Visualizing Human Behavioral Features based on Signature Haptic Data

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Abstract

Haptic technology refers to the technology that connects the user to a computerized system via the sense of touch by applying forces, vibrations and/or motions to the user. With this technology it is possible to measure and record haptic data generated directly as users interact with the system. Haptics can be seen as a mechanism to extract behavioral features that characterize a biometric profile for an identity authentication process. Generally, the haptic data captured during an individual interaction are very large (measured every few milliseconds) and with a high number of attributes (position, velocity, force, angular orientation of the end-effector and torque data, among others). Therefore, the behavioral haptic data that describe users are defined in terms of a large number of features, which adds complexity to the analysis. It is desirable to find a 3D virtual representation that shows the similarity of a user's haptic data during different trials, as well as the existing relationship among other users' features. In this paper, through this approach and with data collected from a multimodal system for signing a virtual cheque, interesting patterns and relationships, which are somewhat hidden in the original data, are described for individual authentication.

Keywords: Biometrics, Data Visualization, Haptics, Visual Data Mining, Pattern Recognition

INDEX TERMS: I.3.7 [Computer Graphics]: Three-Dimensional Graphics and Realism - Virtual Reality; I.5 [Computing Methodologies]: Pattern Recognition; E.0 [Data]: General; I.1 [Computing Methodologies]: Symbolic and Algebraic Manipulation;

1 Introduction

Haptic technology is a force/tactile feedback technology which is growing in disciplines linked to human-computer interaction. The main feature of haptics is the exchange of energy between the user and machine in a bidirectional way through force feedback stimuli, which seems to increase the realism of virtual worlds [1]. This cutting-edge technology allows a user to touch, feel, grasp and alter simulated 3D objects in a virtual environment. So far, most of the existing haptic-based applications have been dedicated to learning or honing human physical skills. For instance, training sensitive hardware repair, medical procedures, handling hazardous substances, handwriting, sculpting and drawing/modelling on 3D surfaces are some examples. On the other hand, the haptic technology is also emerging as a tool to measure the motion and dynamics of the human hand when using haptic devices such as for assessment and diagnosis of stroke rehabilitation [2] and individual authentication [3].

Biometrics is the science concerned with measuring biological characteristics for identifying or verifying individuals [4]. Recently, biometric systems are gaining more interest due to the advantages of such systems over traditional authentication (individual verification or identification) methods, mainly based on textual/numerical passwords and login IDs. These can be easily compromised or "hacked". Biometric systems identify users based on physiological or behavioral characteristics which are significantly more difficult to hijack or fake [5].

Physiological biometric systems can recognize a user by fingerprints, iris patterns, hand geometry and face image, whereas voice, signature and keystroke dynamics have been used as behavioral measures. Recently, within behavioral biometrics it has been shown that identity recognition based on human-haptic interactions is feasible [3-6]. That is, human behavioral patterns can be described throughout user interaction with virtual worlds and there are natural differences between the psychomotor patterns exhibited by individuals that have great potential for authentication purposes. Presumably, every person has a unique way of writing, typing or driving; likewise, each individual's haptic interaction seems to be unique.

Hence, through haptic-based applications users' physical attributes can be captured from the haptic interface and can be utilized in the construction of a biometric system for authentication. The measurement of such psychomotor patterns can be used to verify a person's identity. The complexity comes from the high dimensional space created by the possible number of attributes to be analyzed which are sampled at a high rate (a few milliseconds) and its dynamics over time. In this high dimensional space, the analysis of these data makes it difficult to interpret possible or underlying classificatory relations among attributes and users and the identification of discriminatory attributes.

In addition, these physical attributes change over time; therefore the verification system can misjudge a user as a result of false rejection. In this paper, a 3D VR space created from an n-dimensional space for this classificatory problem is proposed. This approach allows characterizing a user by respecting the interrelationships defined by the original haptic data.

In our previous work, a multimodal system that includes visual and haptic feedback was designed for authentication purposes and is described in [3]. The task was to sign a virtual cheque by using the ReachIn System [7]. Time, position, orientation, force (pressure) and torque, among other attributes were extracted (overall, 18 attributes) as the users performed the task of signing. Such measurements were used to analyze human hand movement patterns while users were interacting with a particular haptic device. Although the results suggested the potential of haptic-based applications for user verification,

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particular behaviors during different trials were difficult to classify and quantify. The results proposed that further analysis was required.

Our main research goal is to build a haptic-based biometric identifier system for individual verification and identification. Due to the significance of post-processing and examination of haptic data, it becomes apparent that a suitable platform to analyze these data is necessary. The creation of a 3D virtual space by using a high dimensional space technique provides a tool where one can navigate and visually inspect the main features of the data. This can lead to the discovery of new information [8]. Indeed through this technique important conclusions have been reached in terms of visualizing diverse human patterns when interacting in virtual domains.

2 RELATED WORK

Scientific visualization of information is an important field of research that relies on visual perception as a mechanism to present the information and knowledge in a comprehensive mode. A conventional method to visualize high-dimensional data is transforming its contents into a 2 or 3 dimensional space. VR is a suitable paradigm for visual data mining. VR allows the choice of different ways to represent the objects and the user can navigate inside the data and interact with the objects, among other characteristics.

In pattern recognition problems, the large number of high dimensional sensory data, such as image and videos, is often addressed manually which is a time-consuming and tedious task [9]. In this domain, interactive data visualization techniques offer a promising solution. Partiview is an example of these techniques [10]. It is a system that was developed in the context of visualizing high-dimensional data of handwriting recognition and image retrieval. Another approach for visualizing and characterizing high-dimensional patterns was described in [11]. This method is based on the distance between points (similarity metric) in a particular 2D space called the Relative Distance Plane. On the other hand, a 3D interactive method for visualizing multimedia data with the use of VR is presented by [12]. That system allows users to explore heterogeneous data characterized by numeric and symbolic attributes as well as sounds, images, videos or web sites. The system can be conceived as an interface that allows users to easily perceive the data and to interact directly with them.

There is a variety of physical parameters (i.e. force, velocity, torque and end-effector orientation), as data sources, that can be recorded when using haptic devices and that characterize users' hand and kinesthetic movements. A framework for active haptic evaluation using parameters coming directly from the haptic device was analyzed in [13]. However, they argued that further research was needed to exploit the advantage of using these physical measurements. In this study, we have used an exploratory technique for understanding data knowledge throughout a 3D virtual space described in [8]. This VR space is obtained by transforming the original set of attributes describing the user's input pattern into another space of reduced dimension (3 dimensional). In order to build a biometric identifier to authenticate the user identity in a haptic system environment, we evaluate the similarity of physical attributes among users through the VR space to understand human behavior when interacting with multimodal environments.

3 THE VIRTUAL REALITY SPACE Ω

The objective of this study is to find a 3D virtual space that allows a rapid assessment of user pattern distributions. This VR space helps in visualizing interesting patterns or relationships, which can be somehow hidden in the original data. Ideally, this VR space should keep as many properties from the original space as possible, in particular, the similarity structure of the data [14].

Consider an *information system* $S=<U,A>$ where U and A are non-empty finite sets, called the *universe* and the set of *attributes* respectively. The objects in A are tuples from a *heterogeneous space* [15] ($\hat{H}$), given by a Cartesian product of different sets: nominal, ordinal, real-valued, fuzzy-valued, image-valued, time-series-valued, graph-valued, and even missing values. Generally, a set of Γ relations of different varieties may be defined over these objects. The idea is to construct a VR space to visualize and interact with heterogeneous and incomplete information systems [16]. It is based on parameterized mappings between the heterogeneous space $\hat{H}$ representing the original data and the VR space. A VR space Ω is composed by different sets and functions: $\Omega =< \underline{O}, G, B, \Re^m, g_0, l, g_r, b, r >$, where $\underline{O}$ is a relational structure (a set of objects and attributes, endowed with a set Γ^v relations defined over the objects), G is a non-empty set of *geometries* representing the different objects and relationships in the VR space, B is a non-empty set of *behaviors* (i.e. ways in which the objects from the virtual world will express themselves: movement, response to stimulus, etc.), $\Re^m$ is a *metric space* of dimension m which will be the actual VR space (usually $m=3$) . The rest of the elements are mappings: $g_0 : O \rightarrow G$, $l : O \rightarrow \Re^m$, $g_r : \Gamma^v \rightarrow G$, and r are a collection of characteristic functions for Γ^v. In this study, the direct transformation between the original space and the VR space was computed by minimizing Sammon's error (1) [17].

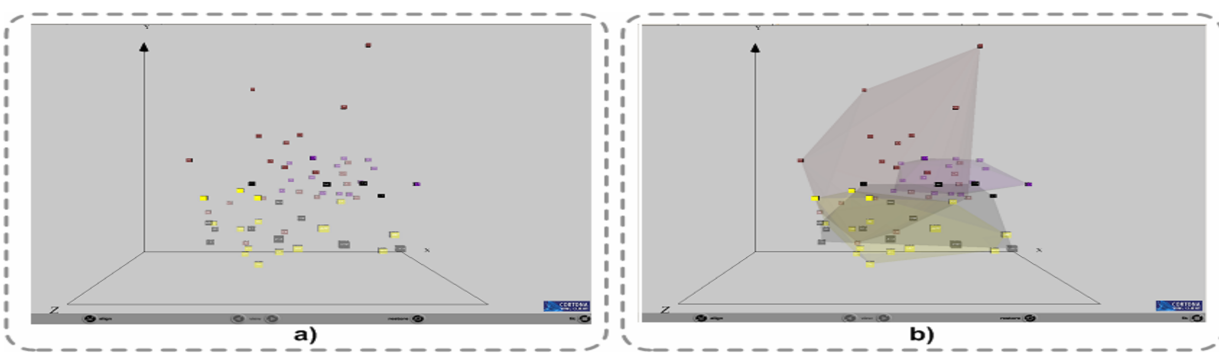

Figure 1. VR space created from four user's haptic data. These data were captured as users performed their signature on a virtual cheque. The users are represented by colored cubes (left) and convex hulls associated with the four users (wrappers around all the cubes belonging to each class defined by a user) (right)

$$Sammon\ \ error = \frac{1}{\sum\limits_{i^v<j^v} \delta_{i^v j^v}} \frac{\sum\limits_{i^v<j^v} \left(\delta_{i^v j^v} - \xi_{i^v j^v} \right)^2}{\delta_{i^v j^v}} \qquad (1)$$

with $\xi_{i^v j^v}$ given by the Euclidean distance and $\delta_{i^v j^v} = (1 - s_{i^v j^v}) / s_{i^v j^v}$ where $s_{i^v j^v}$ is Gower's similarity coefficient [18]. The similarity structure was well preserved in the VR space (Figure 1) with a mapping error = 0.05. Figure 1.a. shows the VR space for four user's haptic data, Figure 1.b. shows the convex hulls that enclose the objects belonging to each class defined by a user. A user can interact with the objects, change their representation and obtain additional textual information which helps in analyzing the data.

4 THE VIRTUAL CHEQUE APPLICATION

This section describes the virtual cheque application for the authentication process and the haptic data captured as users signed a virtual cheque.

4.1 Virtual cheque

A behavioral biometric pattern can be described via the handwritten signature by means of a haptic device. The way a person signs his/her name is known to be a characteristic of that individual [19]. Although handwritten signatures are a behavioral metric that changes over time, and are influenced by conditions such as an individual's physical and emotional state, they have been widely accepted as a method of verification. A virtual cheque environment with visual and haptic feedback was used in this study. The ReachIn system [7] combining the Desktop PHANToM device [20] and stereo viewing was used for the experiments.

Figure 2 shows the virtual cheque where users can perform their handwritten signature. The haptic stimuli, which users feel, are displayed as the sensation of a frictional surface similar to performing a signature on paper. At the same time, as the user signs a colored blue path is displayed in the graphic scene to represent the signature shape.

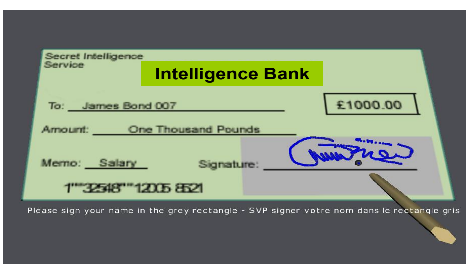

Figure 2. Virtual Cheque Application

4.2 Haptic data set

Fourteen participants signed the virtual cheque 9 times on different days. Each trial was characterized by a number of samples which were continuously measured and stored at around 70 samples per second as users performed the task. Therefore, the haptic-biometric or signature haptic data set to create the VR space consisted of 74,271 objects and 18 attributes for all the different participants. The 74,271 objects correspond to the samples for all the participants. The 18 attributes correspond to time, position, orientation, force (which measures the pressure on the paper) and torque, among other attributes, extracted from the given haptic interface. Enabling the construction of a 3D VR space, where these objects and attributes are represented, will help in analyzing certain features of hand movement patterns for each participant.

5 RESULTS AND ANALYSIS

This section includes results obtained from the 3D virtual space of the haptic data from the participants. Generally, despite some variability that is called intrapersonal variability, each individual maintained certain similarities among signature samples when signing on paper. In our study, intrapersonal variability is referred to as the discrepancy among different haptic data captured by an individual at different trials. On the other hand, the interpersonal variability is based on the differences among haptic data captured by other individuals. Both variabilities play a significant role in terms of differentiation between features and individuals for successful verification. Section 5.1 describes the main features of the new VR space to visually interpret the information. Section 5.2 shows the analysis of the physical attributes, which are common to various users (interpersonal data). In Section 5.3, the results of the haptic data dispersion between different trials for a same user (intrapersonal data) are described.

5.1 Visualization of the VR space Ω

In our study, the VR space is comprised of cubes, which are data objects/features. Each cube represents a set of objects that are mapped to it from the original 74,271 objects (Figure 3). These data can belong to the same or a different user, and that information is visually displayed once you place your mouse on the cube. On the other hand, each cube is colored differently corresponding to each participant. Moreover, some cubes are substantially larger than other objects which indicates that a greater number of objects are represented (Figure 3). These cubes are also drawn with semi-transparent faces for easy identification. A convex hull (a wrapper around all of the points belonging to each class defined by a user) is drawn, to more abstractly represent the shape of the groups of objects (having particular properties) in the constructed VR space.

In particular, it is also shown that the closer the cubes, the more similar the features. The location and adjacency relationships between the cubes provide an indication about the similarity relationships among the participants.

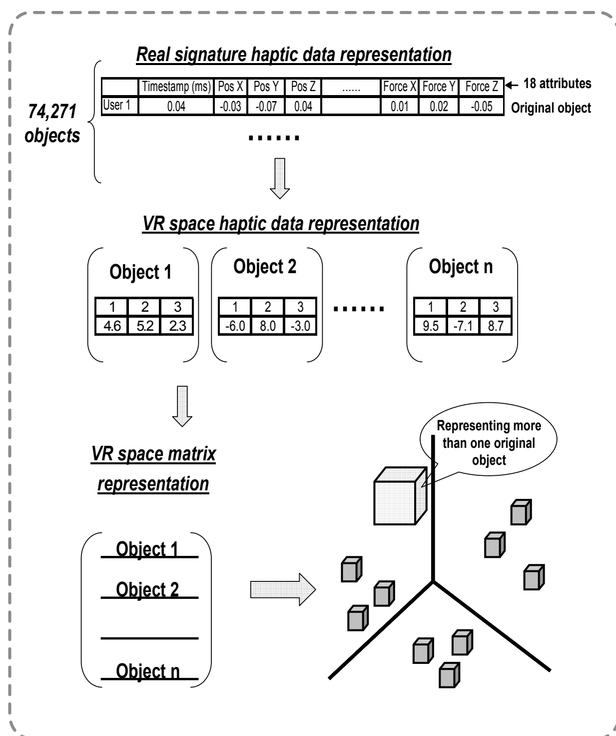

Figure 3. Creation of the virtual reality space

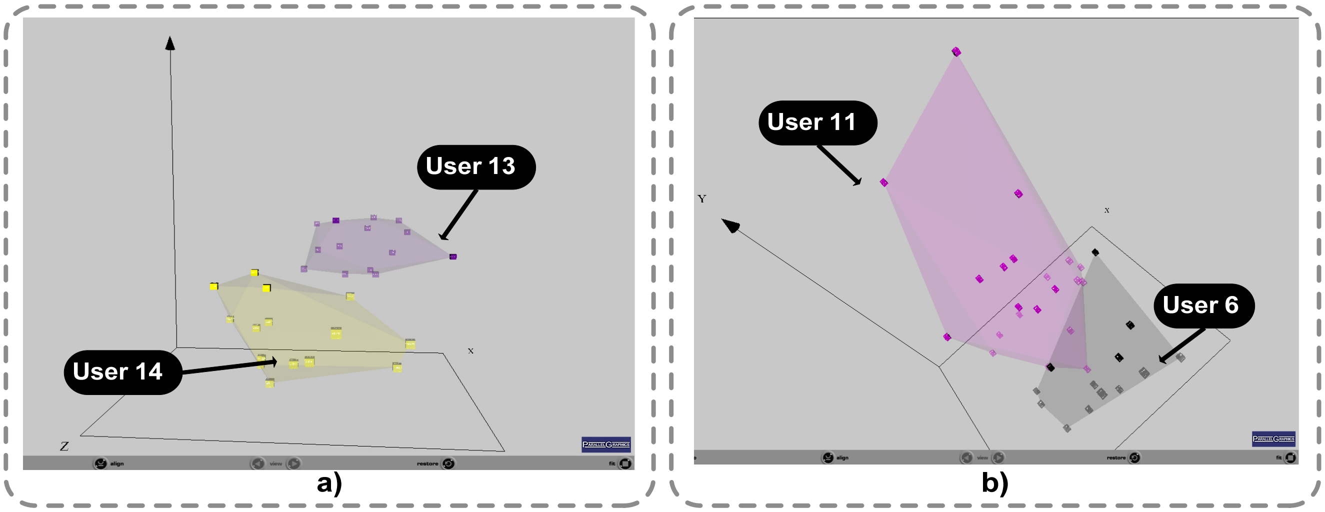

Figure 4. Visual representation of users 13 and 14 (a) and users 11 and 6 (b) and the corresponding convex hulls

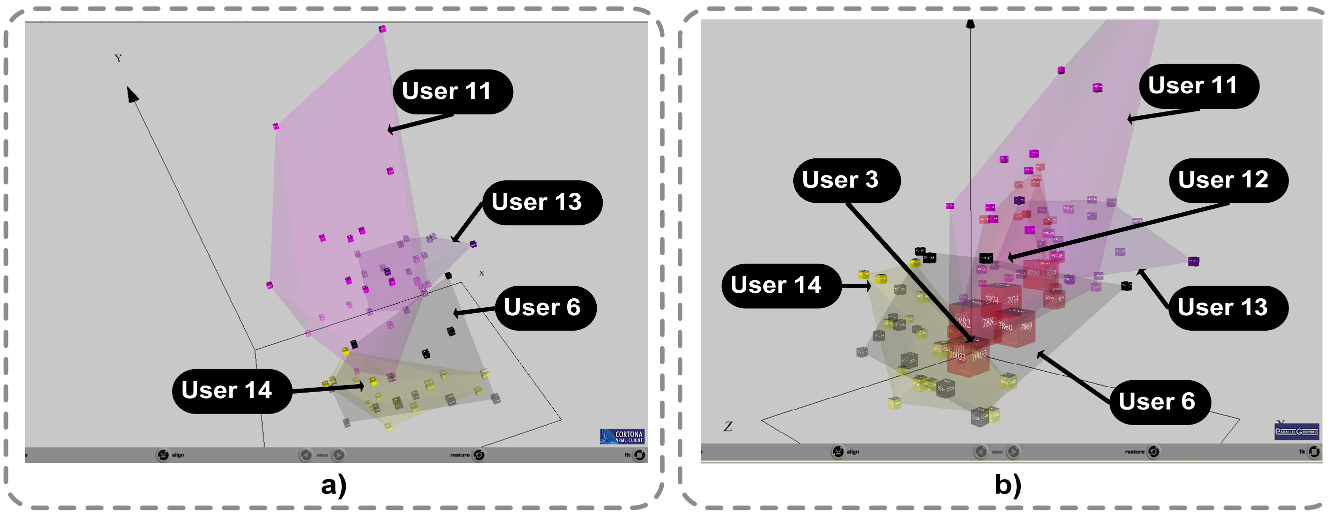

Figure 5. Visual representation of several users' signature haptic data and the corresponding convex hulls

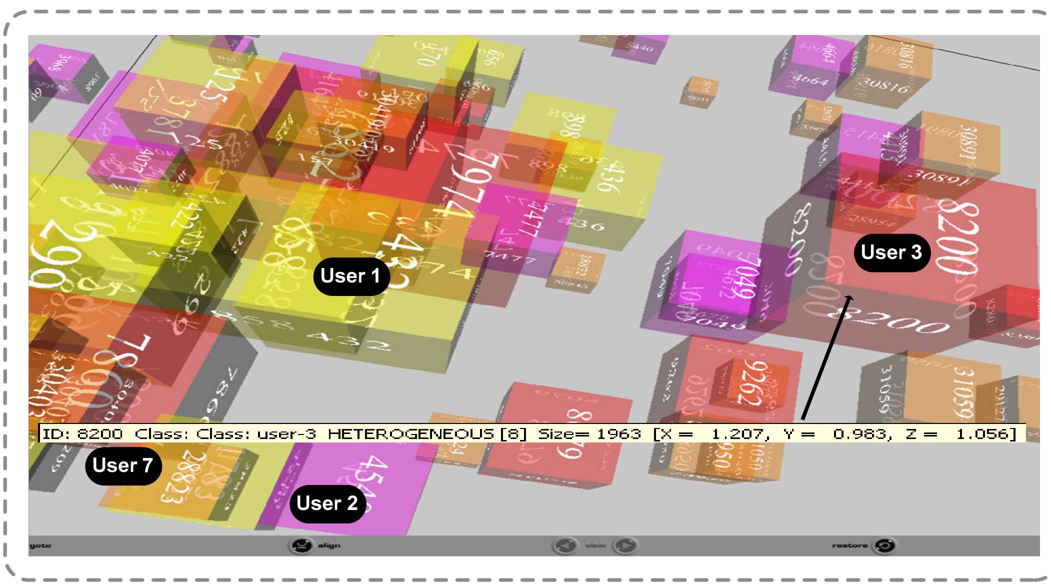

Figure 6. The cube, which represents user 3's haptic data, contains haptic data from 7 different users. This means that some signature haptic data are similar among these users.

5.2 Interpersonal Variability

Figure 4 a) and b) represents the convex hulls for users 13 and 14, and users 11 and 6, respectively. As it is shown in Figure 4 a), convex hulls for users 13 and 14 appear as distant clouds occupying well separated spaces. This means that these users have different physical features and they can be clearly distinguished by their signature haptic data. In Figure 4 b), the same case can be seen. Although there is a cube (representing a single original object) from user 11 that lies just inside the convex hull of user 6, the rest of the cubes are further, which means that the signature haptic data are different between both users.

Two different cases of almost no intersection between the convex hulls have been analyzed; however most of them show an intersection with other convex hulls (Figure 5), meaning that some signature haptic data are similar among different users.

After interacting with the VR space Ω , several conclusions were drawn in terms of similarity among user haptic data. The haptic data from users 1, 2, 3 and 7 showed similarity from other users' haptic data (Figure 6). For instance, Figure 6 depicts a red cube defined from user 3 and it represents haptic data from 7 other users (the majority of haptic data represented by this cube come from users 1, 2 and 7)

5.3 Intrapersonal Variability

It was observed that the convex hulls appeared compact and oriented, which can be interpreted as each user has a particular behavior or tendency when virtually signing (Figure 4 and 5). In particular, user 14 shows uniqueness of the created class, no signature haptic data from other users were presented (Figure 4 a). On the other hand, user 11 had several (bounded with a curve in Figure 7a) irregular and unique samples not common to any other. The cubes (bounded with a curve) contain information of the unique samples from user 11. However, as it can be read in the text box, user 13 seemed to have some similarities in the signature haptic data with user 11.

Figure 7 b) represents the cubes corresponding to user 8. From 2,742 original objects, the VR space defined by this user is formed by only 2 cubes. The fact is that this user seems to have lots of intrapersonal variability, and other users' cubes represent the rest of user 8's haptic data. Moreover, the reality is that neither of these two cubes are characteristic only to user 8, for instance, 5 users have some similarities with this user in terms of signature haptic data.

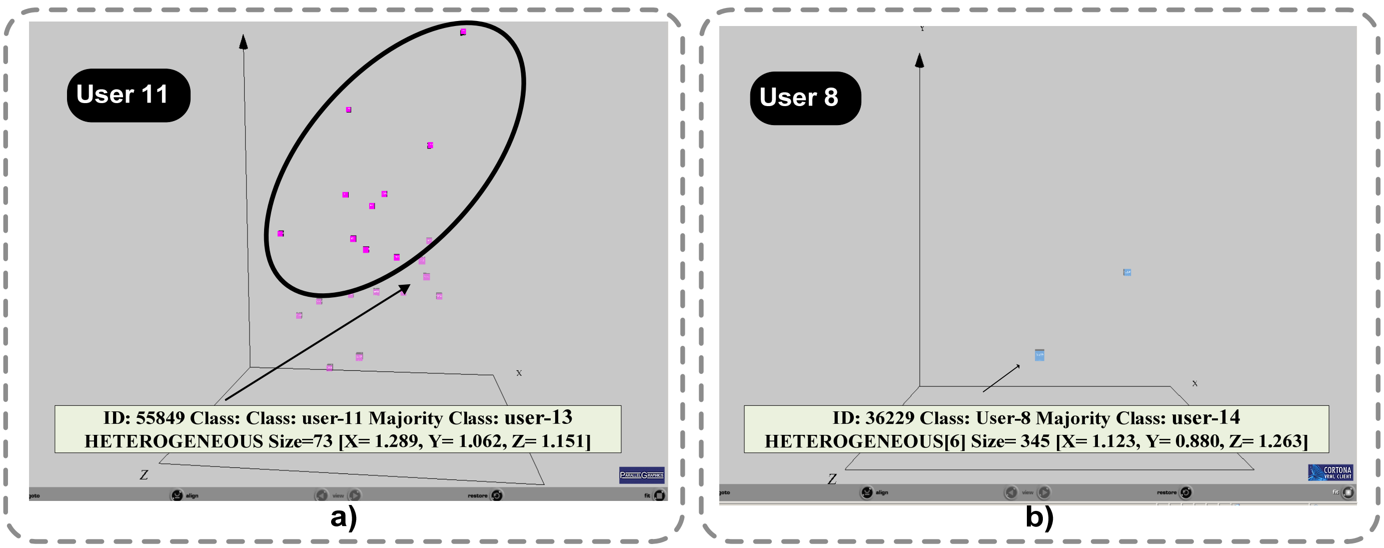

Figure 7. Visual representation of several users' signature haptic data and the corresponding convex hulls

6 CONCLUSIONS

This paper demonstrates the role of a VR space for the understanding of haptic data in haptic users' authentication process. As haptic users signed a virtual cheque, physical attributes, such as, time, position, torque, pressure, among others, were measured and recorded. The signature haptic data of 14 participants and 9 trials required the analysis of high dimensional data, 74,271 objects and 18 attributes. These data were used as data sources for the construction of a VR space where the similarity structure of the data was maintained (0.95 threshold).

Certain properties and patterns through this VR space have been concluded. The shape of the convex hulls containing haptic data appeared compact and oriented, which can be interpreted as if the haptic data had certain uniqueness for each user when virtually signing. Furthermore, some participants' signature haptic data can easily be differentiated. User 14 can be verified by his signature haptic data, and certain users showed striking dissimilarity, such as, users 13 and 14 and users 6 and 11. On the other hand, some showed some similarity of the signature haptic data among them, such as users 1, 2, 3 and 7.

As per future work, assessing the unique-to-the-individual behavioral attributes should be studied. This involves finding relevant attributes with the greatest user-classificatory worth to differentiate the samples for each user. The possibility of discovering a subset of attributes that may be able to discriminate between samples from different users will reduce the number of attributes and enhance the success of individual authentication.

In this analysis the raw haptic data was considered. In future analysis explicit preprocessing could be applied (i.e., by using the Rough Set technique). We believe this research is only the beginning of understanding haptic user patterns and relationships. Hopefully, the use of mentioned analysis techniques in this field will provide us with promising results, such as, the results obtained when using Leukemia gene expression data [21].

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