), (g) and (h), respectively. All the images are inverted and automatically marked by VeriFinger. Matching score of each print with its rolled counterpart is included.

To expand the implementation of this method, we are currently embarking on developing techniques to flatten two dimensional curved surface with improved curvature estimation. With the outcomes of this research, the following conclusions are drawn:

(a) Fingerprint images captured from a curve surface can be flattened by the proposed method, and;

(b) Curvature of the surface can be measured even without having access to the full diameter of the curved surface;

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