On Improving Interoperability of Fingerprint Recognition Using Resolution Compensation Based on Sensor Evaluation

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Abstract. The purpose of this paper is the development of a compensation algorithm by which the interoperability of fingerprint recognition can be improved among various different fingerprint sensors. In order to compensate for the different characteristics of fingerprint sensors, an initial evaluation of the sensors using both the ink-stamped method and the flat artificial finger pattern method was undertaken. Then the resulted image resolution was incorporated to the compensation algorithms. This paper proposes Common resolution method and Relative resolution method for compensating different resolutions of fingerprint images captured by disparate sensors. Both methods can be applied to image-level and minutia-level. This paper shows the results of the minutiae-level compensation. The Minutiae format adhered to the standard format established by ISO/IEC JTC1/SC37. In order to compensate the direction of minutiae in minutia-level, Unit vector method is proposed. The fingerprint database used in the performance evaluation is part of KFRIA-DB (Korea Fingerprint Recognition Interoperability Alliance Database) collected by the authors and supported by KFRIA. Before compensation, the average EER was 8.62% and improved to 5.37% by the relative resolution compensation and to 6.37% by the common resolution compensation. This paper will make a significant contribution to interoperability in the system integration using different sensors.

1 Introduction

After the 9/11 terror incident, the major applications of biometrics have been shifted from personal identity authentication replacing passwords or tokens, towards national ID programs such as border control, e-passport, and seafarer's ID. Fingerprint is the main modality in biometrics due to its high accuracy and low cost. Unlike the other biometric modalities, however, there are many fingerprint sensors on the market, with various sensing mechanisms, such as optical, semiconductor, ultrasonic, thermal, polymer, TFT, and so on. Figure 1 presents various commercial fingerprint sensors and corresponding images of the same finger. Different sensor modules produce fingerprint images of different characteristics and fingerprint features of different types, which prevent them from being interoperable.

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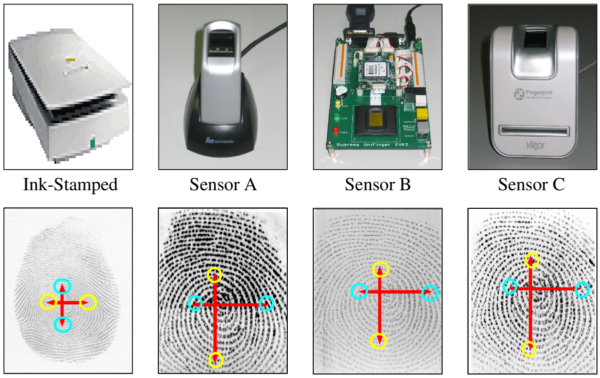

Fig. 1. Images of the different sensors on the same minutiae pairs

In order to analyze the characteristics of the different sensors presented in Figure 1, the actual horizontal and vertical resolutions of each fingerprint sensor are measured by comparing the pixel distances of a pair of the same minutiae between the ink-stamped and scanned image by a 500 dpi flat-bed scanner and the live-scanned image by each fingerprint sensor [1-2]. Table 1 summarizes the horizontal, vertical resolutions and the aspect ratio of the three fingerprint sensors used in this study. It should be noted that there are considerable amounts of differences between the actual resolutions and the vendor-provided specifications.

Recently, ISO/IEC JTC1/SC37 has been establishing the biometric standards for interoperability among disparate sensor modules as well as different modalities [3]. Interoperability between these different sensors can be examined from three points of view; the interface, data format, and algorithm. CBEFF [4] and BioAPI [5] are standards to provide interoperability of the interface between a sensor module and an application, while the standard data formats [6-9] are intended to furnish the interoperability among various fingerprint sensor modules. From the algorithm point of view, the interoperability is achieved by development of sensor-independent features that are invariable from sensor characteristics: resolution, image size, aspect ratio, and distortion. A ridge-counting algorithm [10-14] is a good example of the interoperability in algorithm level. In addition, various activities on interoperability test are underway [15-16].

The purpose of this study is to compensate the fingerprint template resolution and distortion before matching, in order to increase the fingerprint recognition rate

Table 1. Comparison of sensor characteristics

Sensor \ Item	Sensor Image (# of Pixels)		Measured Resolution		Vendor Resolution	Aspect Ratio
	Hor.	Ver.	Hor.	Vor.		
A (500dpi Optical)	136	160	483	497	500	0.971
B (500dpi Capacitive)	138	170	490	529	500	0.926
C (460dpi Optical)	121	141	429	437	460	0.981

between the different sensor systems. The following section describes the proposed method for compensating the resolution and distortion of disparate fingerprint images.

2 Compensation Algorithms

Figure 2 depicts the overall compensation scheme in the image level as well as template level, using 500dpi common resolution or relative resolution method. Various compensation processes between an enrolled sample and a test sample can be implemented, such as template-template, template-image, and image-image.

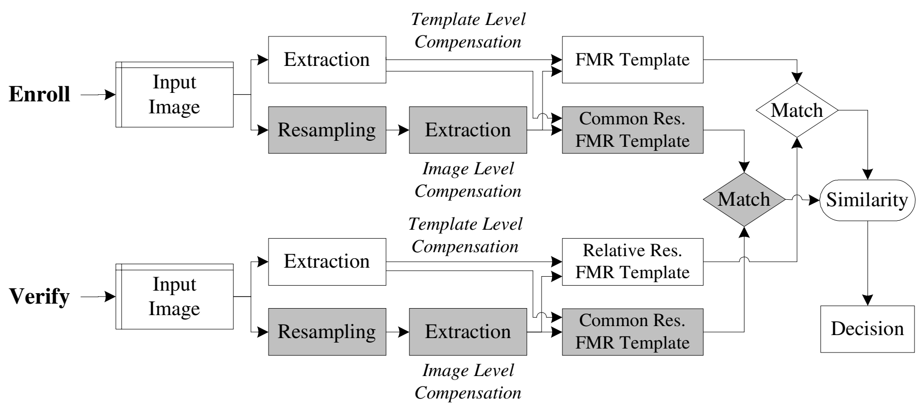

Fig. 2. Overall Compensation Scheme

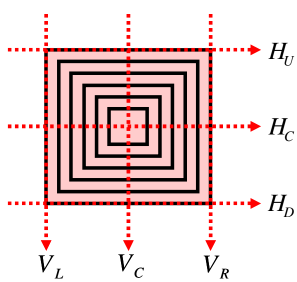

Fig. 3. Specification of flat artificial finger pattern

The resolution and distortion of each sensor should be provided prior to compensation. Figure 3 is the specification of Flat Artificial Finger Pattern which was to measure the actual resolution and distortion of the sensors. The flat artificial finger pattern was made using the pattern mold with silicon and the resolution information of each sensor is measured along six directions: H_U (horizontal upper), H_C (horizontal center), H_D (horizontal down), V_L (vertical left), V_C (vertical center), and V_R (vertical right).

In order to compensate for the different characteristics of fingerprint sensors, an evaluation of the sensors was undertaken using both the ink-stamped method and the flat artificial finger pattern method. The resulting image resolution was then incorporated to the compensation algorithms. Table 2 compares the sensor evaluation results with the manufacturer's sensor specifications.

Table 2. DPI Results of the Fingerprint Sensor Evaluation

Items / Sensor	DPI									
	Vendor Spec.		Ink-Stamped		Flat Artificial					
	Hor.	Ver.	Hor.	Ver.	HU	HC	HD	VL	VC	VR
A	500	500	483	497	494	495	494	499	499	498
B	500	500	490	529	N/A	N/A	N/A	N/A	N/A	N/A
C	723	460	429	437	436	441	444	440	441	440

2.1 Resolution Compensation

Figure 4 describes the relative resolution method of calculating the transformation ratio for resolution compensation. The horizontal and vertical transformation ratios were obtained using equation (1). In order to compensate the difference in resolution and distortion between the enrolled sample and the test sample, the horizontal and vertical coordinates of the test sample must be multiplied by the corresponding transformation ratio. Equation (2) defines the location compensation, LC.

$$R_{x-dpi} = \frac{B_{x-dpi}}{A_{x-dpi}} \quad \text{and} \quad R_{y-dpi} = \frac{B_{y-dpi}}{A_{y-dpi}} \tag{1}$$

$$LC = \begin{cases} x' = x \times R_{x-dpi} \\ y' = y \times R_{y-dpi} \end{cases} \tag{2}$$

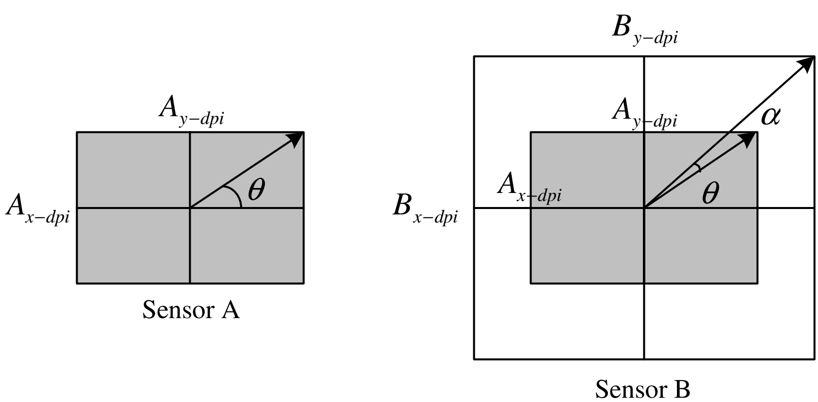

Fig. 4. Relative resolution method

Likewise, both the enrolled sample and the test sample can be converted to the same resolution of 500dpi with the aspect ratio equal to 1. This common resolution method is presented in equations (3).

$$R_{x-dpi} = \frac{500}{A_{x-dpi}} \quad \text{and} \quad R_{y-dpi} = \frac{500}{A_{y-dpi}} \tag{3}$$

2.2 Minutiae Direction Compensation

Given a template sample, instead of converting the coordinates of all the pixels as in Relative and Common resolution methods, only the positions and angles of minutia can be converted using the Unit vector method described in Figure 5, where the new position of a minutiae is computed by equation (2) and the new angle is obtained by equation (4).

$$\theta' = \tan^{-1}\frac{b'}{a'} = \tan^{-1}\left(\frac{R_{y-dpi}}{R_{x-dpi}} \cdot \tan\theta\right) \tag{4}$$

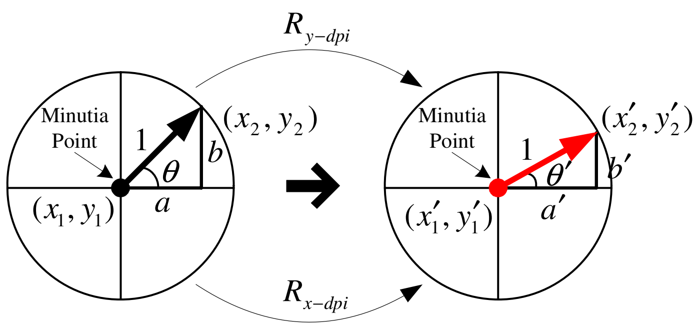

Fig. 5. Unit vector method for compensating minutiae direction

2.3 Distortion Compensation

The proposed approach employs the control line method in order to compensate the sensor distortion. Figure 6 presents the parameter of a single control line. When the position of the control line from before compensation $r-s$ to after compensation $r'-s'$ is obtained, the displacement of each pixel can be obtained by considering the length of the control line and the distance to the control line from the pixel.

Figure 7 presents the measuring method of resolutions along each direction, using the Flat Artificial Finger Pattern. After the six control lines for compensation is defined with initial values of 1/4 and 1/2 of the image width and height, the average resolution is modeled to be equal to the position and length of the initial control lines. If any resolution differs from the average resolution should compensate longer than the initial and vice versa.

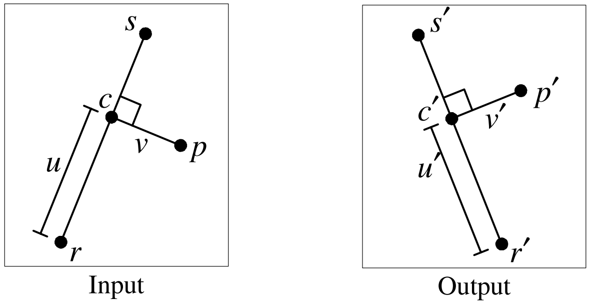

Fig. 6. Control Line Parameter

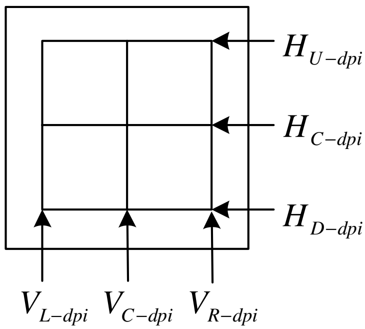

Fig. 7. Control Line Method for Compensating Distorted Images

Resolution transformation is performed using representative value after distortion compensation. The used weight in terms of the control line is shown in equation (5).

$$w = \left(\frac{l^c}{(a+d)} \right)^b \tag{5}$$

where, $a =$ Adherence Constant of the control line
$b =$ Concentration of the strength of the control line
$c =$ Importance of the length of the control line
$d =$ Distance between control line and pixel

The distance d is defined by equation (6). Therefore, the compensation of the transformation is achieved by considering the distance of the points, in order to use the segment feature: far points have small influence in the computation, and near points have a great amount of influence. The number of control lines is six. Final transformation is shown in equation (7) [17].

$$d = \begin{cases} |v| & 0 < u < 1 \\ \|\mathbf{p} - \mathbf{r}\| & u < 0 \\ \|\mathbf{p} - \mathbf{s}\| & u > 1 \end{cases} \tag{6}$$

$$\mathbf{p}' = T(\mathbf{p}) = \mathbf{p} + \frac{\sum_{i=1}^{n} w_i \Delta\mathbf{p}_i}{\sum_{i=1}^{n} w_i}, \quad \Delta\mathbf{p}_i = T_i(\mathbf{p}) - \mathbf{p} \tag{7}$$

where, $i =$ Control Line Index, $w =$ Weight
$\mathbf{p} =$ Considering Pixel
$\mathbf{p}' =$ Target Pixel
$T_i(\mathbf{p}) =$ Transformation Result on *i-th* Control Line
$T(\mathbf{p}) =$ Total Transformation Result

3 Experimental Results

The database used in this test is part of KFRIA-DB (Korea Fingerprint Recognition Interoperability Alliance Database) collected by INHA University and supported by KFRIA in Korea [18]. As presented in Table 3, the KFRIA-DB was collected in order to evaluate interoperable fingerprint recognition systems. The database consists of images acquired from 3 sensors and 344 people. Six fingers were used to obtain images exclusive of ring and little finger for 5 visits offering 5 impressions per visit. Therefore, the total database size comes to 154,800 images. The operator recorded the temperature and humidity during the acquisition period. In addition, the age distribution, which refers to the National Statistical Office, is considered.

The experiments were executed with compensated templates of 3 sensors and corresponding 3 different algorithms. Table 4 shows the results of the performance evaluation in terms of EER comparing between before and after the compensation.

Table 3. Database Specification on KFRIA-DB

Item	Description	
Organization	INHA University	
Modality	Fingerprint	
Purpose	For the Development and Evaluation of Interoperable Algorithm between Disparate Fingerprint Sensors	
Target Sensor	Optical	Sensor A, Sensor C
	Capacitive	Sensor B
Corpus	344 persons (Male:Female = 134:210, Age :10 ~ 70) 154,800 fingerprint images (5 times visiting * 5 impressions * 6 fingers * 3 sensors * 344 persons)	
Environment	Indoor Office Environment (Temperature 23~30°, Humidity 51~75%)	
Period	2005.7 ~ 2005.9	

Table 4. Results of the Performance Evaluation on the Interoperability

EER (%)	**Before Compensation**			**Relative Resolution Compensation**			**Common Resolution Compensation**			**Relative + Distortion Compensation**			**Common + Distortion Compensation**		
Test / Enroll	**A**	**B**	**C**	**A**	**B**	**C**	**A**	**B**	**C**	**A**	**B**	**C**	**A**	**B**	**C**
Sensor A	2.14	15.61	17.72		5.16	8.89		7.67	12.92		5.16	8.89		7.67	12.92
Sensor B	4.05	1.07	3.65	4.08		3.42	3.49		3.49	4.08		3.42	3.49		3.49
Sensor C	7.31	3.40	1.72	7.26	3.40		7.26	3.40		7.26	3.41		7.26	3.40	

The average EER was 8.62% before compensation and improved to 5.37% by the relative resolution compensation, to 6.37% by the common resolution compensation. The relative resolution method produced better performance than the common resolution method because the common compensation error was accumulated by compensating both of the enrolled sample and the matched sample to 500 dpi with the unity aspect ratio.

4 Conclusions

The purpose of this paper is the development of a compensation algorithm by which the interoperability of fingerprint recognition can be improved among various fingerprint sensors. This paper proposed a *Common resolution method* and *Relative resolution method* for compensating different resolutions of fingerprint images captured by disparate sensors. Both methods were applied to image-level and minutia-level. While the common resolution method converts both an enrolled sample and a matched sample to 500 dpi samples, the relative resolution method converts the resolution of a matched sample to that of an enrolled sample. In order to compensate the direction of minutiae in minutia-level, *Unit vector method* was proposed. Various compensation schemes were implemented between an enrolled sample and a matched sample, such as template-template, template-image, and image-image.

Future works include the evaluation of the effectiveness of the resolution and distortion compensation process in an overall fingerprint recognition system with disparate sensors and development of deformation compensation methods against fingerprint elasticity. Development of a sensor independent feature vector and interoperable algorithms, compliant with CBEFF, BioAPI will also be investigated.

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