IDENTIFYING USERS OF PORTABLE DEVICES FROM GAIT PATTERN WITH ACCELEROMETERS

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ABSTRACT

Identifying users of portable devices from gait signal acquired with three-dimensional accelerometers was studied. Three approaches, correlation, frequency domain and data distribution statistics were used. Test subjects (N=36) walked with fast, normal and slow walking speeds in enrolment and test sessions on separate days wearing the accelerometer device on their belt, at back. Identifying the users with this novel gait recognition method showed to be possible. Best equal error rate (EER=7%) was achieved with signal correlation method, while frequency domain method and two variations of data distribution statistics method produced EER of 10%, 18% and 19%, respectively.

1. INTRODUCTION

Portable devices, such as smart phones and personal digital assistants (PDAs) play an important role in our everyday life. These devices contain increasing amount of valuable personal information. For example, some smart phones contain wallet and e-commerce applications. Thus, the risk associated to them is increasing. Currently the user sensitive data in mobile phones is protected with PIN codes, and particularly, in "on" state, not even the PIN code protects the information [1]. Thus, there is a need for improving the security mechanisms of data for these devices.

In this paper we present a biometric method for creating unobtrusive, implicit security mechanism. Particularly, we present a novel method for verifying the identity of the users of a portable device while they walk with devices. The method can also be applied to, e.g., wearable computers, intelligent clothing and other smart artifacts.

Identifying the user of a portable device by gait is intuitive, unobtrusive and it complies to the paradigm of calm computing [2] where the user should not be disturbed or burdened by the technology she is using. Gait, i.e., walking style, is fairly characteristic for individuals [3], whereas deliberate imitation of other person's walking style is difficult.

Gait recognition has been studied as a behavioral biometric for about a decade and methods typically utilized are based on machine vision [4-7]. The performance of the vision based gait biometrics is lower than, e.g., fingerprints, and the method is in its infancy [8].

In the fields of medical, wearable, and mobile computing the related research mainly covers recognition of various human activities, such as walking, running, walking up/down the stairs/slope [9,10,11]. Motivating application scenarios vary, e.g., from patient activity surveillance or energy expenditure estimation to adapting user interfaces of devices users are carrying. The person identification approach can be seen as reversal of the research attempts to recognize activities independent of the user.

Various biometric modalities, such as signature [12], voice [13,14] and fingerprints have been proposed for securing personal portable devices. Fingerprint and signature based methods require explicit input from the user whereas voice recognition based methods are a bit more implicit. However, the methods are more or less obtrusive and require attention.

In this paper a new identification method[1] for personal devices is presented. The method uses the acceleration signal characteristics produced by walking. The method presented differs significantly from the mainstream gait recognition research relying on computer vision [5-7] or sensors installed in the floor [15] since it is unobtrusive and it does not require any sensing equipment in infrastructure. To our knowledge there is no research work published on gait identification using acceleration sensors.

[1] Patent pending

2. METHOD FOR IDENTIFYING PEOPLE

The principle of identifying users of portable devices from gait pattern with accelerometers is presented in Figure 1. The three-dimensional movement produced by walking is recorded with a 3-D accelerometer device worn by the user. The data is first normalized to a range -1 and 1 and then it is processed using correlation, frequency domain methods and data distribution statistics. The motivation for using correlation is based on the assumption that the shape of the signal during gait is unique for every person. Also, the motivation for using frequency domain methods is based on the assumption that there is a characteristic distribution of frequency components for each person in the walking signal. Moreover, the motivation for using data distribution statistics is based on the assumption that characteristics of the signal shape affect on the data distribution. We use separate training set and test set to identify people in all experiments. The data set is described in more detail in the next section.

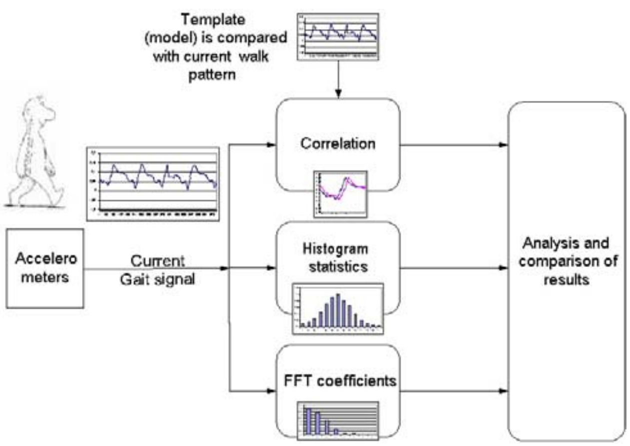

Figure 1. Block diagram of the gait based identification method

2.1 Correlation

In the enrolment phase the 3-D acceleration signals are divided into one step long parts. Since the right and left steps are not necessarily symmetrical, they are processed separately, as *a* and *b* steps. However, we do not try to identify "right" and "left". The steps are found in the signal by searching local minimums and maximums. Steps belonging to both groups are normalized in length and amplitude and then averaged. The averaged *x* (forward-backward acceleration), and *z* (vertical acceleration) acceleration signals for *a* and *b* steps form the template, while *y* (left-right acceleration) signal is omitted. This is because according to our preliminary tests left-right acceleration is less discriminative than the two other acceleration signal components. An acceleration signal for *z* direction is shown in Figure 2.

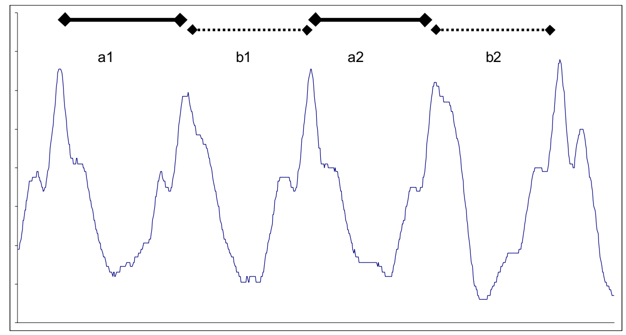

Figure 2. Typical acceleration signal (vertical direction). *a* and *b* steps are marked.

In the identification phase *c* and *d* step models are generated first. Then, comparison of the current step models with the templates is performed with cross correlation. The correlation coefficients of *x* and *z* signals are averaged giving a figure of similarity, *C*. The method is summarized in Table 1 and in [16].

Table 1. Gait recognition method using correlation

Enrolment
1. Divide the signal to parts representing steps
2. Normalize the parts, so that their amplitudes and lengths are equal
3. Average *a*- and *b*-steps forming the templates *a* and *b*
Identification phase
4. Repeat steps 1-3 for the sample, resulting in *c* and *d* step models
5. *C* = Max ((corr(*a*,*c*) + corr(*b*,*d*)), (corr(*a*,*d*) + corr(*b*,*c*)))

2.2 Frequency domain

The FFT is calculated for signals from *x* and *z* acceleration signals using 256 sample frame with 128 samples overlap between frames. The first 40 FFT coefficients per channel are concatenated as a feature vector and used for enrolment and identification.

2.3 Data distribution statistics

10-bin histograms normalized by the length of the data are composed for *x* and *z* acceleration signals. The histograms are concatenated as a feature vector. Also, third and fourth order moments are calculated for both *x* and *z* acceleration signals and concatenated as a feature vector. These feature vectors are used for enrolment and identification

3. EXPERIMENTS AND RESULTS

Experiments were performed to evaluate the potential of the proposed method. The test set-up consisted of a portable device, which the user wore on a belt, in a way similar to carrying a mobile phone or a PDA in a holster. The device contained a three-dimensional accelerometer (composed of two perpendicularly positioned Analog Devices ADXL202JQ accelerometers), and it was worn in the same position, behind at waist, by all the users: x-axis pointed forward, y-axis to the left and z-axis up. The accelerometer signals were recorded with 256 Hz sampling frequency using a laptop computer equipped with National Instruments DAQ 1200 card carried by the test subject.

The number of test subjects was 36, 19 male and 17 female, all adults. Test subjects walked about 20 m in their normal, fast and slow walking speeds. The experiment was repeated after five days to get a second data set.

The experiment contained 108 genuine trials (including slow, normal, fast walking speeds from the same person), in which the templates (day-one) were compared against current signals (day-two). Likewise, 11556 impostor trials were produced. Receiver Operating Characteristics (ROC) curve in terms of Genuine Acceptance Ratio (GAR) and False Acceptance Ratio FAR is presented in Figure 3. It must be noted that Figure 3. represents the strict interpretation of results: if a certain person is correctly identified as the same person, but with different walking speed, this is interpreted as false result.

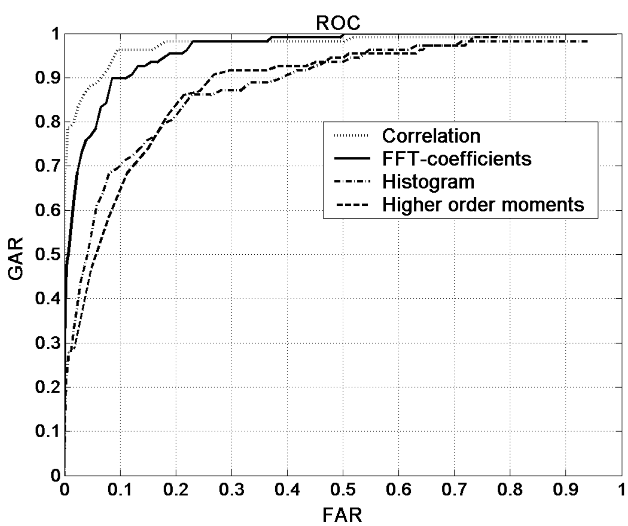

Figure 3. Receiver operating characteristics

The ROC curves show that all four methods provide good results. Particularly, the correlation method outperforms the others while the performance of using FFT coefficients is only slightly lower. Data distribution statistics methods perform almost equally providing weakest results. The Equal Error Ratio (EER) figures for correlation, FFT coefficients, histogram and higher order moments are, respectively, 7%, 10%, 19% and 18%.

Compared to video based gait recognition methods our method performs well. For example, a recent paper on vision based approach reported correct recognition rate between 60% and 85%, depending on image quality, for a test set of 20 persons walking on a treadmill in controlled conditions [4].

4. CONCLUSIONS

The tentative results with 36 test subjects walked with three speeds show that identifying people by their gait using accelerometers worn by them is possible. Although these results are very promising, it is clear that they must be improved for making practical applications feasible. Therefore, we plan to work further on presented methods and also test some other methods. Also, fusing results of several methods might improve the identification performance. It should be noted that we do not see gait biometrics as the sole user authentication method for portable devices, but rather as a complementary method for existing ones.

The performance of the new method presented here is at the same level or even better than those achieved by video based gait recognition in recent studies, which report correct (rank 1) results between 72% and 88% [5, 7, 17, 18]. These gait recognition methods differ both in technical implementation and proposed application. While video based gait biometrics are targeted for surveillance, security and forensic applications, the method presented here is mainly aimed for protection of personal devices users are carrying, such as PDAs and smart mobile phones, of unauthorized use. Protecting personal devices becomes increasingly important since the value of the information stored in them and their capabilities for m-commerce, m-banking and other transactions will be more extensively used. The identification method is by nature unobtrusive, privacy preserving and controlled by the user. The potential drawbacks of the method are partly common to all gait based methods: effect of changes in the speed of walking, shoes (e.g. high heels) and ground; also drunkenness and injuries affect gait. We must study the effect of positioning the personal device holding the accelerometers in different places and positions, such as pockets. These issues remain to be studied in the future.

5. ACKNOWLEDGEMENTS

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