Identification of Individual Walking Patterns Using Gait Acceleration

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***Abstract*—This paper presents an improved approach on identifying users based on three-dimensional gait acceleration signal characteristics produced by walking. When the user carries the wearable gait acceleration acquiring system, acceleration signals are registered by the accelerometer. Through dividing the signals into gait cycles, gait feature code which represents the walking pattern of the user can be extracted. Recognition is based on the general idea of template matching. We use dynamic time warping (DTW) algorithm for matching so that non-linear time normalization could be used to dispose the problems resulted from naturally occurring changes in walking speed. Experiments were performed on 35 healthy subjects walking on their normal speed; Equal Error Rate of 6.7% was achieved. Our preliminary experiments confirm the possibility of recognizing users based on their gait acceleration.**

Keywords-biometrics; gait recognition; acceleration; dynamic time warping; accelerometer

I. INTRODUCTION

As human-friendliness has been increasingly emphasized in the intelligent system's area, many different applications have been developing in the field of biometric identification. Recently much attention has been devoted to the use of human gait patterns as a biometric. As a biology feature, gait has its unique characteristics such as appreciable, non-invasive, without people's attention, difficult to disguise and has little affect when environment changed. So, the study of human gait, as well as its deployment as a biometric for identification purposes, is currently an active research area.

There are many studies devoted to gait recognition, the mainstream gait studies are based on machine vision. Lee [1] found several ellipses to fit to different parts of the binary silhouette of a person; Yoo [2] proposed a method for extracting the body points by topological analysis and linear regression guided by anatomical knowledge; Canado [3] extracted the gait signature by fitting the movement of the thighs to an articulated pendulum-like motion model. Kale [4] and Wang [5] extracted the human silhouette from the sequence, and took it as the feature of gait; Little and Boyd [6] took the frequency of optical flow and phasic information of gait sequence image as gait feature. Differently with all above methods, Ailisto [7] proposed another new method, he used correlation of gait acceleration for gait recognition through capturing acceleration signals with two biaxial sensors; Gafurov [8] attached two biaxial sensors to the participants' right leg, and recognition was achieved by histogram similarity and cycle length method.

In this paper, an improved method to recognize individuals by using their gait acceleration data is presented. The method uses a tri-axial accelerometer MMA7260 to measure gait acceleration signals in three directions: vertical, backward-forward and lateral. In the training phase, the 3D acceleration signals are divided into gait cycles, so as to extract gait feature template which represents the user's gait pattern. In the test phase, the gait templates are matched with user's gait signals for recognition purposes. However, in the case of walking, a user may change his speed from cycle to cycle. Different gait cycles tend to have unequal lengths, and different user may have different gait cycle. In order to identifying different users, we use the dynamic time warping (DTW) [9] algorithm for matching so that non-linear time normalization should be used to dispose the naturally-occurring changes in walking speed. Experiments show that identifying users with this improved gait recognition method is possible.

The organization of this paper is as follows. Section II describes the design of the acceleration acquiring system. Section III introduces the wavelet method of signal denoising. The methodology of identifying people from their gait acceleration pattern is outlined in Section IV. Experimental results are shown in Section V prior to concluding in Section VI.

II. DESIGN OF THE ACCELERATION ACQUIRING SYSTEM

An electrical based board (size 9cm×6cm) was designed for acquiring 3D acceleration data from walking. The wearable accelerometer system consisted of a tri-axial accelerometer (MMA7260,Freescale, USA), a MCU (ADUC841, ALOG, USA) with high speed 12-bit ADC, 32M bytes RAM (62256) and a RS-232 interface for data transfer.

The tri-axial accelerometer was used to register the acceleration signals in three dimensional directions: backward-forward (X-axis), lateral (Y-axis), and vertical (Z-axis) direction. Though the normal human walking period was about 1.5 sec; the sampling rate we used was 250Hz. The signals from the accelerometer were converted to digital signal via the

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built-in ADC of ADUC841, and then stored in RAM, as shown in Fig. 1. The data transfer module performed the task of sending the obtained gait data to the computer. When the gait data had been collected, it was transferred to a computer via the RS-232 interface for further processing.

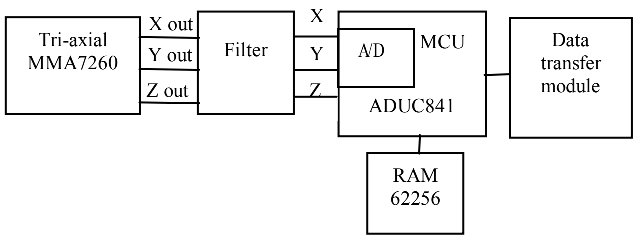

Figure 1. Block diagram of the measuring system

The portable device was firmly attached with a belt to the center of user's waist, close to the center of gravity of the body in a standing position, and all test users walked along with a line. Fig. 2 shows a typical example of the 3D acceleration signals of user 1.

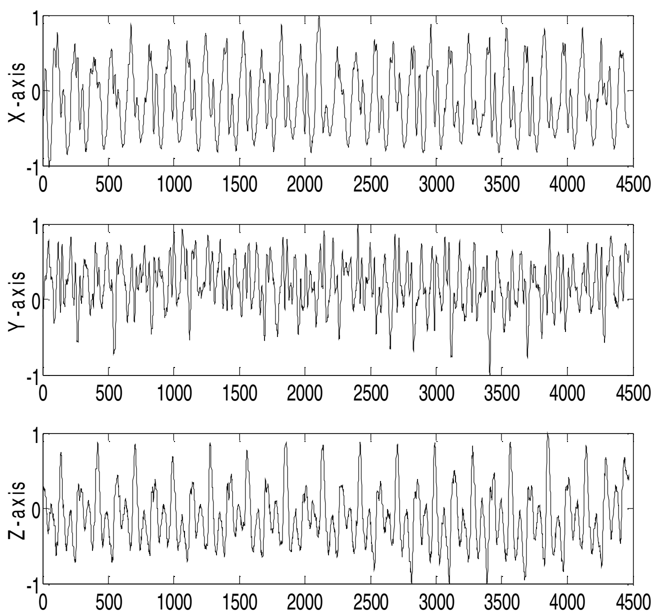

Figure 2. The tri-axial acceleration waveform of user 1

Through displaying in waveform, the various characteristics of users' walking are visible. Z and X axis acceleration signals are fairly repeatable over periods, while Y axis acceleration signal is less discriminative than them. In order to better understand the gait data, more details about the raw gait data is necessary. The Z axis direction data reflects the acceleration providing by the rising and lowering of the body during walking; while the X axis direction data only registers the sideways action of the body, and the Y axis direction data registers the acceleration when the user moves sideways.

III. Signal Denoising

When the wearable microprocessor-based accelerometer device is sampling movement data, some noise is also collected. As measured acceleration signals are low-frequency component, the accelerometer is sensitive to the environmental noise, which leads to the difficult of detecting the gait phases precisely using a simple algorithm in a microcomputer. A digital filter has to be designed to remove noise resulting from the gait data acquisition system. In our experiments, daubechies wavelet of order 8 is seen to remove the noise more effectively than others; we choose the wavelet transform for noise reduction in raw gait signals. Experimental results show the method is satisfying in noise suppression, preserving edges and details; it is also helpful for the following automatic gait cycle divided. The denoising and all subsequent analysis are performed using custom designed software developed in MatLab and C.

IV. Gait Representation and Recognition

A. Gait cycle partition

Since the three-dimensional acceleration signals associated with user's walking pattern are cyclical, they can be divided into gait cycles. The cycles are easiest to detect from the vertical (Z axis) acceleration signal. The division method is as follows:

1) Normalize the acceleration data to -1 ~+1.

2) Eliminate noise of raw signals through wavelet denoising.

3) Look for the local minimum points.

4) Locate those points of zero value just after the local minimum points. These points of zero value are the beginning or the end of a step. As the observations rarely hit to zero, the point of zero value is decided to be the point of transition from positive to negative.

5) Four consecutive points of zero value make of a gait cycle.

After that the gait signal in vertical acceleration direction is divided into cycles, the gait signals in X and Y axis can also be divided into cycles according to the division position in Z axis.

B. Gait recognition algorithm

Generally, the ideal situation is that the user walks with constant speed and walking pattern. This would lead to equal gait cycles. However, during a natural walk, a person may change his speed from cycle to cycle. It is mean that each gait cycle may be of different lengths. Hence, a classifier based on direct template-matching is not suitable. We use DTW to normalize the gait cycles, so that the step length is equal.

The structure of time warping network is as Fig. 3. The number of the points in input layer is n, which represent n sampling data of a user's gait cycle, we denote as A_k^0 (k =1, 2, …, n). After one step transfer, the nearest two continue sampling data are incorporated, and the others remain their old values, so there are n-1 nodes in the first layer. The rest may be deduced by analogy. After n-N steps combination, there exit N nodes in the output layer. The Euclidean distance is used to calculate the distance between the two nodes, d_k^i express the distance between the nodes A_k^i and A_{k+1}^i, so $d_k^i = (A_k^i - A_{k+1}^i)^2$.

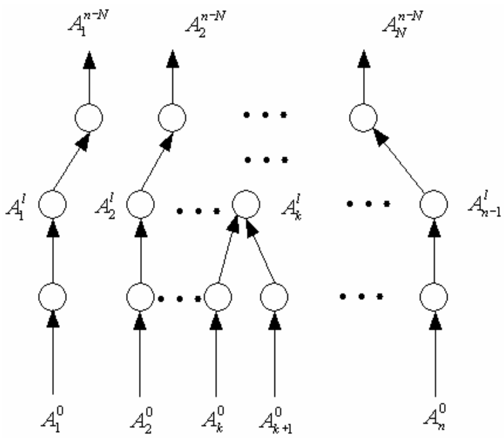

Figure 3. The structure of time warping network

The detailed algorithm description of time warping is as follows:

1) $i = 0$;

2) Calculate d_k^i (k = 1, 2, …, n-i-1) and search the values of j which satisfy $d_j^i < d_k^i$, for all $k \neq j$;

3) Calculate A_k^{i+1} (k = 1, 2, …, n-i-1) according to

$$A_k^{i+1} = \begin{cases} A_k^i & \text{if } k<j \\ \dfrac{A_k^i + A_{k+1}^i}{2} & \text{if } k=j \\ A_{k+1}^i & \text{if } k>j \end{cases}$$

4) Repeat from step 2 till $i = n$-N-1.

After time warping, The average of all these one step long acceleration signals form the template of X, Y and Z axis respectively. The combination of X, Y and Z axis template make up of the biometric template which we call it gait feature code.

In the training phase, we get the gait feature codes which associated with users' walking pattern. We call them gait feature templates. The ith user's gait feature template can be expressed as $T^i = \{T_1^i, T_2^i, ..., T_N^i\}$, N is the number of points in the gait cycle after time warping. In the identification phase, gait signals acquire from output of gait collection device are first divided into cycles. After construct their corresponding gait feature code, we could match the gait feature code with the gait feature templates which have stored in the system for recognition. The Euclidean distance is used as the local distance measure. The cumulative distance at the end of the warping path is recorded as the matching score between the test gait feature code sequence and the template. For an unknown gait feature code $U^j = \{U_1^j, U_2^j, ..., U_N^j\}$, it can be directly used for recognition as:

$$ID = \arg\min_i \sum_{k=1}^{N} d(T_k^i, U_k^j)$$

In DTW, one begins with a set of template streams, each are labeled with a class. Given an unlabeled input stream, the minimum distance between the input stream and each template is compute, and the class is attributed to the nearest template. DTW finds an optimal match between two sequences of gait feature codes.

V. Experiments and Results

Experiment with 35 healthy subjects (19 male, 16 female, aging between 20 and 45 years old) where an acceleration acquiring system was attached to the center of gravity of the body in a standing position were performed. They walked roughly 30 meters at a straight line in their normal walking speed during three weeks, and five sets of gait data were collected from each subjects. So the experiment contained 35×5 genuine trials. We applied the gait analysis method to the gait data sets which were collected from those people.

To ensure accurate results in this work, we split the gait data sets of each participant in two by random choosing one data set for the training data, and the rest 4 data sets were acted as the test set. So the training data set owned 35 genuine trials while the test set contained 35×4 genuine trials. Each of them were compared, this way, it was possible to simulate one genuine verification trial and 34 impostor trials for each test user, resulting in total 175 genuine and 4760 imposter trails.

Fig. 4 plots the Receive Operating Characteristics (ROC) curve in terms of False Rejection Ratio (FRR) and False Acceptance Ratio (FAR). The False Acceptance Ratio (FAR), False Rejection Ratio (FRR) and Total Error Rate (TER) are given for the dynamic time warping threshold T in Table 1. The Equal Error Ratio (EER) figure for our method is 6.7%.

TABLE I. T、FAR、FRR AND TER

T	FAR	FRR	TER
1.700	0.209	0.033	0.242
1.750	0.127	0.056	0.183
1.780	0.082	0.067	0.149
1.785	0.073	0.067	0.140
1.786	0.072	0.067	0.139
1.787	0.070	0.067	0.137
1.788	0.067	0.067	0.134
1.790	0.065	0.078	0.143
1.800	0.055	0.078	0.133
1.820	0.025	0.111	0.136
1.850	0.010	0.144	0.154

Cumulative Matching Score (CMS) curve in terms of cumulative correct matching scores and rank k is presented in

Fig. 5. In order to show the identify result of our method, we compared with the correlation method mentioned in [7], and the data distribution statistic method mentioned in [8]. The CMS curves show that all the methods we compared support the study made by Ailisto [7] et al, their research argued that identifying people by their gait acceleration is possible. From Fig. 5, we could find that our DTW matching method performs better than the correlation method and the data distribution statistic method.

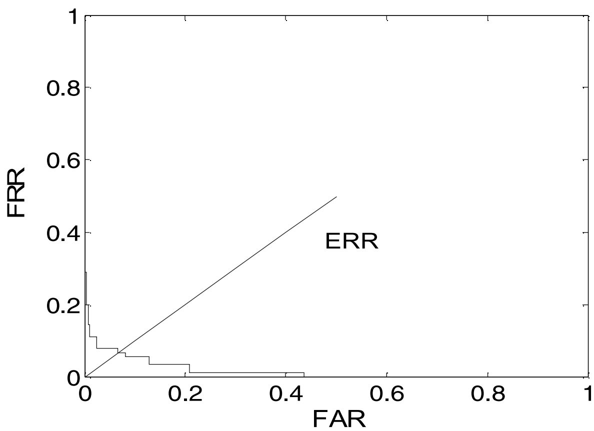

Figure 4. Receive Operating Characteristics

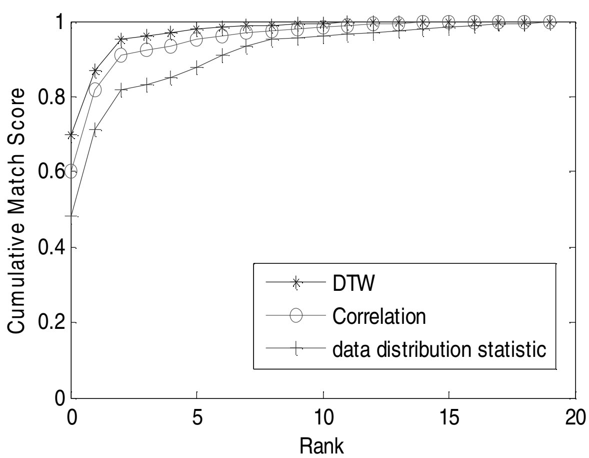

Figure 5. CMS curves

VI. CONCLUSIONS

Our tentative results with 35 test users walked in their normal walking speed confirmed the possibility of recognizing users based on their gait acceleration. Though our method could not compete with methods like fingerprint recognition or face recognition, its potential application for identification is unassailable. When combing with other authentication method, gait biometric might enhance security and even improve the usability of the system. The potential drawbacks of all gait based methods are: drunkenness, injuries, shoes (e.g. high heels) and ground affect gait. Our method shares the common challenges. The application areas of video based gait recognition system are usually surveillance, virtual reality, while our application area can be protecting of personal mobile devices, access control, and personal navigation system. Next works we plan to do include: developing effective methods for gait feature extract and analysis, performing large and long term experiments, real-time gait acceleration data transmission, so as to investigate its new applications in the future.

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