Classifying and Assessing Tremor Movements for Applications in Man-Machine Intelligent User Interfaces

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ABSTRACT
We introduce a new intelligent user interface (**IUI**) and, also, a new methodology to identify the fatigue state for healthy subjects. The fatigue state is determined by means of a new type of input IUI, named Virtual Joystick. The main goal is to prove the ability of the new IUI system to identify the user's state. We describe the method used in data collecting, the method used to highlight the existence of different physiological and psychic fatigue states reflected by the tremor signal, the classifier system and, finally, the performances we obtained.

Categories and Subject Descriptors
H.5.2 [**Information Interfaces and Presentation**]: User Interfaces – *user-centered design, input devices and strategies, theory and methods*

General Terms
Algorithms, Measurement, Design, Experimentation, Human Factors, Theory.

Keywords
Multimodal interface, state recognition, virtual reality, support vector machine.

1. INTRODUCTION
This new IUI, named Virtual Joystick (VJ) – part of a complex system, was build in order to obtain an user state identification via physiological sensing in an real word environment: open-recording, event-elected and internal feeling state [1]. To do this, the main requirement regards the noninvasive character of physiological signals acquirement. This paper subscribes to the direction of the non-contact signals acquisition and presents the ability of a new IUI VJ to detect the fatigue state. The final goal is to build an independent complex system, including other non-contact sensors [2], which is able to identify the users states and to develop the naturalness of the human-computer interaction in applications like supervised learning process, virtual reality, user state alert, entertainment, etc.

The problem of the fatigue state identification through the tremor signal is a "hard" one, mainly because of the two implied factors: tremor signal and fatigue state. Both factors were deeply investigated in specific health condition (e.g. Essential Tremor, Parkinson disease for tremor [3] and cancer [4], childbearing, multiple sclerosis [5], etc. for fatigue state). The evidence that the fatigue is different in healthy and ill people [6] determined a drastically limitation in the possible use of all these researches to our specific problem.

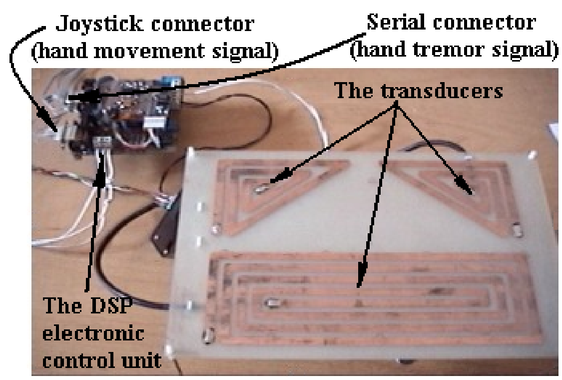

Figure 1. The VJ system

2. THE VIRTUAL JOYSTICK
The VJ [7], **figure 1,** is comprises a sensors system [8] (used to sense the hand in the input 3D space) and an electronic unit [7]. The last is used to pre-process the acquired signals, to extract the hand position and to send this information through the joystick port of the PC and, finally, to send, in serial mode, the acquired tremor signal to the PC. The operating principle of the sensors [8] that are part of the VJ is based on the property that an element generating an external electromagnetic field changes its impedance due to the properties of the objects in its vicinity. When the hand is above one of the sensors, the output of the corresponding circuit has a value proportional with the distance between the hand and the sensor. The system can sense left-right and forward-backward balance based on the paired sensors, such that the signal from a couple of opposite sensors evidences the movements of the hand in horizontal plane. The active workspace, where the position of the hand can be tracked, has the dimension of 40 x 48 x 20 cm.

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3. THE DATA SETS

The data set includes 672 segments of 20 seconds tremor signal acquired under several specified conditions that help us to evidence the subject fatigue state. We admitted six healthy subjects for this study. Five of them are young people (26.6 ± 3 years, mean ± standard deviation) and only one is an elderly man, 53-years old.

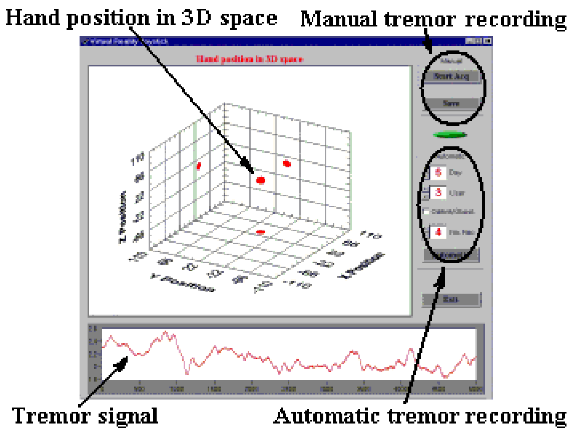

Figure 2. The VJ Graphical User Interface

Two sessions of recordings were scheduled per day. One session was scheduled at 8.00 a.m., ***when all subjects were supposed to be rested***, and the second was made at 14.30 when ***we considered that all subjects were already tired***. In a session, each subject performed the test four times – 90 seconds/each recording, but only the first 20 seconds and the last 20 seconds were kept. The subjects followed one after another until the session was done. Before the last 90 seconds of the each individual recording, all the subjects were required to hold in their hands an object (weighting about 4 Kg) up to 4 minutes. In this mode ***fatigue was induced by force***. The seating subjects were asked to maintain the hand in the same position: just above the bottom (bigger one) VJ transducer. The initial position was with the hand placed parallel with the transducer and the center of the palm pointing exactly the center of the transducer. Supplementary, we controlled the user initial vertical hand position through the virtual 3D hand position supplied by the graphical user interface (GUI) - **figure 2**. The subjects had no visual control of their hand position, neither directly nor though the GUI. GUI particular design is due to the fact that the software was used in the management of the signal-recording phase – in supervising the acquisition and in storing the tremor data segments. The sampling rate was 250 samples per second and we got 10.000 samples per segment of recordings. Based on the data sets, we extracted nine features for each segment of 20 seconds tremor signal.

4. THE FATIGUE STATE

In the data sets acquired either in the morning or in the afternoon, **four different classes** can be easily distinguished. Is there any difference between the *fatigue induced in the morning* and the *neuro-muscular* fatigue state obtained in the afternoon? *Is it possible that the first one to be physiological and the second one to be a combination between physiological and neuro-muscular or psychological fatigue state? Is it possible to make a difference between these two fatigue states*, supposed to be different? To answer the above questions we used a k-means clustering algorithm. To get an idea of the number and how well separated are the clusters, a silhouette parameter [9] was calculated for each features vectors. We choose as the optimal number of clusters – the number of clusters that maximizes the average silhouette value over the entire data set [9]. Because the k-means algorithm faces several problems (sensitivity to noise data and outliers; the cluster must to have a convex shape; the cluster algorithm often terminates in a local optimum minimum) a number of precautions was taken.

In the first test, only the data set acquired in the morning was used. In this way, we aim to determine if there is a difference between the fatigue state induced by force and the normal, resting state. The clustering algorithm was started with two clusters; after the convergence, the plot for the silhouette parameters for the entire data set was obtained and presented in **figure 3(a)**. The mean value of the silhouette parameter was 0.3905. When we increased the number of the clusters to three, the average silhouette took the value of 0.3539 and then, it continuously decreased with the increasing number of clusters. In conclusion, in this case the correct number of clusters is two, this highlighting the possibility to differentiate between the two particular cases already presented.

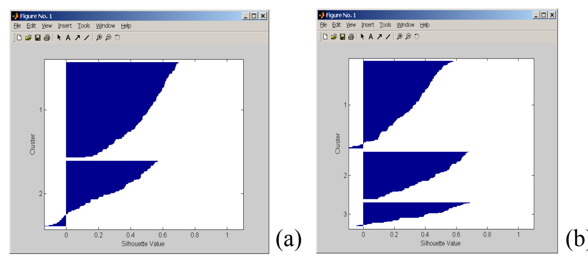

Figure 3. The silhouette plot for (a) two and (b) three classes

In the second test, we aim to determine *if it is possible to differentiate between the fatigue state induced by force and the fatigue state that is installing normally, at the end part of the workday*. The training set was composed only by the recordings acquired in the morning, in the condition of fatigue and by the entire set recorded in the afternoon. The average silhouette value for the two classes was 0.4074 and it went up to 0.4565 for the case of three classes; after that, it started to decrease with the increasing number of the classes.

As a conclusion it can be discriminated between the fatigue state induced by force (mainly muscular fatigue) and the fatigue state normally installed at the end of the workday, and more - in the data sets recorded in the afternoon, we can differentiate between the two particular fatigue states.

5. THE CLASSIFIER

For a deeper understanding of the features' space complexity we used PCA to visualize if there exist clear structures in the data sets. For the visualization, we used only the first six outputs of the PCA network that represent 96.983 % from the power of all the features involved. The analysis was done for all data sets and for all subjects. In spite of the fact that in the projected eigenvector space the data cluster in some parts of the space, **figure 4**, the overall impression is that the data from the both classes are very scattered and mixed in all the space and no clear clusters can be found. For this reason, a Support Vector Machines was chosen for the classification part; its main idea is that in a high dimensional space the data become linearly separable.

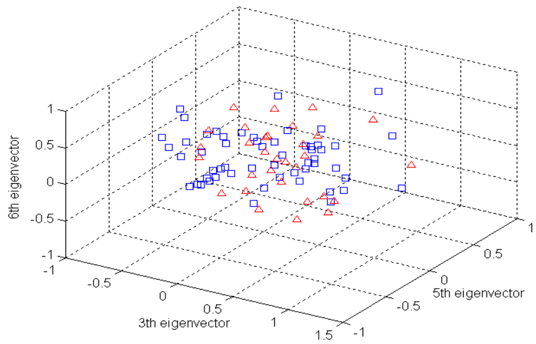

Figure 4. A distribution of the user state (rest-triangle/tired-square) on the third, fifth and sixth eigenvector axes space

The first classifier made within this application was used to differentiate between the rest and the tired states. The rest state is reflected in all the recordings acquired in the morning but without the recordings' parts where the fatigue was induced by force; the rest of the recordings are representing the tired states. The performances on the test set of the classifier are shown in **table 1**. Although these results are preliminary, we observe good performance of 31.57% correct status recognition in the case of tired state and 85.71% for the rest state. These results are good, mainly because we identify the tired state only from one physical signal, namely the tremor signal, and we do not use any other type of information.

Table 1. The confusion matrix for the experiment results

	Rest	Fatigue
Rest	**85.71 %**	**14.29 %**
Fatigue	**68.42 %**	**31.58 %**

The results for the cases when we tried to discriminate between one particular fatigue state and the rest of the investigated states were very weak. This happens because the training sets are not statistical representative. If we consider only the case of the fatigue induced by force in the morning, this data set represent 11.86% (69 features vectors) from the entire data set. More, if we take into account the cross validation and the test sets extracted from the same original data set, we can get a clear image regarding the poor results.

6. CONCLUSIONS

We presented the ability of a new IUI, a VJ, to discriminate between the rest and the fatigue state. Besides its potential use in applications that require the tremor signal acquisition, the VJ could also be used as an input user interface instead of a standard joystick.

The difficulty of classifying the user's state, exclusively based on the tremor signal, appears mainly because the tremor assessment in medical investigation is not a well-developed technique yet and, also, a clear characterization of the signal does not exist. Apart the assessment of Parkinsonian tremor, the mechanics of tremor generation in normal subjects is not well understood. Tremor in normal subjects has been known for a long time to be related to emotions and fatigue, but the specific characteristics of such tremor movements are not well known.

Tremor signal analysis is not a simple task from the engineering point of view. Classification of tremor movements is somewhat blind, because little is known on the classes. But, as we can see from the reported results, in the tremor signal it exist significant information related to the subject state. So, it must be done more in this direction in order to obtain a reliable decision system.

In this research, we presented several new results related to analyzing, classifying, and assessing tremor movements, in view of applications in man-machine intelligent interfaces.

7. ACKNOWLEDGMENTS

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