A Real-Time Image Selection Algorithm: Fingerprint Recognition using Mobile Devices with Embedded Camera

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Abstract

This paper proposes a real-time image selection algorithm for fingerprint recognition system, which uses the embedded camera of the mobile device. In general, auto-focusing algorithms of the camera system use the gradient measures to estimate high-frequency components of an image. In mobile device, images are greatly affected by environmental light sources. Therefore, obtained image might not qualify for the fingerprint recognition system, even when the image is focused. Consequently, image should be investigated whether it is usable or not. Variance-Modified-Laplacian of Gaussian(VMLOG) and Image quality index(QI) proposed in this paper solve such problem. VMLOG considers high-frequency component and repeatable patterns of ridges. Experimental results shows that the processing time of the proposed algorithm is enough fast to be adapted in real time system as like mobile device and the proposed algorithm selects exactly a recognizable image.

1 Introduction

Today, specifications and functions of mobile devices such as cellular phone and PDA are improving dramatically. Inevitably, mobile devices store more and more secret information of the user. In addition, applications of mobile devices are broadened to include services requiring security system, e-banking and e-commerce. Therefore, higher security level than the conventional PIN method is desirable. In order to fulfill this demand, some recent mobile devices adapt fingerprint recognition function. Unfortunately, current system embeds an extra sensor for fingerprint acquisition, pulling up the price. In order to cut down the expense for adding fingerprint recognition function, already-embedded camera in a device could be used to obtain fingerprint image. Nowadays, camera embedded in mobile devices has high-resolution and supports close-shot. Hence, this idea is realizable in near future.

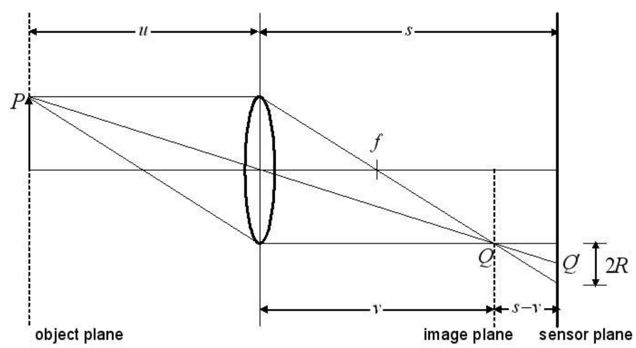


Figure 1. Image formation geometry

1.1 Background

Once the camera embedded in a mobile device is used as the input device, acquisition of an image which is suitable for fingerprint recognition is the fundamental step. Generally, the most focused image is the best quality image. Auto-focusing implements such task and has been studied for decades. Most auto-focusing methods consist of two steps; a focus measure for images is acquired at several different lens positions, and the lens is moved to the maximum focus measure position[6, 4].

The basic image formation geometry is shown in Fig. 1. Lens intercepts light rays radiated by the object point P. After refraction by the lens, these light rays converge at point Q on the image sensor. Relationship between the object distance u, focal distance of the lens f, and the image distance v is described by the Gaussian lens law.

$$\frac{1}{f} = \frac{1}{u} + \frac{1}{v} \quad (1)$$

If the object point P is exactly focused, two conditions are true; the image distance v is equal to the sensor distance s, and the image plane corresponds with the sensor plane. However, if the sensor plane is displaced from the image plane by a distance $s - v$, object point P is blurred over a circular region Q' with radius R on the sensor plane. Distribution of light energy over this circular region can be modeled using physical optics[7]. A two-dimensional Gaussian function is often used to approximate such the physical model[7, 9].

$$B(x, y) = \frac{1}{\sqrt{2\pi}\sigma_b} e^{-\frac{x^2+y^2}{2\sigma_b^2}} \quad (2)$$

Focused image contains more high frequency component than defocused image. Many previous researches proposed focus measures using this property. Several focus measures are summarized. Tenengrad measure estimates the gradient at each image point and simply sum all these magnitude[10]. Sum-Modified-Laplacian(SML) obtains the absolute value of each second partial derivative[5]. Sum-Modulus-Difference(SMD) sums the first intensity differences between neighboring pixels along a scanned line[3]. Although most algorithms are based on the sharpness functions evaluated by gradient, other approaches exists; wavelet[11], DCT[1], median filter[2], and absolute central moment(ACM)[8].

1.2 Considerations in Mobile device

Up to date, auto-focusing algorithms have restrictions; users must locate his/her finger in appropriate position to obtain usable image for fingerprint recognition. Whenever the object distance of the user's finger is changed, size of the fingerprint is changed accordingly. Two elements change the object distance, finger position and image position. If the finger is located too far or too close from the lens, input image may not be suitable for recognition. To overcome this problem, location of the finger must be fixed using special tools; however using tools is not convenient to user. Undoubtedly, finger-moving method with fixed-lens position is more useful than lens-moving method.

In mobile devices, environment is the huge factor in obtaining image. Particularly, illumination could influence the input image greatly, forcing the focused image unusable for fingerprint recognition. Consequently, the quality of image should be checked as well as the focus condition.

This paper first describes the focus measure for input image. Then, the real-time image selection algorithm using quality index is proposed.

2 The proposed Image Selection Algorithm

2.1 Test Area

Close-shot is essential to obtain the fingerprint image from camera embedded in mobile devices. Focusing in close-shot is affected by the shape of the object (unlike long-shot where the shape of the object is not important). Since depth of field(DOF) is very low in close-shot, focusing an image with deeply-curved surface like finger is very difficult. As shown in Fig. 2, fingers have the cylinder-like shape which slants to the fingertip. When the area perpendicular to the optical axis is well-focused, the curved-surface area is defocused. As the slope of the curvature increases, such areas are more defocused.

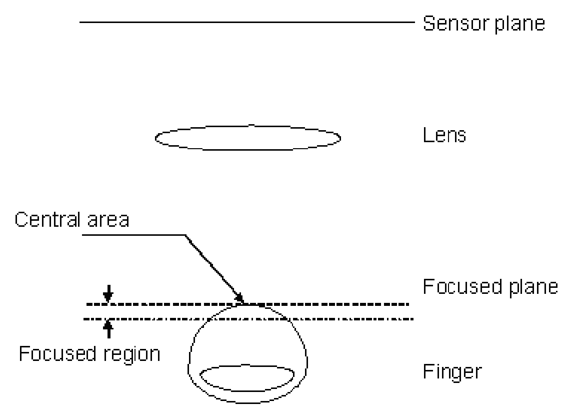


Figure 2. Shape from Focus

In this paper, central area(CA) is defined as a block which is perpendicular to the optical axis and is located in the nearest position from the camera lens. At this stage, position of CA is changeable according to the rolling and pitching of the finger. Test area(TA) is defined as the area including CA and its neighbor blocks. Since most of the high-quality regions are located near CA, TA is enough to estimate the quality of the input image. Following describes the procedures for assigning TA:

1. Divide input image into blocks of n×n.
2. Calculate the focus measure in each block(see section 2.2).
3. Select blocks with higher focus value using the P-Tile threshold method.

4. If the number of the regions is more than one, only the blocks belonging to the largest region are selected.
5. Calculate the center of gravity (CG) of the selected blocks and set the block including CG as CA.
6. Establish TA based on CA as shown in Fig. 3. Larger area is assigned below CA(slant of the area below CA is less than other areas).

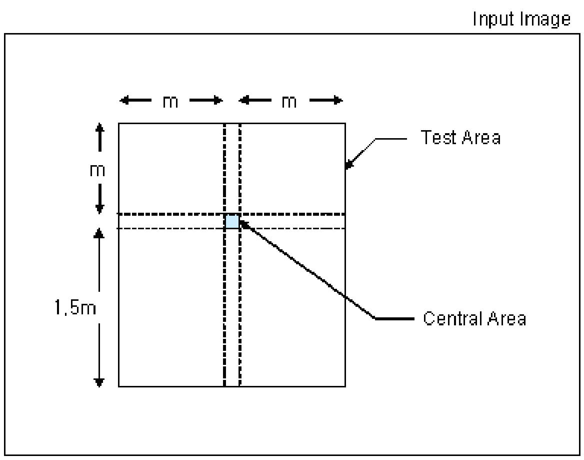


Figure 3. Establishment of TA

2.2 Focus Measure

High-frequency selection methods are generally used to measure the degree of focus; Tenengrad[10], SML[5], and SMD[3] are such methods. These methods use first or second partial derivatives with respect to horizontal and vertical direction. Practically, theses methods are simple but effective in estimating the degree of focus. Although these methods consider high-frequency effectively, repeatable patterns like fingerprint are not considered sufficiently. Therefore, performance of these methods is limited. This paper proposes the Variance-Modified-Laplacian of Gaussian(VMLOG) method to estimate the degree of focus in repeatable patterns effectively.

If $I(x, y)$ is input image and $G(x, y)$ is Gaussian filter, the modified LOG can be expressed as follow:

$$\nabla_M^2 [G * I] = \max \left\{ \frac{\partial^2 (G * I)}{\partial x^2}, \frac{\partial^2 (G * I)}{\partial y^2} \right\} \quad (3)$$

where $*$ is convolution operator. In order to accommodate for possible variations in the size of repeatable patterns, we use a variable spacing(step) between the pixels. The discrete approximation to the modified LOG is computed as follow:

$$MLOG_x = \sum_{k=-N}^{N} \omega_k I (x - k \times step, y) \quad (4)$$

$$MLOG_y = \sum_{k=-N}^{N} \omega_k I (x, y - k \times step) \quad (5)$$

$$MLOG = \max \{MLOG_x, MLOG_y\} \quad (6)$$

where ω_0 is positive, and other kernels are negative. The value of kernels and step are decided by the intervals of repeatable patterns.

Finally, the focus measure for a block or an image is computed as the variance of modified LOG values in a given area as follow:

$$VMLOG = VAR\{MLOG\} \quad (7)$$

where $VAR\{\}$ is a variance operator. We use this focus measure in each block and decide that block is the recognizable region or not.

2.3 Blur Model

Most of the previous methods use long-shot images. Since the degree of blur is similar over the entire image in long-shot images, focus measure had to be calculated over the entire image. Contrarily, in close-shot images, the degree of blur is very different between the object area and the background. This property can be adapted to differentiate the fingerprint region from the background region. Degree of blur according to the distance from the lens to the object is described in this section.

Few variables should be defined first; u_0 is the object distance of the focused image and v_0 is the image distance of the focused image. Variables u and v are the object distance and the image distance of the defocused image, respectively. And variables f, H, and R are the focal length, the height of any point of object, and the radius of the blurred region, respectively, the blur effect is modelled as follow:

$$R = \begin{cases} H \left(\frac{v_0}{u} - \frac{f}{u - f} \right), & u > u_0 \\ H \left(\frac{f}{u - f} - \frac{v_0}{u} \right), & f < u < u_0 \end{cases} \quad (8)$$

Fig. 4 is the graphical representation of eq. (8). It is easily conceivable that when the object is focused, u is equal to u_0 and $R(= \sigma_b)$ is equal to zero. When u is less than u_0 and greater than f, the rate of increase of blur is significant. On the other hand, the rate of increase of blur saturates as the object distance increases.

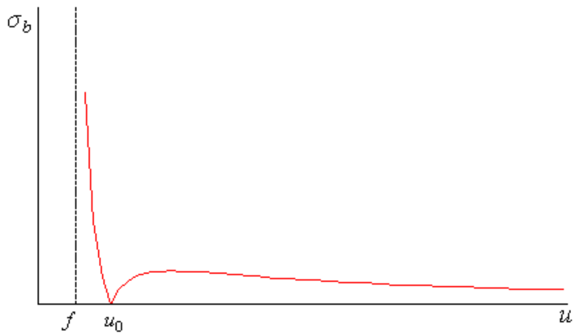


Figure 4. Blur model according to object distance

2.4 Quality Index

As shown in Fig. 4, pixel values of the defocused region are similar to its neighbors and the focus measure decreases due to the blurring effect. As a result, the best-focused image can be obtained by selecting an image with the maximum value. However, inputting a finger along one direction with equal speed is impossible. For example, user may pass quickly through the focused region or change the direction of the finger movement. In such occasions, the best-focused position cannot be measured. Only the maximum focused position among the inputted image sequences is possible. Furthermore, image at the maximum-focused position may not be the recognizable image. Hence, each inputted image should be checked for validity in real-time.

Key element is the fact that the entire finger regions cannot be focused simultaneously. Finger has the curved-surface and, therefore, the image quality decision should be processed in each block. If the value of the focus measure is greater than the predefined threshold T_f, that block is valid. T_f is previously set by considering the focus measure in the recognizable region and non-recognizable region.

If the total number of blocks in TA and the number of valid blocks in TA are NTB and NVB, respectively, Quality Index(QI) is defined as follow:

$$QI = \frac{NVB}{NTB} \tag{9}$$

2.5 Image Selection Algorithm

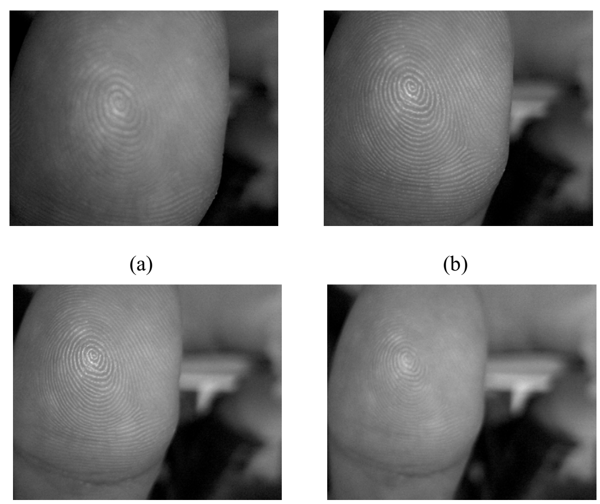
Real time image selection algorithm for obtaining a recognizable image is summarized as follows:

1. Bring image from camera.
2. Establish TA(see section 2.1)
3. Calculate QI(see section 2.4)
4. If the number of the region is more than two, select blocks which only belongs to the largest region.
5. If QI is greater than T_q, the current image is selected as a recognizable image. Otherwise, bring new image from camera.

3 Experimental Results

The development board for PDA and a mega pixel camera used to test the proposed algorithm. PDA board includes ARM 920T core processor and 64 MB main memory. Also, a point light source is used to reduce the effect of exterior illuminations. The size of the image obtained from camera is 640×512 pixels. The focal length f is 5.25 and the lens position is manually adjusted to focus the finger. The sensor distance v_0 is set to 6 mm and the image distance u_0 is 42 mm by calculation using Gaussian lens law.

Fig. 6 shows the respective normalized focus value of the proposed VMLOG and other conventional focus measures with test sequence whose focused and defocused image frames are shown in Fig. 5.



(a) (b) (c) (d)

Figure 5. Examples of image frame. (a) The 80^{th} defocused frame, (b) The 85^{th} well focused frame, (c) The 90^{th} slightly defocused frame, (d) The 95^{th} defocused frame.

Fig. 6 shows the normalized focus values of the finger region and the background region, depicting that the proposed algorithm and Tenengrad are useful to differentiate the finger region from the background region. A value which distinguishes the finger region from the background region is defined as a threshold which decides whether each block is recognizable or not.

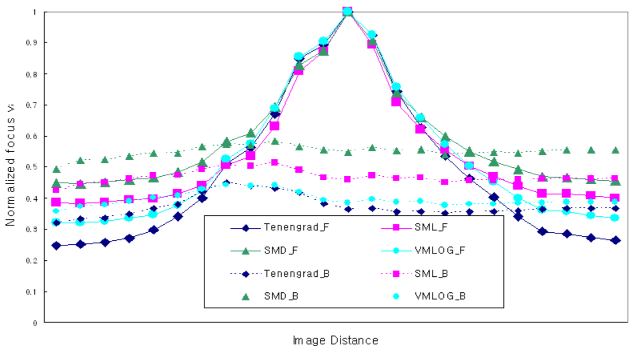


Figure 6. Comparison of the normalized focus value curves using the proposed method and conventional methods: solid line - value in finger region, dashed line - value in background region.

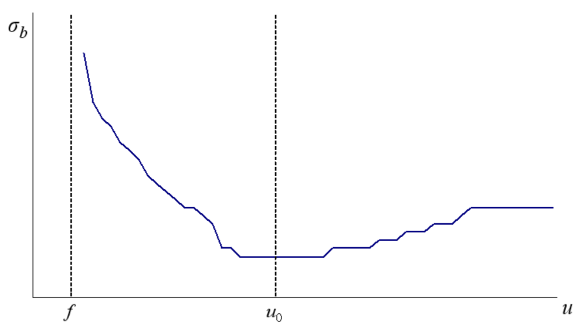


Figure 7. Real blur model according to object distance

Fig. 7 shows the real blur model according to image distance. The shape of curve is very similar to the theoretical blur model in Fig. 4. However, when u is smaller than u_0, value of the real model is smaller than the theoretical model. On the contrary, when u is greater than u_0, value of the real model is larger than the theoretical model. This phenomenon occurs because as the object distance u increases, the object size decreases.

In image selection experiment using QI, QI classifies input sequences into recognizable images and non-recognizable images. In test using full image frames, QI classifies several image frames which are captured in near position of the best focused image frame into recognizable image frame. The number of the recognizable image frame is changed according to the input conditions, especially exterior illuminations.

The average processing time of the proposed algorithm is $32ms$ in ARM920T core processor. This time is short enough to process in real time.

4 Conclusions

A real-time image selection algorithm for fingerprint recognition of the camera-embedded mobile device is proposed in this paper. Previous auto-focusing methods are not suitable for this application in many ways; users may pass quickly through the focused region and users may change the direction of the finger movement. Proposed algorithm overcomes these problems by using QI and VMLOG which considers high-frequency component and repeatable patterns of ridges. Experimental results shows that the processing time of the proposed algorithm is enough fast to be adapted in real time system as like mobile device and the proposed algorithm selects exactly a recognizable image.

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