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New System Implementation on SIMD Processor for Reliable Fingerprint Singularity Detection by Singular Candidate Method

Daisuke Tomizawa[1], Yuta Hasegawa[2], Tomohiko Ohtsuka[3], Hiroyuki Aoki[3]
[1] Advanced Course of Electric and Electronics Engineering, Tokyo National College of Technology, Tokyo, Japan
[2] Regulus Corporation, LTD., Tokyo, Japan
[3] Department of Electronics Engineering, Tokyo National College of Technology, Tokyo, Japan

Abstract

In this paper, a new system for fingerprint singularity detection by the singular candidate method is proposed. The singular candidate method, which can realize high success detection rate of the fingerprint singularity detection against poor quality fingerprints, is embedded to realize a high performance system. The system is implemented as firmware on a multi-processor system, which is called as Ri2001 produced by Ricoh. Singularities from a sample database of 800 fingerprint images were detected with a success rate of more than almost 80%. The efficiency of this system is shown to be 242.6 times that of a single processor system. In order to use this new system, it will be necessary to improve its accuracy as well as test this system on other databases. Future prospects of this system appear very promising.

1. Introduction

For many years, fingerprint identification has been a well-known and attractive identification method. Due to the progress in the field of computers and embedded processors, fingerprint identification can now be automatically accomplished using a stand-alone system. Fingerprint identification technology is widely used in personal recognition systems, for example, door lock control systems and PC user management systems [1] [2]. When the number of registered users in a fingerprint identification system is large, the number of comparisons required for fingerprint identification increases drastically. Therefore, the processing time of identification increases. The total processing time can be reduced if the time required for comparison is reduced. A common strategy employed to achieve this objective is to partition the fingerprint database into several subsets using a fingerprint classification technique. In general, fingerprints are classified on the basis of the global features of their ridge direction patterns. Figure 1 shows five typical fingerprint classes. The most evident structural characteristic of a fingerprint is the pattern of interleaved ridges and valleys. In Figure 1, the ridges are shown with bold lines, whereas the valleys are shown with white regions. Some parts of the ridge curves resemble semicircles whose center is called a core. Triangular patterns can also be observed in the fingerprints, whose center is called a delta. The core and delta are defined as the singular points of a fingerprint. According to Refs. [3]– [8], there is a strong relationship between fingerprint classes and the location of singular points. It is known that the singular points of a fingerprint are important reference points for its classification. A reliable approach for the detection of the singular points is required in order to classify the fingerprints easily.

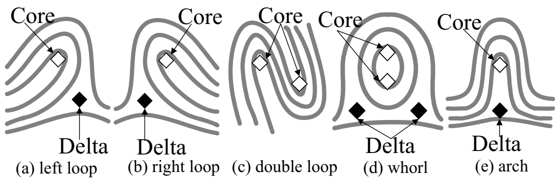

Figure 1. Examples of typical classes of fingerprints.

The *Poincaré index method* is the most popular and practical method used for detecting singular points in fingerprints [3]. By this method, the core and delta candidates are extracted on the basis of the difference in the local ridge directions between adjacent blocks. Since the algorithm of the Poincaré index method is quite simple, the computation overhead is rather small. However, singularity detection is considerably difficult when the fingerprint images contain local image noise and are of poor quality. This may lead to incorrect detection of singular points, because the Poincaré index method uses only the local features of fingerprints. Although some improved versions of the Poincaré index method have already been proposed to enhance the success rate of singularity detection [4]–[7], the tolerance to local image noise is not sufficiently high.

A detection method using an extended relational graph has been proposed, whose success rate of singularity detection by using the global features of the ridge direction patterns is high [9]–[11]. In this method, an extended relational graph that reflects the global ridge direction is generated. The success rate of singularity detection by this method is high even if the images are of poor quality. However, in the case of ridge curves having a strong nonlinearity, the detected locations of core and delta do not agree with the actual core and delta locations. The greater the sensing area of the fingerprint sensor, the larger is the precision error. Therefore, the positional precision is still not sufficiently high. A precision error is generated when a ridge has a high curvature in local regions.

In the above-mentioned singularity detection method, both the local and global features of the ridge direction patterns were required. That is, only the global feature of ridge direction is not enough to detect precise positions of singularity. To evaluate the local features of a ridge orientation field with tolerance to local image noise, singular candidates—the positions at which the probability of the existence of singular points is high—are extracted. Three types of singular candidate models are proposed to realize tolerance to local image noise. To evaluate the global features of the ridge direction patterns, the extended relational graph is used. By using both the local and global features of the ridge direction patterns in the proposed method, reliable singular point detection can be realized with a high computation speed.

Experimental results show that an improvement of more than 10% in the success rate of singularity detection from standard fingerprint image databases FVC2000 [7] and FVC2002 [7] is achieved [12]. Even though several images in these databases have a poor quality due to creases, scars, smudges, dryness, and dampness, the average computation time is almost the same as that of the Poincaré index method, keeping high success detection rate.

In this paper, a new system for fingerprint singularity detection by the singular candidate method is proposed. The singular candidate method, which can realize high success detection rate of the fingerprint singularity detection against poor quality fingerprints, is embedded to realize a high performance embedded system. The system is implemented as firmware on a multi-processor system, which is called as Ri2001 produced by Ricoh. Several experimental results are also described to evaluate the system performance.

2. Overview of the proposed system

2.1. Objective of the singular candidate method

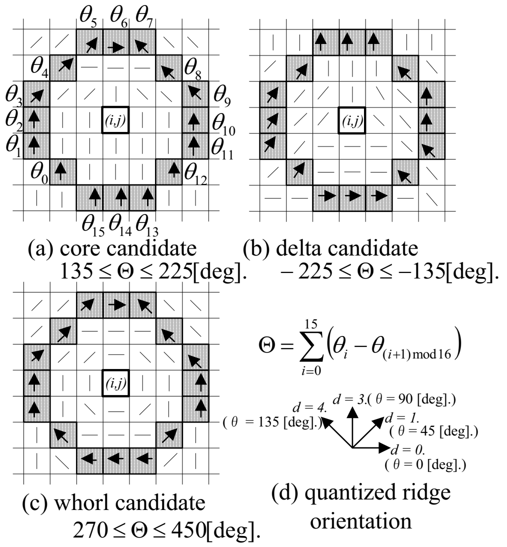

Figure 2. Three singular candidate models used in proposed method.

The Poincaré index method is quite simple, and its positional detection accuracy is excellent in the case of high-quality images. However, the detection results are sensitive to local image noise generated by creases, scars, smudges, dryness, and dampness, because the Poincaré index method uses only the differences in the local ridge directions. Reliable detection can be achieved in the case of poor quality images by using an extended relational graph from which the global features of the ridge direction patterns are extracted. However, the positional accuracy is not sufficiently high when the local ridges have strong curvatures.

To estimate the local features of the ridge direction patterns with high tolerance to local image noise, the singular candidate models, which indicate the positions where the probability of the existence of singular points is high, are used.

The proposed models are shown in Fig. 2. Each model is similar to a mask pattern used for evaluating the rotation angle of a ridge curve within a specified block. Although a singular point detected using the Poincaré index method completely satisfies the condition that the differences in the ridge orientation around a specified block should only be –180°, +180°, or 360°, the proposed method has several limitations in relation to this condition in order to realize tolerance to local image noise.

In this method, three types of singular candidates, i.e. a core candidate, delta candidate, and whorl candidate, are introduced. According to the density of the singular candidates, the core and delta positions are computed as the averaging point of each candidate region, which is a set of singular candidates placed adjacently. Since a singular candidate analysis—in which the singular candidates and their densities are extracted—is carried out in the detection process, it can precisely detect the core and delta positions, even when the segment boundary has strong curvatures. Further, few core and delta positions are misjudged, because the ridge directions around the specified blocks are actually evaluated using singular candidate models whose size is larger than the mask pattern used in the Poincaré index method.

To extract the global features of the ridge direction patterns, an extended relational graph is also generated in the proposed method. By carrying out the singular candidate analysis using this extended relational graph, both the local and global features of the ridge distribution pattern are evaluated in this method, and this helps in realizing reliable singularity detection.

2.2. Overview of the experimental system

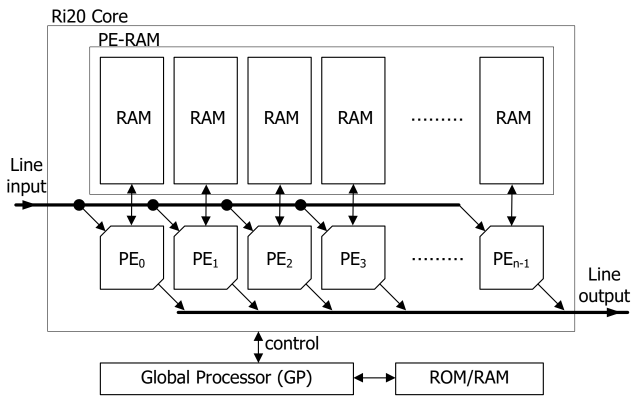

Figure 3. Architecture of the SIMD Processor, Ri2001.

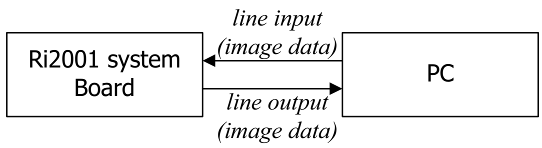

Figure 4. Block diagram of the experimental system.

Ri2001 is a type of image-processing-oriented multi-processor system. Since Ri2001 has a SIMD architecture (Figure 3), the same instruction is executed by the multi-processor using different data streams. SIMD stands on Single Instruction / Multiple Data, which means a type of multi-processor systems. SIMD structure contains an array of uniformed processor elements (PEs), which can work similarly by the same instruction and can access multiple data in each PE. In case of Ri2001, there are 352 processor elements (PEs) inside, each of which provides a 16 bit data path. Each PE has its own data memory (PE-RAM). The global processor (GP) controls the Ri2001 core, and it can execute a sequential process.

A *SNIPER EXPRESS* platform from *Regulus* Co., LTD., with a Ri2001 processor is used to implement the singular candidate method for fingerprint singularity detection. A block diagram of the *SNIPER EXPRESS* platform is shown in Figure 4. Image data from a frame is decomposed into lines, and the line data is transferred from the PC to the line input port. This line data can be observed on the *SNIPER EXPRESS* board through the line output port. The *SNIPER EXPRESS* board has three channels for the input and output ports each. The singular candidate method for singular point detection is implemented as firmware on the Ri2001 platform. Therefore, it can be achieved good speed-up rate in the parallel machine. The functionality of each block in Figure 5 is as follows.

2D LPF In this block, the LPF with 3 x 3 neighborhood average is applied to smooth the image. Since there are several procedures, each of which is independent for execution in the LPF process, these procedures can execute parallelly. The performance of the parallelism becomes higher by using the multi-processor system.

Directional image generation In this block, the directional image is generated by sliding 4 kinds of 8 x 8 directional masks, to quantize the ridge direction into 4 steps, i.e., 0, 45, 90, and 135 [degrees]. Since the process of directional image generation has the time invariant feature, the performance of the parallelism becomes higher by using the multi-processor system.

Directional image reconstruction In this block, the revision of the quantized ridge direction is performed to reduce the effect of local image degradations. Since almost all procedures are sequential, such as the labeling and the majority decision, the performance of the parallelism does not become so higher by using the multi-processor system.

Directional filter based on directional image In this block, the 1 dimensional LPF along the quantized ridge direction is applied to reduce the effects of creases, scars, smudges, dryness, and dampness. Since the process of directional filter based on directional image has the time invariant feature, the performance of the parallelism becomes rather higher by using the SIMD architecture.

2.3. Overview of the firmware for singularity detection

First, the algorithm of the singular candidate method is analyzed to find the availability of parallelism. When two processes with a time invariant relationship are to be executed parallelly, the algorithm is separated into several procedures to achieve good speed.

An outline of the implemented firmware is shown in Figure 5. Based on the results of an investigation, the procedures of *2D LPF*, *Directional Image Generation*, and *Singular Candidate Extraction* were found to have high availability of parallelism. Therefore, a good speed-up rate can be achieved in a parallel machine.

3. Experimental Results

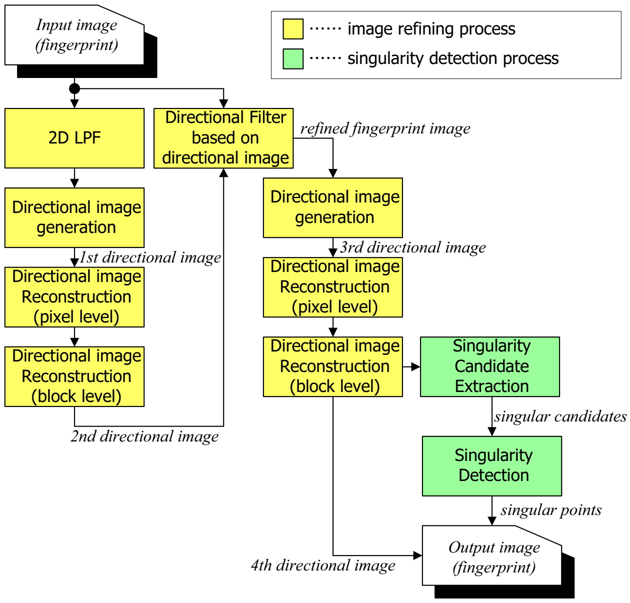

Figure 5. Outline of the firmware for fingerprint singularity detection.

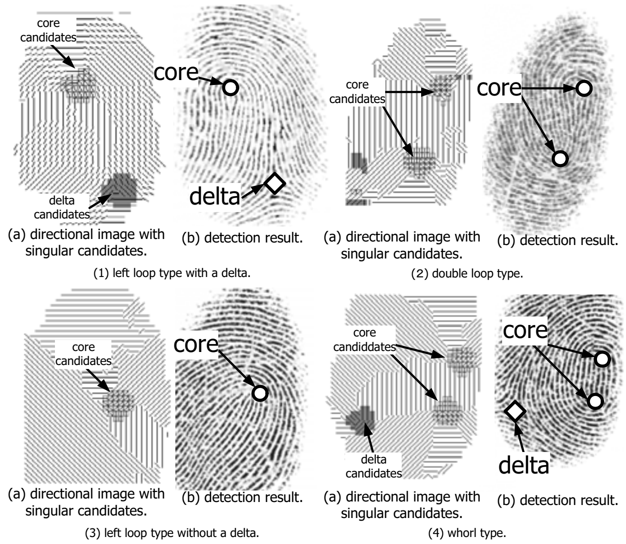

Figure 6. Examples of fingerprint singularity detection results obtained using the Ri2001 platform.

Table 1. Experimental results of the success rate of detection.

Database name	Sensor type	Image size	Success rate [%]
FVC2000DB1a	Capacitive	240 × 320	79.9
FVC2000DB2a	Optical	300 × 300	80.4
FVC2000DB4a	Synthetic	256 × 364	90.9

Table 2. Speed-up rate of the proposed system

Procedure name	Speed-up rate [times]
2D LPF	234.9
Directional image generation	309.2
Directional image reconstruction	22.2
Singular candidate extraction	162.6
Total	242.6

To evaluate the reliability of detection, this method is applied to several actual fingerprint images. Figure 6 shows the experimental results of the detection of the core and delta positions from four typical fingerprint classes in the FVC2000 database [7] by using the implemented Ri2001 platform. FVC2000 is one of the popular and public fingerprint image databases; each database contains 800 samples. For the performance evaluation of the fingerprint identification, many of the fingerprint images are damaged by local image noise due to creases, scars, smudges, dryness, and dampness. The success rate of detection of singular points in the case of three popular databases is shown in Table 1. According to Figure 6, reliable singular point detection can be achieved using the proposed system.

All correct locations of singular points for each fingerprint are determined by human expertise in this evaluation. A successful detection is defined as one in which each extracted singular point is within an allowance region having a size of 16 × 16 around each correct singular point. The success rate (*SR*) of detection is defined as

$$SR = \frac{N_{fail}}{N_{total}} \times 100[\%],$$

where N_{fail} is defined as the number of fingerprints for which the singular points can be successfully detected in an experiment, and N_{total} is defined as the total number of fingerprints assessed in the experiment.

The success rates of core and delta detection for each database are summarized in Table 1. Evidently, when a fingerprint image contains little noise, a success rate of almost 100% can be achieved. However, the success rate decreases when each fingerprint image contains local image noise. Table 1 shows that a success rate of more than almost 80% for singularity detection can be achieved by using the proposed method.

To evaluate the parallelism in the Ri2001 platform, a performance metric, *speed-up rate* (*SP*), is measured. The number of actual cycles N_{SIMD} executed by the Ri2001 platform is defined as the sum of the cycle number $N_{\text{sequential}}$ of instructions in sequential procedures, which are constructed the algorithm, and the cycle number N_{parallel} of the instructions in the procedures, each of which are independent of the execution, and can be mapped into the multi-processor elements (PEs). That is,

$$N_{\text{SIMD}} = N_{\text{sequential}} + N_{\text{parallel}}.$$

Moreover, the number of ideal cycles N_{single} executed by the single PE embedded in Ri2001 is defined as the sum of the cycle number of all procedures in the algorithm, when only one PE is available. The product of the effective PE numbers N_{PE} and cycle number of the procedures mapped into the multi-processor. That is,

$$N_{\text{single}} = N_{\text{sequential}} + N_{\text{parallel}} \times N_{PE}.$$

SPEEDUP is defined as

$$SPEEDUP = \frac{N_{\text{single}}}{N_{\text{SIMD}}}$$

The speed-up rates of different procedures are summarized in Table 2. It shows that *SP* tends to increase when the procedure has high availability of parallelism. The total speed-up rate achieved by the proposed system is 242.6.

4. Conclusion

In this paper, a new system for fingerprint singularity detection by the singular candidate method is proposed. The system is implemented as firmware on a Ri2001 multi-processor system. A success rate of more than 80% for the detection of singularities from a sample database of 2400 fingerprint images has been achieved. The efficiency of this system is shown to be 242.6 times that of a single PE system. In order to use this new system, it will be necessary to improve its accuracy as well as test this system on other databases. Future prospects of this research system appear very promising.

Acknowledgements

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