Personal Authentication by Free Space Signing with Video Capture

Masaji Katagiri and Toshiaki Sugimura
Multimedia Labs. NTT DoCoMo, Inc.
katagiri@mml.yrp.nttdocomo.co.jp

Abstract

The authors propose a new personal authentication method that is specially suitable for mobile services. Signatures are written in the air by hand and the resulting movements are captured by a video camera. Since video cameras can be much smaller than tablet devices, this technique will reduce terminal size. We build a prototype system and evaluate its performance under ideal conditions. The results confirm the technique's feasibility. The experiments reveal the unique property that signatures signed in the air are hard to imitate.

1. Introduction

The recent dramatic increase in the popularity of mobile phones is placing more attention on mobile applications. Mobile E-commerce is one of the promising applications that could grow rapidly in the near future. This emphasizes the importance of the security of mobile services. Personal authentication / verification is critical if we are to minimize the damage caused by lost terminals and other malicious activities.

Biometrics is a promising approach to personal authentication / verification [4]. Fingerprint verification is the most often discussed technology. Its adoption is, however, somewhat problematic due to its poor social acceptance and several technical problems.

We examined signature verification with the view of applying it to mobile terminals. Signature verification is considered to have better social acceptance. Electronic tablets are the usual way of capturing signatures, but they require a fair amount of flat space and so are not suitable for small mobile terminals. In order to overcome this problem, we propose a new method that uses a video camera to capture signatures. In our method, the signatures are made in the air; the resulting pen movements are captured by a video camera and tracked by image processing technology. We confirmed the method's feasibility experimentally. This method contributes to miniaturizing the terminal. Moreover, no contact is needed. The essence of our work is the method of capturing the signatures. To evaluate the feasibility of the proposed method in a preliminary experiment, we utilize a commercial signature verification engine. Such engines offer reasonable performance since commercial signature verification systems based on electronic tablets are on the market [2].

The rest of this paper proceeds as follows. Section 2 outlines the proposed method for personal verification by free-space signing. Section 3 describes the configuration of the prototype system. Section 4 shows the initial experimental results.

2. Free-space signing for authentication

2.1. Personal verification by signatures

Signature verification is a well-established and well-accepted method, especially in western countries. Even in the IT era, signatures are the predominant technique for sensitive commercial operations such as check validation and credit card processing. A lot of effort has been done to automate the verification process using computers to process electronically captured signatures.

On-line (dynamic) signature verification uses time sequences of pen velocity and pressure data, as well as signature shape. It has better performance than with the static approach that uses only signature shape [2]. Since electronic tablets can measure these parameters, they are the most popular input devices for signature systems.The barrier preventing their use in the next generation of mobile terminals is their excessive space requirements. One alternative is the recently proposed range of special pen-type devices[7], [8],[9], [10]. The pens use small sensors and/or laser devices to capture pen movement. Unfortunately, such pen-type devices must transfer the signature data to the computer where the verification process is performed, therefore they are problematic for use with mobile terminals in terms of size and battery consumption.

However it is captured, the input signature data must be compared against the registered reference signature. If they are similar enough, the signature is determined as genuine. On the other hand, if the similarity is insufficient, it is not accepted as a valid signature. It is obvious that two signatures written by the same person will not be exactly the same. Therefore, the system must cope with this kind of difference as well as catching the differences created by forgeries.

To permit the rapid testing of our key advance, video capture, we employed the signature verification engine produced CyberSIGN JAPAN Inc. [2], [3] without any tuning. Since this engine assumes normalized signature data in terms of size, position, and time scale, all signature data is normalized before being fed to the engine. The engine performs DP matching between the reference signature and the input signature using time-based data. The difference in the time domain is calculated by summing the widths in the time domain shifted by DP matching for all sampling points. Moreover, the shape difference after DP matching is calculated by summing the absolute distances for all sampling points. The system uses these two factors to determine signature similarity. The system determines the signature as genuine or not by a comparison to a threshold.

2.2. Capturing signatures by video tracking

2.2.1 Assumptions

The point of this work is the use of signatures made in free space and captured by a video camera, instead of drawing them on electronic tablets.

When making signatures in the air, there is no guarantee that the pen will move across a flat virtual surface. The pen can move freely in 3 dimensions. It is possible to measure the 3 dimensional movement of the pen by employing a stereo measurement system created with multiple cameras. However, multiple cameras are not suitable for mobile terminals because of the size and weight of the equipment required. We considered that the data captured by single camera would be sufficient for our application by making the following assumptions.

1. Signatures made in the air are drawn on a plane orthogonal to the camera.
2. There is no significant movement of the pen in the depth direction while signing.

2.2.2 Space and time resolution

Video cameras usually have lower resolution in terms of space and time than electronic tablets (table 1). This lower resolution may degrade the performance of personal verification.

Table 1. Comparison of tablets and video cameras

item	tablets	video cameras
spatial resolution	$0.025\,mm$ (accuracy:$\pm 0.5\,_{mm}$)	640×480 $dots/screen$
time resolution	$100\,points/sec$	$30\,frames/sec$
other information	pen up/down, pen pressure	intensity, color

The standard frame rate is 30 frames/sec (i.e. 60 fields/sec) following the *NTSC* specification. However, recent imaging devices can achieve the frame rate of 120 frames/sec in terms of capture speed and data transfer rate. That means there are no major technical or cost barriers to realizing such high-speed video cameras. Please note that actual manufacturing costs strongly depend on production volume.

Based on the above consideration, although our final goal is to utilize the video cameras embedded in visual phones, we assumed the following ideal environment to simplify this initial feasibility study.

1. full *NTSC* spatial resolution
2. double the frame rate (time resolution) of *NTSC*'s field rate (60 *fields/sec*)

The basic condition above shows our evaluation strategy. That is, we eliminate the low time resolution from video cameras by using commercial high speed video cameras, and limit the weak points to the spatial resolution and difference in input method. We clarified their influence on the personal verification performance of the prototype system.

2.2.3 Start / end point of signatures, strokes and characters, and pen pressure

Electronic tablets can measure pen pressure. Such data can not be directly determined from video images. This causes problems because the system cannot find the beginning or ending of signature strokes. Our assessment of this is given below.

1. **Beginning and ending of signatures**

   The precise detection of the beginning and ending of signatures is important to achieve acceptable verification performance.

   In our experiments, we asked the subjects to let the pen stay in the same place for several seconds when beginning and ending their signatures.

2. **Strokes and characters**

   Isolating strokes and characters is important for character recognition. However for signature verification, it is not so important, since signatures are more like free line drawings rather than sets of characters. Therefore, we did not isolate strokes/characters. We treated all signatures as drawn in one stroke.

3. **Pen pressure**

   Obviously the prototype system can not obtain any data related to pen pressure. Since the commercial signature verification engine we used needs pen pressure values to be input, we entered constant dummy values as pen pressure values.

3. The prototype system

We built a prototype system in order to study the feasibility of the proposed method. Its configuration is shown in figure 1. Since the main purpose of this prototype system is to confirm the feasibility of the method, we used an “ideal environment” as the first evaluation step. In this environment, lighting variation and all other such variables were ignored. This policy allowed us to construct the prototype quickly by combining commercial equipments.

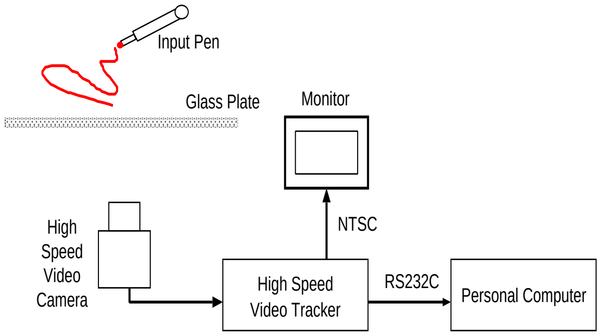


Figure 1. Configuration of the prototype

3.1. Input data

To capture pen movement, it is necessary to track the pen across the screen and to generate a time sequence of screen coordinates. We used a commercial video tracker for this purpose. The video tracker can track a bright point across a screen at the time resolution of 120 *points/sec* (twice *NTSC*'s field rate). Basic specifications of the video tracker are shown in table 2.

Table 2. Specifications of the video tracker

Model	OKK Inc. G280-204S
Space resolution	640×416
Time resolution	$120\ points/sec$
I/F	RS232C
Input video	monochrome (special high speed camera)
Target to be tracked	choice of bright point or black point

The video tracker is not robust against environmental light sources since it simply finds the brightest region on the screen and outputs the coordinates of its center continuously. Though this would be a serious problem in actual use, we leave the resolution of this problem for a later study. As a rough countermeasure, the pen used in the tests had an LED at its tip (figure 2). With the LED lit, the video tracker could track pen movement reliably.

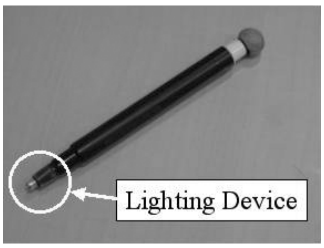


Figure 2. Signing pen with LED

Figure 1 shows the glass panel that was placed orthogonal to the camera. The panel was used to guide the subjects when signing. That is, the panel helped to keep the pen in the camera's field of view during signing. In addition, the glass panel had other purposes in other experiments (see section 4.2.2).

3.2. Verification process

We used the commercial signature verification engine provided by Cyber-SIGN JAPAN Inc [6]. We normalized the size, position, and time factor (number of sampling points) of signature data in a preprocessing operation.

4. Experiments

4.1. Overview of experiments

We focused on the following items in the experiments.

1. basic functionality (personal verification performance)
2. the effect of making signatures in free space
3. the repeatability of such signatures

4.2. Basic experiments

We asked approximately 100 subjects to sign their name using the three styles described below using the prototype system. They were (a) signing in the free space just above the glass panel, (b) signing on commercial electronic tablets, and (c) signing on the surface of the glass panel (figure 3).

For each of these three styles, the following number of signatures were collected from each subject. Three signatures per subjects were collected for registration, and their average was used as the reference signature. Ten signatures were collected as genuine signatures for verification testing. In addition, each subject was shown the signatures of three other subjects and was asked to forge the signatures. Five forgeries per signature were collected from each subject.

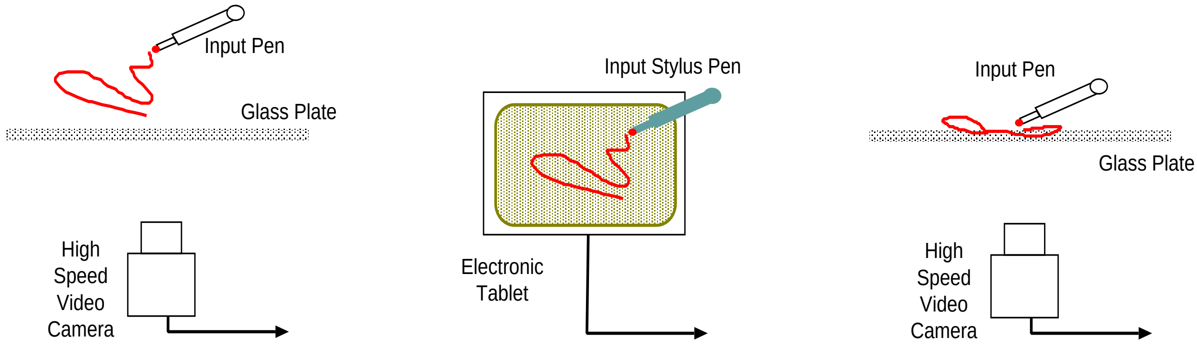
Sample signatures are shown in figure 4.

Table 3. Basic functionality experiments

item	collected samples	valid samples
number of subjects	105	96
signatures for registration	315	288
genuine signatures for verification	1050	870
forgery	1575	1240 - 1270

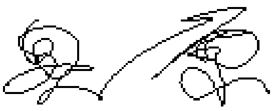
Table 3 shows the scale of experiment. "Collected samples" in the table indicates the number of subjects/signatures collected for each signing style. Some data were incomplete (mostly due to battery problems), they were manually excluded. "Valid samples" in the table shows the number of subjects/signatures for each signing style after this exclusion.

The results are plotted in figure 5. Each graph shows the distribution of distances (similarity) from the registration signatures for genuine signatures and forgeries. The X-axis

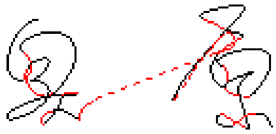


(a) Signature in free space *(b) Signature on a tablet* *(c) Signature on the glass panel*

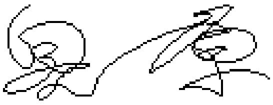
Figure 3. Experimental signing methods



(a) Signature in free space



(b) Signature on a tablet



(c) Signature on the glass panel

Figure 4. Sample signatures

shows the distance in the shape domain, and the Y-axis shows the distance in the time domain. The threshold function was taken as a linear function. Under the condition that *FRR* (False Rejection Rate) equals *FAR* (False Acceptance Rate), we calculated the optimized threshold function. The results of *FRR*(=*FAR*) and *verification rate* are indicated in the graphs. In addition, excluding the assumption of the equality of *FAR* and *FRR*, *ROC* (*Receiver Operating Characteristics*) for signatures in free space are calculated and shown in table 4.

4.2.1 Basic functionality

We first evaluated the basic functionality of the proposed method using free-space signatures.

The distribution of distances (similarity) of free-space signatures is shown in figure 5(a). For reference, the distribution of distances of signatures collected using an electronic tablet is also shown in figure 5(b).

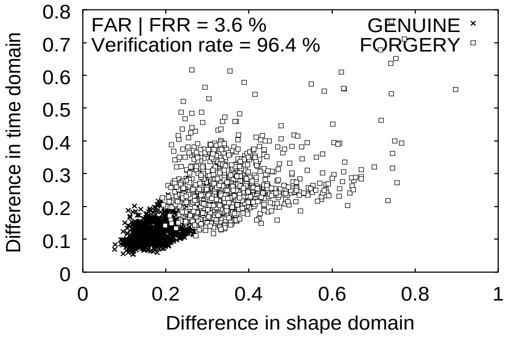
Genuine signatures have similar distributions in figure 5(a) and (b). The forgeries, on the other hand, show different trends. Though forgeries drawn in free space have bigger divergence in the time domain, they have less divergence in the shape domain; the result is greater overlap of genuine signatures and forgeries. This worsens the verification rate of signatures in free space. The lower spatial resolution of the camera (compared to the tablet) is considered to be the reason for this.

Table 4. Receiver Operating Characteristics

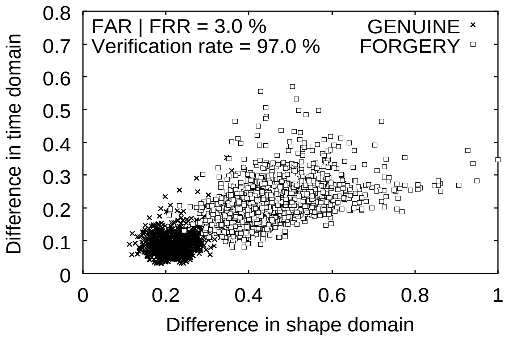
FAR(%)	*FRR*(%)
0.1	16.4
1.0	7.0
2.0	4.4
3.5	3.6
5.0	2.6
7.0	2.0
16.3	0.5

In actual E-commerce applications, the failure to detect forgery causes severe problems like swindling. Therefore, *FAR* is often required to be less than 0.1%. According to the *ROC* achieved by our method (see table 4), in the case of 0.1% *FAR*, *FRR* is 16.4%. This means that a false rejection will happen once in every 6 trials.

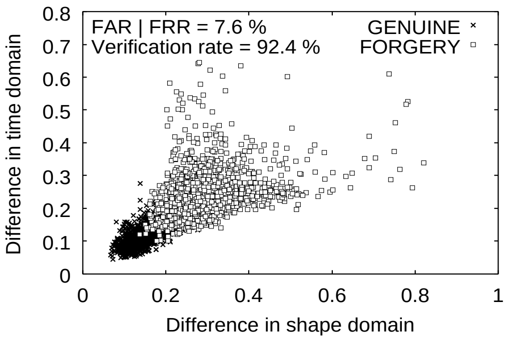
In general, it is not easy to evaluate the accuracy of biometrics authentication under practical conditions [1],[5]. In our case, the forgeries were made after viewing the genuine signatures and undergoing some training. That means, every non-genuine signature represented a deliberate forgery. On the other hand, evaluations for fingerprint authentication are usually conducted using random fingerprints. Actually, fingerprints are hard to imitate, but forgers can practice the signature before attempting the forgery. This implies that the signature authentication method should be evaluated under certain strict conditions. However, we believe the assumption, that every signature except genuines is forgery, is still handicapped too much, and the system is expected to have better *ROC* in actual use. Moreover, there is considerable room for improving system performance by parameter tuning, such as introducing a higher order threshold function and applying a gray zone. This implies that the method will have acceptable



(a) Signature in free space



(b) Signature on a tablet



(c) Signature on the glass panel

Figure 5. Evaluation results of performance

performance in actual use.

As we mentioned before, the beginnings and endings of signatures were determined by intentionally halting pen movement. However, we observed that in some cases the pen did not remain stationary long enough, leading to failure of start/end point determination.

In order to overcome this problem, we created a pen that had a push switch to activate the LED. The subject depressed the switch (activating the LED) while signing. Since this pen provides the subjects with feedback, the subjects made fewer errors. Although some training was needed, all subjects were able to sign properly. This eliminated the errors made in determining the beginning and ending points. Although only a few evaluation experiments were conducted with this new pen, we considered that this switch overcomes the problem, so we eliminated the signature data containing wrongly estimated beginning and ending points.

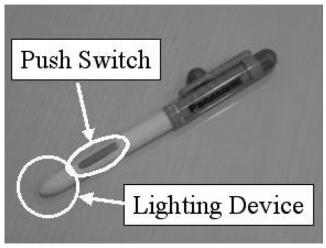


Figure 6. Pen with switch

4.2.2 Effects of signatures in free space

We evaluated the impact of moving the pen in free space by comparing system performance with free space signing to signing on top of the glass plate.

Genuine signatures have similar distributions as shown in figure 5(a) and (c) as well as (b). However, the results show that forgeries have less distance in the shape domain and that results in larger distribution overlap between genuine signatures and forgeries. This yields the significant result that the verification rate of signatures in free space is better than that possible with signatures drawn on the glass plate. We expected that the depth variation of the pen used in free space would cause a decrease in verification performance. However, the results deny this expectation. A rough analysis implies the following.

1. Good forgeries can not be created from just the shape of the genuine signature
2. Personal differences are emphasized if the degree of freedom is large

However, in order to fully clarify the reasons, more careful experiments and studies are required.

4.3. Repeatability over time

For signature verification to be successful, all signatures written by the same signer should be stable so that their shapes are very similar. Signing in free space offers a larger degree of freedom. Moreover, it is not easy for signers to adjust the signing motion, since the visual feedback available is weak. These factors suggest the possibility of signature instability. We conducted an experiment to confirm the stability of signatures made in free space over a one month period. Ten signatures per subject made in free space were collected from ten subjects after a one month period. These signatures were compared against the reference signatures collected in the original experiment (the reference data generated in section 4.2 were used).

Some details of the experiment are shown in table 5. We observed that one subject made completely different signatures. According to interview notes, he forgot his reference

Table 5. Time stability experiments

item	collected samples	valid samples
subjects	10	9
genuine signatures	100	90
time elapsed	approx. 1 month	
method of signing	signing in free space	

signature. Since we considered that would not occur in practice, we removed his data from the evaluation set. "Valid samples" in the table shows the number of subjects/signatures after the removal of this data.

The results are plotted in figure 7. *GENUINE* in figure 7 denotes the distribution of distances for the signatures collected at the same time as the reference signatures. *LATER* denotes the distribution of distances for the signatures collected after the one month period. *LATER* values are shifted towards the upper right. This indicates an increase in the distance of signatures from the reference data. The *FRR* was 7.8% based on the same threshold function calculated in the experiment of section 4.2.

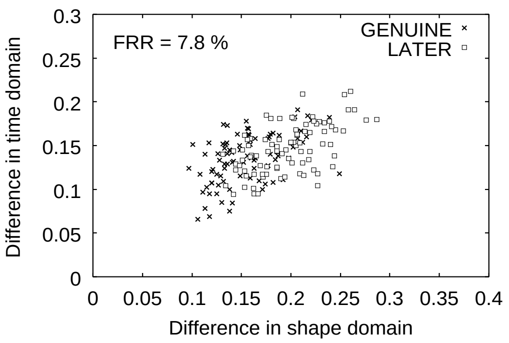


Figure 7. Signature stability over time

We analyzed the results for each subject and found significant individual variations. Table 6 shows the distribution of subjects who had the corresponding number of false rejection occurrences. Some subjects had very stable signatures and so had zero false rejections. Other subjects suffered false rejections.

Table 6. Number of subjects and false rejections

Number of false rejections	0	1	2	3	4	5+
Number of subjects	5	1	3	0	0	0

According to the above results, the stability of free space signatures is not adequate (too many false rejections). The subjects (all Japanese) were not really familiar with signing since it is not a Japanese custom. This might be one factor. Since some subjects could create stable signatures, it seems likely that most people could achieve the same performance with practice.

5. Conclusion

The authors have proposed a new personal authentication method suited for mobile services. Signatures are written in free space and the resulting gestures are captured by a video camera. A prototype system was built and tested. The results confirmed the feasibility of our method and showed its promise.

This method enables to people to be verified without any physical contact. In addition, the experiments revealed that signatures made in free space are hard to imitate. We are proposing this method as an alternative to using electronic tablets for personal verification. It also seems feasible to use it to achieve personal verification by gestures.

As future work, we should improve the method's robustness against non-orthogonal signing planes, coping with environmental interference, making implementation feasible by reducing size and weight, and developing a methodology to improve time stability.

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