A New Scheme for Touchless Fingerprint Recognition System

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Abstract—**Fingerprint-based recognition systems are widely used in the field of biometrics. Most of the fingerprint sensors developed so far acquire fingerprint images through a solid plate of the surface, which degrades the recognition performance due to deformations. These deformations are caused by the pressure of the physical contacts that are costly and hard to estimate. In this paper, a touchless fingerprint recognition system is devised using a camera sensor to resolve this problem. However, this system raises some new problems such as defocusing, low ridge-valley contrast, 3D-to-2D mapping and so forth. Herein, adequate solutions will be discussed by introducing modified steps of the algorithm. Our proposed system is compared with the primitive touchless sensor with no manipulation and the algorithm of the preceding touch-based system, and future works are suggested.**

I. INTRODUCTION

As the automatic personal authentication became the essential technology in this era, fingerprints are one of the most widely used biometric features for personal identification and verification. So far, various types of sensors have been developed to acquire good fingerprint images with their appropriate virtuous characteristics. A good number of algorithms have also been proposed to achieve better authentication performance. In spite of all their algorithmic efforts to enhance the performance, there has been an innate problem of distortion in the fingerprint images captured by the preceding types of sensors due to the pressure of contact with the solid sensing plate. The distortion is quite significant because it affects the feature information being dealt with in the fingerprint recognition process and degrades the total performance. Unfortunately, this distortion is very non-linear and arbitrary, which makes estimation or compensation difficult and unreliable. Although many algorithms have been devised to overcome this problem [1], a large amount of cost and error still require further study.

Due to the inevitable distortions of the touch-based fingerprint images, there have been attempts to contrive touchless fingerprint recognition systems. Some sensors, such as the ultrasound sensor, work without touch, but their large size and production cost are impractical. Moreover, they also require a long capture time, which is critical for on-line authentication systems.

In this paper, a new touchless fingerprint sensor, which does not require costly equipments or restricted conditions, will be designed using a camera, and the algorithm to process the acquired images properly will be discussed. Section 2 refers to the distortions of the fingerprint images from the touch-based sensors. In Section 3, we explain the advantages and the drawbacks of the touchless fingerprint images and present a sensor design to obtain good images. Section 4 suggests solutions for image enhancement in algorithmic respects and introduces the problem of view difference. Finally, in Section 5 conclusions are drawn and future works are suggested.

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II. PROBLEM OF THE TOUCH-BASED SENSORS

When using the preceding touch-based fingerprint sensors, such as optical sensors or solid-state sensors, a user needs to place his or her finger skin on a solid sensing surface of the sensors. Because the fingerprint surface is not flat, a user is required to press down the fingerprint area onto the sensing plate to get the image, which is necessary to secure a sufficiently large common area between the input and the reference fingerprint images. The plastic distortions created by the contact pressure are usually non-linear in arbitrary direction and strength [1]. Moreover, the distortion occurs globally, while its deformation parameters could be different locally in a single fingerprint image. All of these factors make it difficult to estimate and compensate the distortions accurately and consequently deformation errors of the touch-based fingerprint sensors still remain. As shown in Fig. 1, two fingerprint impressions from one finger can result in different minutiae due to the different physical pressures.

III. TOUCHLESS FINGERPRINT SENSOR DESIGN

3.1 Overviews

We used a monochrome CCD camera to capture the fingerprint image in our touchless system. By using the camera, there is an evident advantage: fingerprint image acquisition without plastic distortion from the pressure of contact.

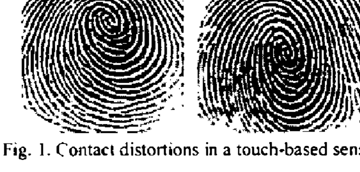
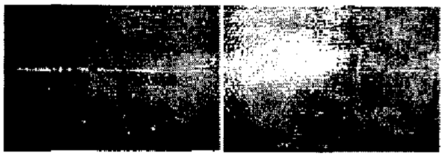


Fig. 1. Contact distortions in a touch-based sensor



(a) (b)

Fig. 2. Problems in touchless fingerprint images: (a) motion blur, (b) partial defocusing

Distortion-free fingerprint images are most desirable to acquire minutiae in the same relative location and direction at every instance and help the authentication system to have low FAR and FRR. Besides, the touchless fingerprint images are free of extra problems in hygienic user interface, maintenance, latent fingerprint problems, etc.

While there are some strong advantages, there appear new weak points such as motion blur, CCD background noise, Dof(depth of field) issue, non-uniform lighting, low ridge-valley contrast and so on (Fig. 2). In addition to the solutions for these problems, algorithmic amendments are needed in the process of image acquisition, segmentation, quality check, image preprocessing, ridge enhancement, etc.

3.2 Device Design

A touchless sensor is designed in two respects as follows to solve the new problems mentioned in Section 3.1.

A. Structure: Motion blur generally stems from the long capture time relative to the slight motion of the finger. Although the high-sensitivity CCD can handle fast shutter speed, it normally contains increased electrical background noise. Although a large aperture stop could be an alternative way to keep the shutter speed fast enough, it is unsuitable to guarantee the required Dof, which is important to keep the variation range of the finger position in focus. Hence, a small aperture as well as a fast shutter speed is essential, which leads us to conclude that a stabilizing apparatus and additional lighting gadgetry are necessary. For this reason, a finger support to decrease motion blur and a ring-type illuminator to obtain uniform lighting are adopted.

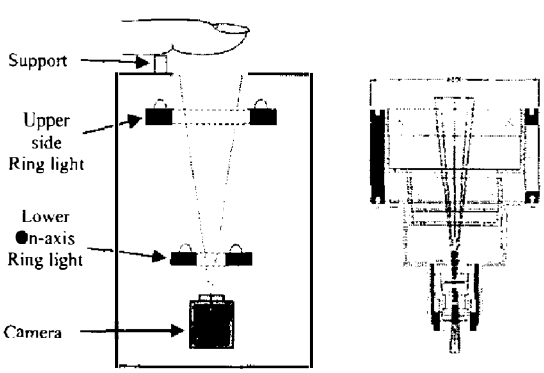


Fig. 3. Touchless fingerprint sensor: (a) structure, (b) double ring-type illuminator

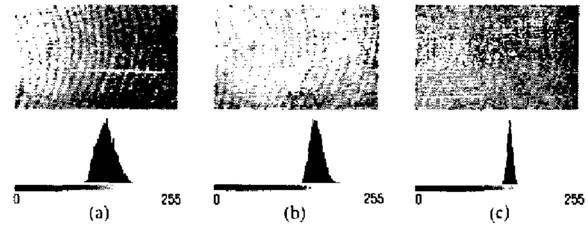


Fig. 4. Gray-scale histograms of the foreground from color filtered images: (a) blue filter, (b) green filter, (c) red filter

Fig. 5. A fingerprint image acquired by the proposed touchless sensor

Due to the convexity of the fingerprint surface, images acquired with the aid of a single illuminator lighting the center is not enough for the moderate quality of the peripheral fingerprint. Hence, an on-axis ring-type illuminator and a sub-side ring-type illuminator are assembled in a double ring-type structure (Fig. 3).

B. Color: Another obvious problem of the images from the camera is the low ridge-valley contrast. Through the experiments, we found that the long wavelength rays including the infrared ray tend to penetrate into the skin, and the epidermis of the ridge-valley pattern was of less clarity. To get a touchless fingerprint image with high contrast, a blue colored filter was installed. Blue light is adequate to get the most detailed fingerprint pattern response from the visible rays.

Another reason to employ blue light as the illuminator is that blue is the complementary color to yellow and red, which are the dominant colors of fingerprint skins. Fig. 4 shows that the image obtained using blue light shows the highest contrast.

In addition, a blue colored filter also helps to diminish the unnecessary lights from outside by cutting off the other wavelengths, which minimizes the interfering noise that deteriorates the acquired images. To supply sufficient amount of illumination, blue light LEDs (Light Emitting Diodes) are used as the light sources. The uniformly lighted fingerprint images with improved contrast are acquired as shown in Frig 5.

IV. APPROACHES FOR IMAGE ENHANCEMENT

A fingerprint image acquired through our touchless sensor is processed as depicted in Fig. 6.

4.1 Image Processing

While we designed a hardware scheme to acquire fingerprint images with less noise, high contrast and uniform quality, here

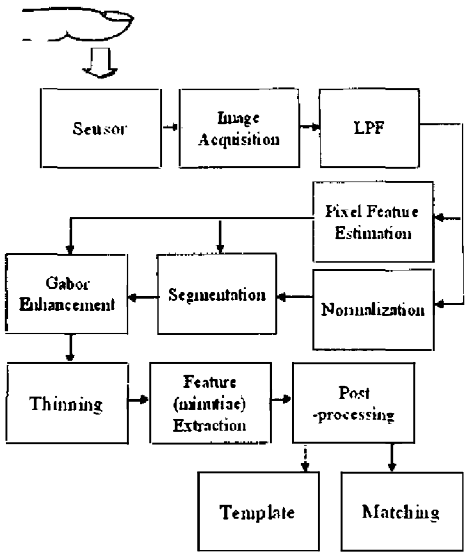
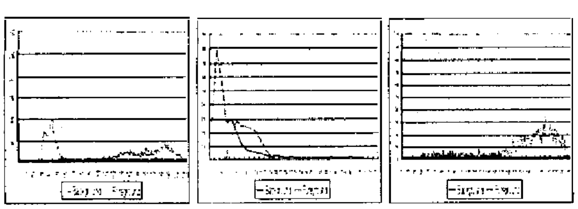


Fig. 6. Flowchart of the proposed touchless fingerprint system

is an approach to reduce noise in the respect of image processing. The low-pass filter such as the Gaussian filter is one of the most useful and simplest ways to reduce noise in one of the most useful and simplest ways to reduce noise in image processing [2]. An adaptive but costly method using directional mask was proposed in [3], but we examined average ridge periods and set the size of the low-pass filter mask. The block-wise ridge frequency and the ridge orientation are obtained in multi-scale hierarchical estimation [4]. Block-wise normalization for contrast enhancement is applied afterwards [4].

4.2 Image Segmentation

Pixel features [5] are the simplest and frequently employed measures for segmentation. They are extracted from the images to yield proper classifier parameters in preceding touch-based systems. As studied in [5], the most useful distinctive pixel features are the mean, variance, and coherence of each pixel block. Here, those block-wise pixel features still hold their characteristics for foreground segmentation. As values are examined from the manually segmented images, those block-wise pixel features of the foreground and the background are shown in Fig. 7.



(a) (b) (c)

Fig. 7. Sample histograms of block-wise pixel features from manual segmentation of an image: (a) mean, (b) variance, (c) coherence

A. Mean: With the touchless fingerprint sensor devised above, the background regions of the images have very low gray-levels. Therefore, the block mean can be a satisfactory measure for segmentation. By the experiments, it was shown that a block mean value gives a fair separability to the foreground and the background (Fig. 7(a)). However, brightness cannot be sufficient for segmentation due to the noise irritating and degrading ridges in some regions. In this respect, block variance of the images acquired through our device is not suitable for segmentation measures (Fig. 7(b)).

B. Coherence: In fingerprint images, the coherence represents the consistency of the fingerprint texture of the corresponding pixel block. The coherence value is proportional to the strength of the consistent directivity which is evident in the foreground with ridges and valleys. On the other hand, small values are estimated in the background or the heavily noised regions, where pixel gradients show little consistency. The touchless fingerprint images captured by our device have redundant areas around the finger region to cover the variance of the finger size. Since block coherence filters out the bad-quality regions due to the noise, blur or darkness, it could be regarded as a quality check measure.

Different from the images of the touch-based sensors, the edge of the finger makes an apparent contour (see Fig. 5). Since the block coherence is estimated in a multi-level resolution just as the orientation and ridge frequency to get rid of the noise interference, the strong contour of the finger affects the coherence estimation to have a high value in the region with little ridge information. This disturbs our purpose to segment the foreground of a well-defined ridge-valley pattern using block coherence. To settle this problem, a 4-step segmentation is executed. First we crop the finger area with the block mean, apply morphology to exclude the edge region [2], then estimate the coherence of the eroded area, and pick out the well-defined foreground with the block coherence to get the segmented output.

4.3 Ridge Enhancement

A bank of the Gabor filters is produced and applied block-wisely according to the block orientation and the block frequency of the ridges [4]. The filter bank parameters are adjusted to cover possible ranges of the ridge frequency for 16 directional orientations. The Gabor filters work as a Gaussian filter for the direction of the ridge orientation and a band-pass filter for the orthogonal direction to the block orientation. In the near-boundary[1] region, the ridge frequencies are so high that those blocks should not be blurred with the Gaussian filter of large deviation to preserve high detailed information. Here we use the Gabor filter bank with frequency-adaptive deviations to preserve ridges in all frequencies by applying large deviation in low frequency blocks and small deviation in high frequency blocks. Ref. [6] proposes (1) to specify the relation between the frequency and the deviation (σ) to

[1] The near-boundary region refers to the area between the central foreground and the finger contour boundary, where the depth curvature of the finger skin is significantly large. For this reason, ridge patterns with minutiae change by the rolling or pitching of the finger.

determine the frequency-adaptive deviations of the Gabor filters.

$$e^{-\left(\left(\frac{3}{2f}\right)^2 / 2\sigma^2\right)} = 10^{-3} \qquad (1)$$

4.4 View Difference

Since a touchless fingerprint sensor acquires 2-dimensional fingerprint images from 3-dimensional finger skins, a significant problem of view difference is generated in the presence of rolling or pitching of the finger in the image acquisition step (Fig. 8). The view difference usually changes the minutiae information to be extracted, because the foreground turns to be the near-boundary region with the rolling or pitching. In this case, ridges get inseparably close to each other and the minutiae information may be lost.

Weak view difference usually gives small influence on the minutiae and is allowable through the elastic matching by the tolerance parameters of the bounding box with linear scaling [7].

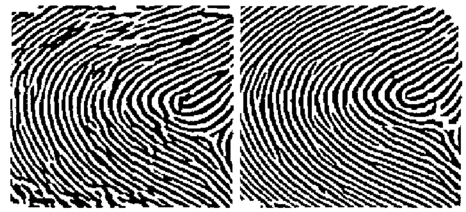
When strong view difference outbreaks from the rolling or pitching along the major axis of the finger, ridges on the slant skin are densified on the image due to the 3D-to-2D projections and are apt to have type-changed, missed or even false minutiae. Moreover, the foreground is turned to the near-boundary region and becomes dark or out of focus. This decreases the number of usable minutiae as well as good quality foreground and reduces the common area between the fingerprint impressions, which results in bad performance of the system. Therefore, it is desirable to reject the images with strong view differences and instruct the user to retry an input without serious view difference.

V. CONCLUSIONS AND FURTHER STUDIES

In this paper, we have suggested a new scheme for a touchless fingerprint sensor to get rid of the plastic distortions created through contacts. While we have the distortion-free large fingerprint images, new problems needed to be dealt with arise in the process. Herein, those issues are treated step by step.

(a) (b) (c)

Fig. 8. Fingerprint images with (a) no view difference, (b) weak view difference, and (c) strong view difference



(a) (b)

Fig. 9. Results of the touchless fingerprint image enhancement process: (a) with single white light source, no amendment on the process of preceding algorithm, (b) with the devised sensor, the proposed process

A touchless sensor using double ring-type illuminators with blue LEDs and a filter was designed to get images of good quality. We also manipulated the fingerprint image process to obtain output with less error. Segmentation was performed by the pixel features estimated adopting morphology to exclude the finger edge. Due to the curvature of the finger skin, peripheral region of a fingerprint tends to have densified ridges from 3D-to-2D projection. This can lead the images to erroneous result if neglected. Also, some frequency-adaptive filter design techniques were adopted to extract and keep accurate ridge information against noise. Finally, a new problem, view difference, was introduced with the strategy to treat it. The result output of the enhanced image is shown in Fig. 9(b), compared with the image from primitive sensor without optimized algorithm (Fig. 9(a)).

For future works, performance evaluations between touch-based system and suggested touchless system need to be executed. In addition, a study on the matching algorithms regarding strong view differences by adopting perspective distortion model is required.

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