Person Authentication by Handwriting in air using a Biometric Smart Pen Device

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Abstract: The phenomenon of writing reflects developed fine motor skills of a person. Specially, the dynamics of writing can be used for the characterization of the individual writer or written object. Person authentication based on the dynamics of handwriting on pad and in air using biometric Smart Pen (BiSP) device are presented in this paper. We regard hand movement with pen in space as handwriting (or hand gesturing) in air. The acquisition device BiSP is a ballpoint pen equipped with a diversity of sensors, measuring the acceleration and tilt angle of the pen, the grip forces of fingers holding the pen, and the forces and vibrations in the refill during writing, drawing and hand gesturing in air or on any solid pad. For classification, queries and references of multi-dimensional time-series provided by BiSP are matched by fast dynamic time warping DTW. To judge the biometric authentication of a writer, the recognition score rates of PIN words and single characters are computed. It was found that the score rates of performance are better 99.99% and the response time is below 2 seconds for a population of 40 enrolled persons. The proposed handwriting in air is a promising authentication method because performance of writing on paper pad and in air differ marginally. It can create a new dimension of freedom in unconstrained data input, and access control and can compete with the emerging hand gesture recognition methods.

1 Introduction

Key mouse and a touch sensitive screen can be considered emerging alternatives to the keyboard as input devices now. Especially, a touch sensitive screen is becoming more useful input device in downsized mobile units like notebooks, personal digital assistants (PDAs), cell phones or flash–memories. Hand gesture is another promising data input method. This inspired us to advance the Biometric Smart Pen BiSP [BIS] which is a device for online digital input of handwritten characters and words, drawings and gesture movements. In previous studies, many software methods have been used for the analysis of BiSP multidimensional time-series data [MJ09][MJ10]. Variants of dynamic time warping DTW [RV05][VLOK01] had been applied successfully for recognition of single characters, signatures [SL09] and PIN words [MJ09][MJ10] handwritten on a paper pad. With the diverse sensors embedded, the BiSP device allows to capture handwritten movement not only on solid pad but also free in air. The domain of handwriting in air is a huge research which has been of interest to many researchers over the past decades.

Because gesture based handwriting in air is a prerequisite to design methods allowing human–computer interaction (HCI). The area of gesture based HCI shows a high diversity with respect to the modalities. It addresses the problem of recognition of textual content of handwritten items like letters, digits or words. Approaches exist by either video-based tracking or data gloves or the analysis of hand held object (pen tip, cell phone) movements resulting from well-defined gestures like those used in handwriting. The kinematics of handheld objects is mostly captured by miniature 3-axis accelerometers, gyroscopes and magnetometers. The sensors embedded in the pen device BiSP also allows to assess the dynamics of the person specific fine motor skills of fingers in terms of force or pressure generated during writing. Other pen based approaches capture and analyzes dynamic features of handwriting by using a graphic tablet or a pad that samples the position coordinates of the pen tip [RV05][WAC]. An advanced graphic tablet, where in addition, the pen tilt and the grip pressure of fingers holding the pen are measured, proofed enhanced performance in biometric handwriting recognition [MJ11]. However, in practice, pen-based tablets obviously are inconvenient due to limited mobility and extended hardware sources are required.

This paper deals with the biometric person authentication based on handwriting in air by using DTW classifier. To create an advanced biometric input system for handwriting in air various issues of BiSP were studied from sensing to signal analysis, from feature extraction to classification, and much more to improve their performance. This paper will be a further step towards the implementation of our two-factor authentication method proposed in [MJ09], where biometric PIN word or writer recognition will be combined with the verification of biometrically recognized PIN code.

2 Biometric Smart Pen Device for Data Acquisition

The advanced BiSP is a ballpoint like pen system which allows the record and analysis of handwriting, drawing and gesture movements on a solid pad or free in air [BIS]. For a comprehensive assessment of pen movements, the device is equipped with a diversity of sensors measuring the acceleration and tilt angle of the pen, the grip forces of fingers holding the pen and the forces and vibrations generated in the refill during writing, drawing and hand gesturing on a paper pad or in air (see figure 1). The change of stylus forces and vibrations resulting from handwriting on paper pad and transferred by the refill are monitored simultaneously (1) across and (2) longitudinal to the refill axis by a piezoelectric polymer film and a piezoelectric ceramic stack placed in close contact to the front part and the end of the refill, respectively. The superimposed vibration which is mainly determined by the surface roughness and writing speed [SK03] is obtained from the piezoelectric ceramic signal high-pass filtered above 100Hz. The (3) grip pressure of the fingers holding the pen is detected by a piezoelectric foil wrapped around the case of pen at the griping area. There are two different versions of grip pressure detection available:

The first one measures the grip pressure (1) averaged over all three fingers (middle finger, index finger and thumb) and the second the pressure (2) of index finger and thumb separately by using two subdivided piezoelectric sensing foils.

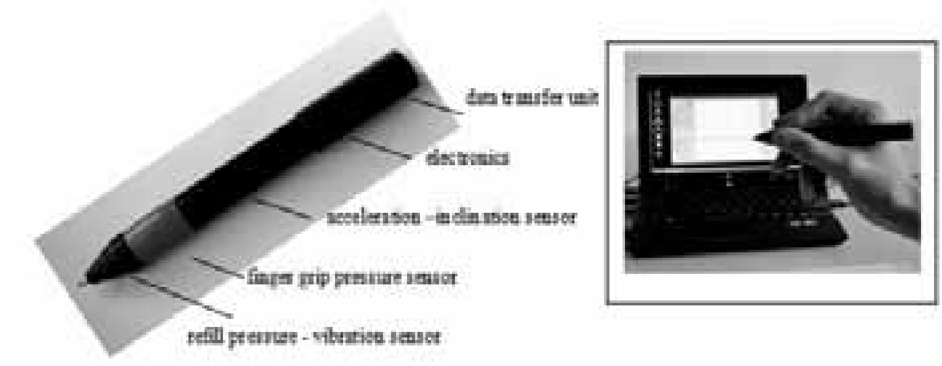

Figure 1: a view of the Biometric Smart Pen "BiSP" equipped with a diversity of sensors for monitoring handwriting movements on paper pad and in air.

The latter version is unique and provides more detailed information of fine motor skill of fingers during writing. At last a three axes micro-electro-mechanical (MEMS) sensor measures the acceleration and inclination of the device.

3 Biometric Authentication Method

A biometric person authentication system is proposed where single characters or PIN words as a sequence of seven characters handwritten by BiSP are recognized for writer identification. Handwriting words instead of signatures leads to better performance in person identification or verification [MJ09][MJ10]. Further advantages arise from handwriting in air, because it requires no solid pad and leaves no visible image of the PIN word, which is easily copied or guessed otherwise. The DTW based classifier is useful for classifying single characters or words based on a similarity match of time series [RV05][VLOK01][MJ11]. The modified fast DTW method used in the paper is described in [MJ09]. In order to judge quantitatively the performance of classification or authentication two criteria established in [MJ11] are used in the paper: (a) the score of recognition (SR) and (b) the certainty of best match decision (CM).

4 Experiments and Result

This study evaluates the person authentication based on handwritten single characters and PIN words. For this, the data is captured by BiSP device for handwriting on paper pad and in air and performance rates are compared.

4.1 Databases

The datasets used in the experiments was collected from 40 writers. Each of them has written ten times on paper pad and in air single characters and a private PIN word for all enrolled persons. The PIN word (e.g. *3WüKQ45*) used is a sequence of seven single characters selected from a set of captical letters, digits and symbols. Using BiSP device, for writing in air the elbow is resting on a desk to nearly exclude arm and shoulder movements (Figure 1). Writing in air enables the items handwritten in a small frame at the same position of space. Therefore, the collected samples were neither affected considerably by a displacement and rotation of the instrument nor by repositioning or moving the involved arm and wrist. Data processing and classification of time series were done by using a computer with a Pentium 4 processor (2.4 GHz, 3 GB RAM).

4.2 Pre-processing of multi-dimensional time series

Data analysis was performed after an adequate pre-processing of the original signal data without discarding valuable information, including the fusion of multi-dimensional time series, re-and down-sampling, smoothing, segmentation and normalization. The pre-processing steps used in the paper were established and discussed in more detail in former study work [MJ09][MJ10].

4.3 Results and Discussion

A) Handwriting in air

Writing in air activates only the sensor channels of finger grip pressure and tilt–acceleration, whereas vibration and refill pressure signals are extra generated by writing on paper pad. The movement of the pen tip over the paper fibers generates vibrations with excitation frequencies and amplitudes controlled by the roughness, hardness and the velocity. It was found in former study work [SK03] that vibration data can provide high performance rates of handwriting recognition. The writing movements are more or less controlled by the biomechanics of fingers, wrist, arm and shoulder joints so that the diverse writing modalities lead to quite different movement patterns. For comparison typical handwriting parameters of writing on pad and in air are listed in Table 1.

Table 1 typical values of parameters in comparison estimated for handwriting on paper pad and in air, ‘g’ terms the gravitational acceleration (9.81 m/s^2).

Typical values	Angular tilt $\Delta\phi$	Writing speed	Acceleration	Writing size	Grip forces	refill force
On pad	±5°	~2cm/s	0.05g	0.5-1cm	<10N	<10N
In air	±10°	~2cm/s	>0.05g	1-2cm	<10N	-------

The values estimated by own observations in the laboratory are close to such found in literature [Th96]. Force levels of finger grip and refill impact of both modalities vary in the range of about 10 Newton. The inclination is characterized by the angles measured between the longitudinal axis of the pen and the gravity direction.

It can be recorded with a resolution of less than 0.5 degree. Acceleration varies in the range of about 0.05g, where g stands for gravitational acceleration. The common size of writing on paper pad is about 0.5-1 cm. Writing in air requires less biomechanical constraints due to increased degree of freedom and more flexion and extension of joints. This results in higher writing sizes (typ. 1-2cm) and angular values of tilt (up to 10 degree) and more pronounced acceleration effects.

Note: neglecting the joint of elbow and shoulder, which generally is not actively involved in handwriting on pad, the hand-finger system has in total ten effective degrees of freedom [Th96]. Even though features and properties of writing on pad and in air differ considerly, both provide quite similar performance rates of person authentication or character recognition as shown below.

The movement patterns are the result of an abstract neuro-motor program for controlling the fine motors of fingers, wrist, etc., which can be executed largely independent of visual feedback. As a consequence a high reproducibility of signal features is obtained even if the item is written in air many times in succession without optical feedback. As seen in Figure 2 the grip pressure and tilt signals obtained for character “5” after handwritten in air up to twenty times in succession are very similar., i.e. reflect a high reproducibility in wave shape.

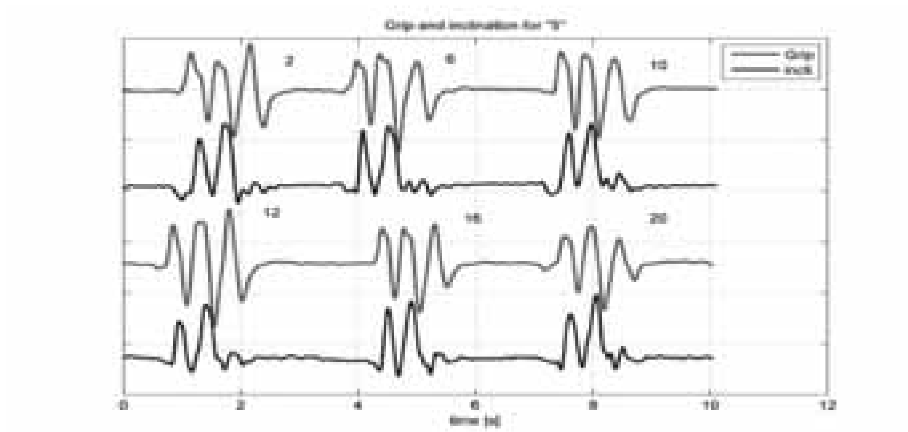

Figure 2: Grip pressure and tilt signals obtained from character “5” handwritten in air up to twenty times in succession.

B) Person authentication

Single character recognition

For single character recognition, the intra-individual DTW similarity match is accomplished for all enrolled persons. The performance averaged SR values calculated for each single character presents writer independent scores. They are obtained from data generated by writing on pad and in air and down-sampled by a factor M value of 10 as shown in Figure 3.

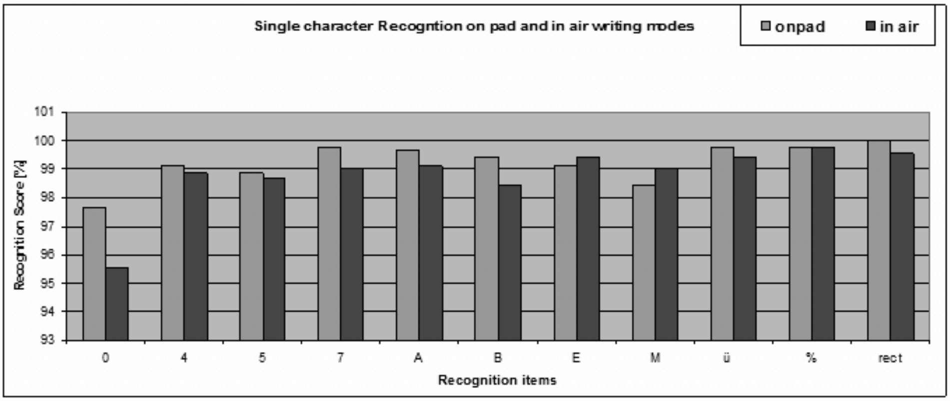

Figure 3: bar chart of performance rates of single character recognition based on writing on pad (blue) and in air (red). The values are averaged over all enrolled persons

The bar charts in Figure 3 reveal comparable results of performance for both writing modalities. Further single characters handwritten by the same person are recognized at an excellent character independent score with an algebraic mean above 99% and with a response time of less than 0.5 seconds. It indicates that the short length of a single character encodes an amazing amount of person and item specific information.

Person or PIN word identification

In [MJ09] better score rates were obtained with PIN words than with individual signatures so, here PIN word identification is considered.

Table 2: Performance parameters (SR and CM) of Person or PIN word identification based on 40 enrolled persons. Non separated finger grip pressure is measured.

M	Score SR		Certainty CM		Run time (s)	
	On pad	In air	On pad	In air	On pad	In air
20	100	100	84.94	65.89	10.5	14.5
40	99.989	99.97	41.74	45.16	3.8	4.9
80	99.138	99.83	18.20	23.83	1.6	2.0

For comparison SR, CM and run time are determined. The values averaged over all 40 persons enrolled by writing on pad and in air and determined at different M are listed in Table 2. Table 2 shows comparable performance scores in writing on pad and in air and reflect a very high quality of performance. It is shown that in air data requires higher computing time because of larger size of writing leads to more data points per entry. A drawback is the computing time of a few seconds needed to identify a PIN word among its population. To cope with this problem the speed up methods as described in [EM00][VLOK01][SC07] for DTW can be helpful especially for a larger population. Due to the highly scored recognition down-sampling allows us to tailor the computing time down to less than two seconds without a rigorous degradation of performance. We conclude that handwritten single characters and PIN words in air can be recognized at an excellent performance (better 99%) with a response time of less than two seconds.

5 Summary and outlook

Apparently, the authentication method based on the multi-sensor acquisition device BiSP for writing in air is a promising approach to increase user's acceptance, level of security and enhance reliability of biometric person authentication. Preliminary results have shown better identification score 99.9% and the response time can be less than 2 seconds. In further respects writing, drawing or gesturing in air is creating a new dimension of freedom in unconstrained data input and access control especially for more and more downsized mobile units like cellular phones, PDA's, mobile flash memories, etc. An application seen for the BiSP device is the biometrical protection of the mobile USB memory stick. For this, the stick is plugged on the USB port of the pen device. The biometrical data needed are generated during handwriting free in space. This pen based technique is a compelling alternative for fingerprint to secure a USB stick. An objective of our ongoing future work is to implement two-factor authentication method where biometric PIN word recognition is combined with biometric PIN code verification. Further, to investigate the feasibility of the proposed system based on movements of any handheld body. It is to understand whether any handhold mobile system like, cell phone, etc., can recognize its owner by how the person performs a particular gesture, acting as a gesture signature, password or PIN in air. The gesture in air can be used for access to the mobile device, but the handheld device can also act as an intelligent key to provide access to services in an ambient intelligence scenario. For these modalities well-defined gesturing patterns has to be captured, analyzed and classified using the sensor and software techniques developed for the BiSP system.

Acknowledgment

The support given by the BiSP team from the University of Applied Sciences Regensburg is highly acknowledged. We thank Florian Kempf of University of Wuerzburg, Germany for his useful comments and discussions on this work.

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