Haptic: The New Biometrics-embedded Media to Recognizing and Quantifying Human Patterns

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ABSTRACT

Authentication for the purposes of security has taken giant strides since the introduction of Biometrics to help identify people by their behavioral and physiological features. From organizations and corporations to educational institutes, electronic resources, and even crime scenes, Biometrics offers a wide application scope to detect fraud attempts. This paper proposes a research path to achieve the task of authenticating users that are working in a haptic-based environment. The field of Biometrics can be divided into two main classes of human features. Birth-given characteristics like fingerprints and facial features cannot be developed or altered by humans. Behavioral characteristics such as hand signature and voice fall into the second class [1]. The work presented in this paper pursues the latter class and specifically studies how a person reacts to using daily devices or tools. The fact that we can exploit people's habits in handling devices to detect identity was the hypothesis that motivated this work.

Categories and Subject Descriptors

I.3.7 [Computer Graphics]: Three-Dimensional Graphics and Realism - *Virtual Reality*. I.5.3 [Pattern Recognition]: Clustering – *Similarity measures*.

General Terms: Design, Verification, Experimentation.

Keywords: Biometrics, Haptic Systems, Hapto-task.

1. INTRODUCTION

Our society is rapidly becoming more computerized. Access to high-restricted areas, documents, privilege services and executions of tasks are, among others, the main concerns in terms of security in many organizations. Biometrics is contributing immensely to ease those concerns; related technology has already been implemented to help identify people via fingerprints, face images, iris, handwritten signatures, and voice signals. Many normal executions of daily tasks have been simulated in a completely virtual world that simulates applications of surgery, military training, tele-operation, and tele-manipulation. Such virtual environments require the installment of sense of touch and force feedback interaction scenarios to provide realism. Haptic systems provide a sensory channel to the human-computer interaction scenarios through tactile and kinesthetic. Haptics is a term that has its origins in the ancient Greek language to mean "to touch" or "to handle". This technology requires a level of security that guarantees that only the correct user gains control over the system. By using the physical output and facilities of the haptic devices, this study proposes a software system that could extract the user' characteristics when he/she performs a designed task using the haptic device in a particular session. These personal features are analyzed and compared with a reference or against others models in order to provide a level of authenticity.

As mentioned before, the field of Biometrics can be divided into two main classes: according to features that humans are born with, such as fingerprints or facial features, or behavioral characteristics, like a handwritten signature or voice [1]. We will pursue the latter class. Among the many examples of the potential uses of this class of Biometrics is the particular force applied to the keys in a keyboard. There's also the time interval between each keypad when dialing a telephone number. Another example that can be extracted from the latter would be the map described by the fingers in the dialing operation. Extracting these features by using a haptic-based application and defining the subsequent individual pattern is the objective of this research. A framework that identifies behavioral patterns through physical parameters such as direction, force, pressure and velocity has been built. The set up for the experimental work consisted of a multi-sensory tool, using the Reachin API software and the Reachin Display hardware [7]. A virtual mobile phone was implemented where the user interacted through the haptic pen to complete a series of dialing trials. This study followed principles that had already been studied in the traditional biometric system, such as signature verification, speech processing and keystrokes dynamics [2,3,4]

This research has been motivated by the idea of using the haptic devices as mechanism for analyzing individual's biological and physical attributes such as hand-finger positions, velocity and force exerted during the haptic sessions [3,4, 5].

2. RELATED WORK

This innovative concept of introducing haptic systems to the security systems for identifying users has not been investigated yet. In other words, we would not exaggerate if we said that, to the best of our knowledge, no other work has examined haptics from a Biometric point of view. Indeed there are some close related works [3,5]. However, our concept is somewhat based on that of traditional behavioral biometric systems, such as keystroke dynamics, speaker recognition, and signature recognition [2,3]. In the past two decades, keystroke dynamics research has been studied in terms of latency timings [3]. These studies describe a particular pattern defined by a simple approach that the keystroke durations provide. It can be said that our study is a child of

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previous works, but it extends the concept by using the dynamic devices that provide real time physical parameters in order to obtain a biometric template for each user. This system adds parameters such as force exerted, speed of hand motion, and the pen's position during the haptic training [11].

3. METHODOLOGY

3.1 Experiment

3.1.1 Using a stylus to dial telephone numbers

Every day, people interact with different devices, whether it is while checking e-mail messages via the computer, driving a car, or using a mobile phone. These devices have become part of our daily environment. It would not be an understatement to say that almost everybody has a unique way of opening a door or typing a message using a keyboard. In order to discover such patterns, we designed an experiment where users dial a set of telephone code by using a virtual mobile phone with force feedback stimuli.

3.1.2. Subjects

For our subjects, we chose 20 students from the University of Ottawa. There were 7 females and 13 males. Being that most of them were unaware of haptics, the selected students were introduced to such scenarios through some demos that familiarized them with the device.

3.1.3 Apparatus and Stimuli

To create the all important force feedback, a haptic set and stereo viewing were utilized to provide a highly realistic multimodal stimulation [7][8][9].

3.1.4 Software Application

The haptic application was developed using the Reachin® API [7], which provides the haptic stimulus. This application-programming interface provided direct access to the tracking device via various position (Θ), orientation, time (t), force (F) and torque (T), etc events. The haptic software application was developed in a combination of VRML-based scene and Python scripting programming language. The VRML-node fields' approach created the 3D virtual environment. The other hand Python provided the procedural process to handle the programmed events and registered the output data to a file.

3.1.4 Procedure

The subjects wore stereo glasses to be able to see through the semi-transparent mirror. The glasses and the mirror became the interface where the graphics and the haptics were co-located so that users could feel and see the object. The virtual environment depicted a realistic mobile phone with haptic characteristics. Its key buttons were dynamically deformable and provided a real pressing sensation.

Before each trial, subjects were instructed to explore the scenario and get used to the haptic device and its feedback sensations. The trial started when the subject dialed the 5 telephone numbers. When carrying out the skill mode test, the numbers appeared on the right side of the screen. To signify a call, the subject had to press the "green-phone" key. Then, after a short interval of time, the subject pressed the "red-phone" to terminate the call and consequently, be able to carry on with the next telephone number until the fifth number was dialed. In the second testing mode, the user dialed a familiar number several times.

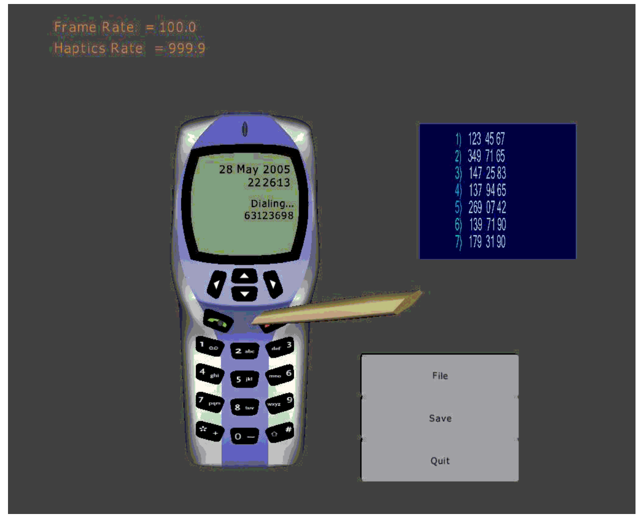

Figure 1. Screenshot of the user dialing code process. The user is required to dial the 7 numbers that appear on the right side of the screen.

3.2 Framework

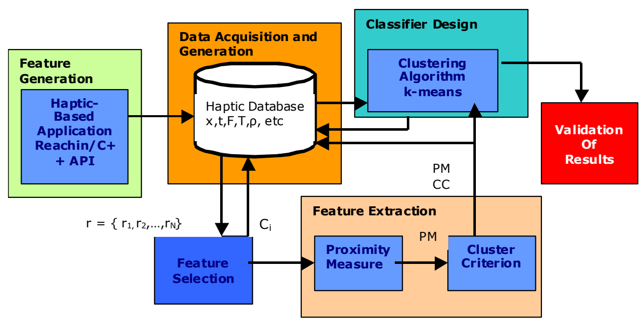

Figure 2. The proposed dynamic haptic-based authentication system.

The proposed haptic-based authentication system is illustrated in Figure 2 and is composed of five modules: 1) data acquisition 2) Feature Extraction; 3) Feature Selection; and 4) Classifier Design and 5) Verification.

In the data acquisition module, the dialing code sessions are acquired and digitized by the software application. The keystroke duration, pen's position, force exerted parameters are recorded according to the programmed application of the haptic device API [7]. The discrete signals of the mentioned variables are computed in the feature selection process module. Then, they are normalized before being sent to the feature extraction module. In the feature extraction module, pre-configured feature extractors calculate the key information of the input dynamic dialing code. For the training dialing codes, the extracted sampling feature vectors are clustered and sent to the verification module to be compared with other templates by using a signature classifier.

3.3 Data Acquisition

The performance results reported here are based on a database of profiles collected over a period of 4 weeks. The data was collected on a workstation at our lab, where the Reachin system [7] had been installed. We used a virtual phone model in a set of trials where the users were asked to dial the 7 digits telephone code that appeared in the right side of the screen. This virtual environment provided a mechanism to test individual skills in dialing and handling concentration in such a process. Volunteers who took part in this experiment performed the same dialing code 10 times. An example of users' profile of the force exerted during the dialing code is illustrated in the Figure 3.

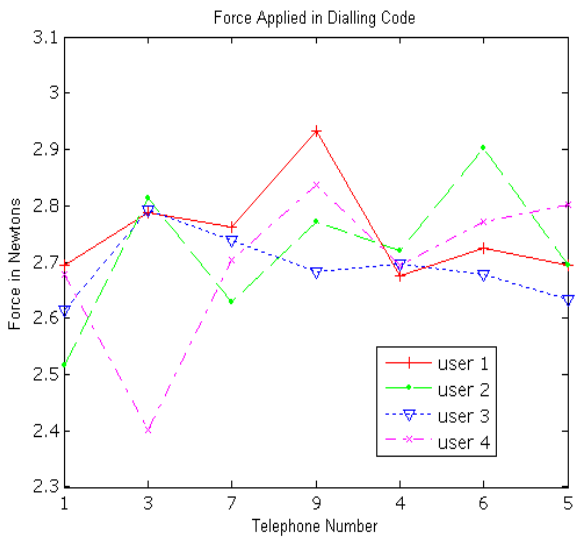

Figure 3. Profile of the force exerted during the dialing code for 4 users from the group.

It is important to mention that each user provided a remarkable profile for the force applied to each of the virtual keys, but it is equally, if not more important to note that there were some difficulties encountered in discriminating one user from another.

3.4 Analysis

In order to explore and ultimately provide an index of reliability, a method for classifying the data was implemented. The data generated was analyzed with principles of the pattern recognition discipline in mind [6].

3.4.1 *Feature Extraction*

The 'theme' of this experiment is somewhat related to the keystroke dynamics. The exercise of dialing a telephone number sets the stage for a similar pattern, where a user types on a keyboard or autographs a handwritten signature. Therefore, the design of the feature set is a hybrid approach. It considers the dynamic signature verification point of view [5], and authentication based on keystrokes dynamics [4]. It crucially takes advantage of the physical output recorded by the haptic device [7]. Understanding that dialing a telephone number describes keystroke information, we extended the concept introduced in [4] and modified it by adding the physical measurements such as force, speed, and pen's angle position captured by the software application.

A simple and promising approach for tackling the authentication issue by applying keystroke dynamics was introduced by Joyce and Gupta [3]. In the work of Q Tong [5], an algorithm based on observing the keystrokes characteristics in terms of gradients of pressure, velocity, and pen's angles was introduced. By combing both approaches and taking advantage of the haptic device in terms of the physical data output, a feature generation process was designed. The keystroke information generated during the dialing code session is obtained from pressing the numerical keys of a 7-digits telephone code. These are the duration between phone keys (numbers), the speed of dialing, force exerted by pressing each key and the pen's position of the haptic device during the dialing code process. The mean values of each variable were calculated and an outliner removal threshold between 2 and 5 times the standard deviation was applied. By observing these 4 variables in a dialing process of 6(7 number dial) steps we generated, feature set (S) of 24 attributes according with the following:

$$S = \{s_1, s_2, \ldots s_N\} \quad \text{For} \quad i = 1,2\ldots, N$$

$s_i = \{t, v, F, \theta\}$ Where, for example, the sub vector of the features of duration is defined as follow:

$$t = [\bar{t}_1, \ldots, \bar{t}_m, \sigma_1, \ldots \sigma_m]^T \quad \text{For } m = 1, 2, 3$$

Information falls under different domains, which require data normalization as preprocessing stage [6]. It is carried out by calculating the mean and variance values for a *k*th feature from a set of N available data. Some user's data sets were discarded without affecting the overall analysis.

3.4.2 *Clustering Stage*

In the following stage, we face the task of disclosing the organization of the user's templates into sensitive groups or clusters predefined, in order to explore dissimilarities and similarities among them. Partitioning the data set can provide a quick overview for adding useful conclusions. We are currently incorporating the K-means method to observe the mentioned user attributes.

The goal of clustering is to determine the intrinsic of grouping in a set of unlabelled data. It is important to identify common attributes between users, according to the way they handle the pen or the dialing code speed or by the force applied. The nature of the experiment dictates that the users' templates be organized into more sensible groups or domains defined for the above mentioned attributes. Among different minimum distance classifiers we select the well-known Euclidean distance as a proximity measure, which is a particular case of the Mahalanobis metric. Heuristically, we believe that in this experiment, the way that user's stylus is handled in terms of position is considered as a good measure for the sensibility of classification of the information.

3.4.2 Classification

The results obtained through this clustering technique need to be materialized in order to find a compact description of each cluster. Suitable methods for quantitative evaluation of the results of a clustering algorithm have been studied exhaustively. Therefore, a term denominated cluster validity is in charge of the assessment of the clustering procedure's output. In this preliminary study, we follow an approach of validating a single clustering scheme based on an additional index matrix. The main idea in this technique is to find the degree of match score between a given clustering scheme *S*, consisting of *K* clusters, and the proximity matrix *P*. [10].

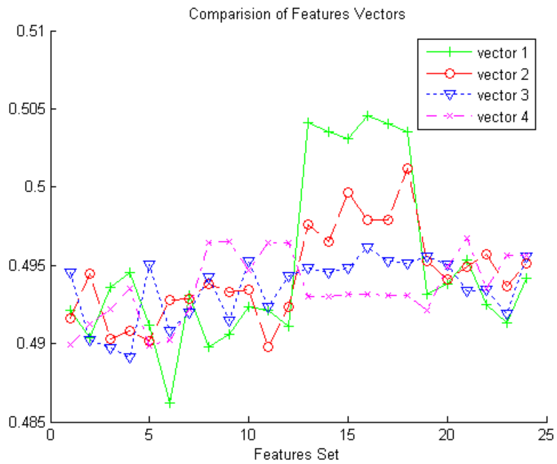

Figure 3. Profile of the force exerted during the dialing code for 4 users from the group.

4. RESULTS

The performance of the classifier and the statistical analysis obtained by comparing different feature sets show an acceptable performance with a probability of verification (PV) of nearly 80% of the users that took part in the experiment, with a threshold of 3 times the standard deviation over the mean. The experimental results reveal that the best performance was that of features related to the pen's position. Those features provided the weighted value for recognizing individuals. The variables such as velocity (v) and keystroke duration (t) provided rare behavioral schemes in the definition of the patterns from the same user. Force measurement (F) did not provide the remarkable dissimilarity weight that we had expected. In addition, force applied for most of the users fall into very compact band of values where the error rate was high.

The speed profile for each user varied considerably in the first two trials then it exhibited a more stable performance from which we can conclude that dialing speed is an important parameter to define a user pattern applied to the haptic systems.

5. DISCUSION

This study presented proof that there is a possibility of using haptic devices for authentication of users working in a process which involves haptic systems. The data generated for the purposed experiment was the key point to finding the valuable parameters, which define individuals' behavior. In overall view of the parameters captured to generate the participant's templates, some showed highly remarkable differences from keystroke information from the same user. This observation essentially proposes analyzing this haptic data from different perspectives, like removing the mental interference in the dialing process and also introducing new approaches such as HMM, statistical classification. In other words, it suggests designing an experimental set similar to the scenario represented when a person performs his/her handwriting signature spontaneously. We would like to extend this study by considering other behavioral characteristics for different test conditions such as tiredness, happiness, and time stress for analyzing this behavioral data.

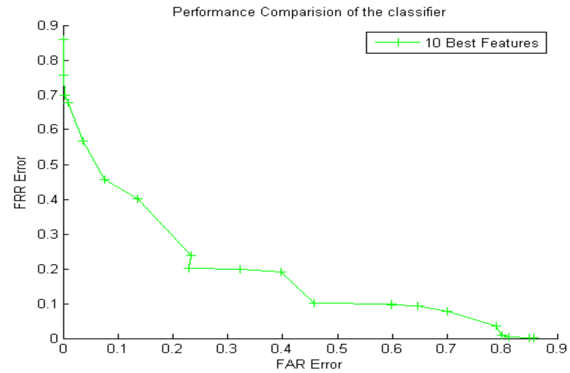

Figure 6. The output of the clustering analysis identify two classes of errors False Acceptance Rate (FAR) and False Rejection Rate (FRR) obtained by the performance with 10 of the best features

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