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Mathematical Context of Recurrent Line Tracking Enhancement Algorithm in Fingervein Technology

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***Abstract*—*Biometrics based technology varies from one system to another. Using human physiological characteristics such as fingerprints, iris, fingervein, face shape, hand geometry and so on for identification has been a long time effort made to improve on the security of personal identification system. But most of these systems have their limitations. Conventional methods for extracting line-shaped features from images include the matched-filter method, mathematical morphology, connection of emphasized edge lines, and ridge line following for minutiae detection in gray scale fingerprint images. The matched-filter and morphological methods for example, can execute fast feature extraction because all that's required is to filter the image. However, this can also emphasize irregular shading, which presents an obstacle to personal identification since this obscures parts of the pattern of veins. Moreover, dots of noise are also emphasized because continuity is not considered. When the connection of emphasized edge lines is used to extract a fingervein pattern, line extraction can be executed if one takes into account continuity. However, the differential operation and optimization of the line connections carry immense computational costs. It may take ten or more minutes to process an image. Therefore, this method is not suitable when real-time processing is required. The minutiae detection algorithm is based on ridge line following. The ridge line following, which is executed by checking the local darkest position in the cross-sectional profiles, works well if the ridge appears clearly. However, fingervein images are not clear enough for this method to be used. Fingervein pattern is characterized not only by the vein blood vessel pattern but also by the irregular shading produced by the various thicknesses of the finger bones and muscles captured under infrared light. The captured images contain not only vein patterns but also irregular shading and noise. For a robust line extraction, this paper presents the mathematical context of recurrent line tracking enhancement algorithm in fingervein technology over conventional methods for reliable, efficient and effective personal identification system.*

Keywords*— *Biometrics; Algorithm; Fingervein technology; Physiological characteristics; and Recurrent line tracking.

I. INTRODUCTION

Biometrics is applied in functions such as voter's card registration, driver's license application, international passport application, national identity number registration among others for personal identification purposes. There are ample opportunities to perpetrate fraudulent acts during the activities that involve the applications of some of these technologies as found in voting exercise as it is witnessed in some developing countries of the world. In most cases, frauds are perpetrated because the mechanism put in place to reduce fraud during the exercise is very weak. It is noted that the only means to identify an individual is through a voter's card. Identification of person can be compromised, multiple registration and voting can occur, imposters may be allowed to vote, voter's card can be sold and so on. A reliable, efficient and effective voter's registration and flawless election systems require personal identification technologies that are developable, implementable, reliable, convenient and affordable. In recent times biometrics system (Fig. 1) has enable the identification of individuals either by physiological characteristics [1], such as fingerprints, iris, fingervein, face, hand geometry and so on or the behavioral characteristics such as voice, signature, hand clap and so on [2] as seen in Fig. 2.

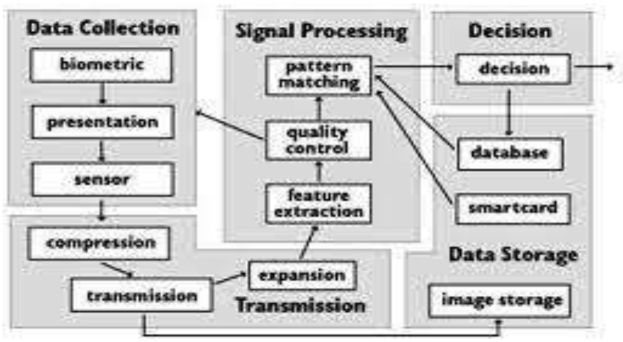

Fig. 1. Block diagram of biometrics system.

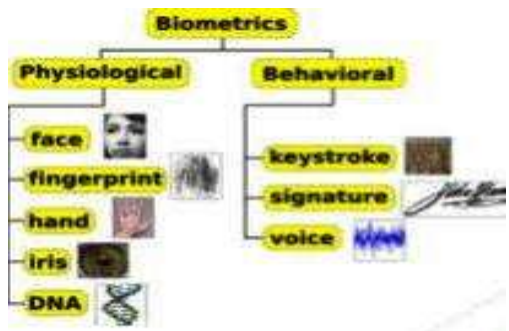

Fig. 2. Personal identification using physiological and behavioral characteristics.

II. RELATED WORKS

According to [2], biometrics is not only a fascinating pattern recognition research problem but, if carefully used, is an enabling technology with the potential to make our society safer, reduce fraud and provide user convenience. The fingerveins are today the biometrics features most securely used for personal identification (Fig 3). A fingervein pattern is characterized not only by the vein blood vessel pattern but also by the irregular shading produced by the various thicknesses of the finger bones and muscles captured under

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infrared light [3]. The captured images contain not only vein patterns but also irregular shading and noise. The shading is produced by the varying thickness of finger bones and muscles. Therefore, regions in which the veins are and are not sharply visible exist in a single image. To develop highly accurate personal identification systems, fingervein patterns should be extracted precisely from the captured images, and the process must be executed speedily in order to satisfy requirements for user convenience.

Fig. 3. Fingervein personal identification technology.

Conventional methods for extracting line-shaped features from images include the matched-filter method [4], mathematical morphology [5], connection of emphasized edge lines [6], and ridge line following for minutiae detection in gray scale fingerprint images [7]. The matched-filter and morphological methods can execute fast feature extraction because all that's required is to filter the image. However, this can also emphasize irregular shading, which presents an obstacle to personal identification since this obscures parts of the pattern of veins. Moreover, dots of noise are also emphasized because continuity is not considered. When the connection of emphasized edge lines is used to extract a fingervein pattern, line extraction can be executed if one takes into account continuity. However, the differential operation and optimization of the line connections carry immense computational costs. It may take ten or more minutes to process an image. Therefore, this method is not suitable when real-time processing is required. The minutiae detection algorithm [7] is based on ridge line following. The ridge line following, which is executed by checking the local darkest position in the cross-sectional profiles, works well if the ridge appears clearly. However, fingervein images are not clear enough for this method to be used.

III. MATHEMATICAL CONTEXT

Explained in this section is the mathematical context of recurrent line tracking enhancement algorithm which starts at various positions. Local dark lines are identified, and line tracking is executed by moving along the lines, pixel by pixel. When a dark line is not detectable, a new tracking operation starts at another position. All the dark lines in the image can be tracked by repeatedly executing such local line tracking operations. Finally, the loci of the lines overlap and the pattern of fingerveins is obtained statistically. As the parts of the dark lines are tracked again and again in the repeated operations, they are increasingly emphasized. Although noise may also be tracked, noise is emphasized to a smaller degree than the dark lines. This makes line extraction robust. Furthermore, reduction of the number of tracking operations and the spatial reduction of the pattern can reduce computational costs. The method of feature extraction is described as follows.

$F(x, y)$ is the intensity of the pixel (x, y), (xc, yc) is the position of the current tracking point of line tracking in the image, Rf is the set of pixels within the finger's outline, and Tr is the locus space. Suppose the pixel in the lower left in the image to be (0, 0), the positive direction of the x-axis to be rightward in the image, the positive direction of the y-axis to be upward within the image, and $Tr(x, y)$ to be initialized to 0.

Step 1: Determination of the start point for line tracking and the moving-direction attribute. The start point for line tracking is (xs, ys), a pair of uniform random numbers selected from Rf. That is, the initial value of the current tracking point (xc, yc) is (xs, ys). After that, the moving-direction attribute Dlr and Dud are determined. Dlr and Dud are the parameters that prevent the tracking point from following a path with excessive curvature. Dlr and Dud are independently determined as follows.

$$Dlr = \begin{cases} (1,\ 0) & \left(\text{if } \mathrm{R_{nd}}(2) < 1\right). \\ (-1,\ 0) & (\text{otherwise}); \end{cases} \tag{1}$$

$$Dud = \begin{cases} (0,\ 1) & \left(\text{if } \mathrm{R_{nd}}(2) < 1\right). \\ (0,\ -1) & (\text{otherwise}); \end{cases} \tag{2}$$

where $\mathrm{R_{nd}}(n)$ is a uniform number between 0 and n.

Step 2: Detection of the direction of the dark line and movement of the tracking point. This step is composed of several sub steps.

Step 2-1: Initialization of the locus-position table Tc. The positions that the tracking point moves to are stored in the locus-position table, Tc. The table is initialized in this step.

Step 2-2: Determination of the set of pixels Nc to which the current tracking point can move. A pixel to which the current tracking point (xc, yc) moves must be within the finger region, have not been a previous (xc, yc) within the current round of tracking, and be one of the neighboring pixels of (xc, yc).Therefore, Nc is determined as follows.

$$Nc = \overline{Tc} \cap Rf \cap Nr(xc,\ yc), \tag{3}$$

where $Nr(xc, yc)$ is the set of neighboring pixels of (xc, yc), selected as follows.

$$Nr(xc,\ yc) = \begin{cases} N3(Dlr)(xc,\ yc) & (\text{if} Rnd(100) < plr); \\ N3(Dud)(xc,\ yc) & (\text{if} plr + 1 \le Rnd(100) < plr + pud); \\ N8(xc,\ yc) & (\text{if} plr + pud + 1 \le Rnd(100)), \end{cases} \tag{4}$$

where $N8(x, y)$ is the set of eight neighboring pixels of a pixel (xc, yc) and $N3(\boldsymbol{D})(x, y)$ is the set of three neighboring pixels of (xc, yc) whose direction is determined by the moving-direction attribute $\boldsymbol{D}$ (defined as (Dx,Dy)). $N3(\boldsymbol{D})(x, y)$ can be described as follows.

$$N3(\boldsymbol{D})(x,\ y) = \{(Dx+x,\ Dy+y),\ (Dx-Dy+x,\ Dy-Dx+y),\ (Dx+Dy+x,\ Dy+Dx+y)\}. \tag{5}$$

Parameters plr and pud in Eq. 4 are the probability of selecting the three neighboring pixels in the horizontal or vertical direction, respectively, as $Nr(sc, yc)$. The veins in a finger tend to run in the direction of the finger's length. Therefore, if we increase the probability that $N3(\boldsymbol{D}lr)(xc, yc)$ is selected as $Nr(xc, yc)$, we obtain a faithful representation of the pattern of fingerveins. In preliminary experiments, excellent results are produced when plr= 50 and pud= 25.

Step 2-3: Detection of the dark-line direction near the current tracking point. To determine the pixel to which the current tracking point (xc, yc) should move, the following equation, referred to as the line-evaluation function, is calculated. This reflects the depth of the valleys in the cross-sectional profiles around the current tracking point:

$$Vl = \max\left(xi, yi\right) \in Nc \begin{cases} F(xc + r\cos\theta i - \dfrac{W\sin\theta i}{2},\ yc + r\sin\theta i + \dfrac{W\cos\theta i}{2}) + F(xc + r\cos\theta i + \dfrac{W\sin\theta i}{2},\ yc + r\sin \\ \dfrac{\theta i}{2} - W\cos\theta i) - 2F\left(xc + r\cos\theta i,\ yc + r\sin\theta i\right) \end{cases} \tag{6}$$

where W is the width of the profiles, r is the distance between (xc, yc) and the cross section, and θi is the angle between the line segments $(xc, yc) - (xc + 1, yc)$ and $(xc, yc) - (xi, yi)$. In consideration of a thickness of the veins that are visible in the captured images, these parameters are set at $W = 11$ and $r = 1$.

Step 2-4: Registration of the locus in the locus-position table Tc and moving of the tracking point. The current tracking point (xc, yc) is added to the locus position table Tc. After that, if Vl is positive, (xc, yc) is then updated to (xi, yi) where Vl is maximum.

Step 2-5: Repeated execution of steps 2-2 to 2-4. If Vl is positive, go to step 2-2; if Vl is negative or zero, leave step 2 and go to step 3, since (xc, yc) is not on the dark line.

Step 3: Updating the number of times points in the locus space have been tracked. Values of elements in the locus space $Tr(x, y)$ are incremented $\forall (x, y) \in Tc$.

Step 4: Repeated execution of step 1 to step 3 (N times)

Step 5: Acquisition of the pattern of veins from the locus space. The total number of times the pixel (x, y) has been the current tracking point in the repetitive line tracking operation is stored in the locus space, $Tr(x, y)$. Therefore, the fingervein pattern is obtained as chains of high values of $Tr(x, y)$.

Fig. 4 is the infrared image from which Fig. 5 is produced as the distribution of values in $Tr(x, y)$. The higher values are shown as brighter pixels.

Steps 1 to 3 are thus executed N times. If the number of repetitions N is too small, insufficient feature extraction is performed. If, on the other hand, N is too big, computational costs are needlessly increased. Through an experiment, it was determined that N = 3000 is the lower limit for sufficient feature extraction

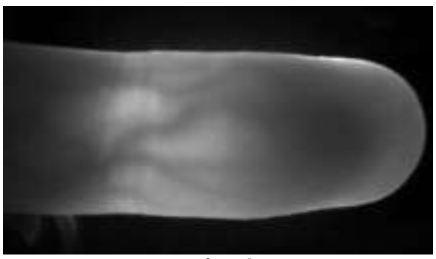

Fig. 4. Infrared image

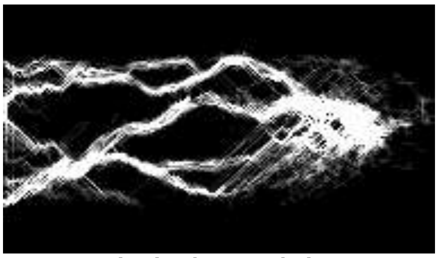

Fig. 5. Value distribution in the locus space

IV. RESULTS AND DISCUSSION

Conventional methods for extracting line-shaped features from images include the matched-filter method [4], mathematical morphology [5], connection of emphasized edge lines [6], and ridge line following for minutiae detection in gray scale fingerprint images [7]. The matched-filter and morphological methods can execute fast feature extraction because all that's required is to filter the image. However, this can also emphasize irregular shading, which presents an obstacle to personal identification since this obscures parts of the pattern of veins. Moreover, dots of noise are also emphasized because continuity is not considered. When the connection of emphasized edge lines is used to extract a fingervein pattern, line extraction can be executed if one takes into account continuity. However, the differential operation and optimization of the line connections carry immense computational costs. It may take ten or more minutes to process an image. Therefore, this method is not suitable when real-time processing is required. The minutiae detection algorithm [7] is based on ridge line following. The ridge line following, which is executed by checking the local darkest position in the cross-sectional profiles, works well if the ridge appears clearly. However, fingervein images are not clear enough for this method to be used. According to [3], a fingervein pattern is characterized not only by the vein blood vessel pattern but also by the irregular shading produced by the various thicknesses of the finger bones and muscles captured under infrared light. The captured images contain not only vein patterns but also irregular shading and noise. Although, noise may also be tracked, noise is emphasized to a smaller degree than the dark lines. The mathematical approach employed in recurrent line tracking enhancement algorithm makes the line extraction robust over the conventional methods.

V. CONCLUSION

Mathematical context presented in this paper intended to represent recurrent line tracking enhancement algorithm as an improved method over the conventional methods for extracting line-shaped features from image. The steps taken in the context showed the robustness of the method for personal identification system.

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