A Non-invasive Approach to Detect and Monitor Acute Mental Fatigue

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Abstract. In our day to day, we often experience a sense of being tired due to mental or physical workload. Along with that, there is also a feeling of degrading performance, even after the completion of simple tasks. These mental states however, are often not felt consciously or are ignored. This is an attitude that may result in human error, failure, and may lead to potential health problems together with a decrease in quality of life. States of acute mental fatigue may be detected with the close monitoring of certain indicators, such as productivity, performance and health indicators. In this paper, a model and prototype are proposed to detect and monitor acute acute fatigue, based on non-invasive Human-computer Interaction (HCI). This approach will enable the development of better working environments, with an impact on the quality of life and the work produced.

Keywords: Acute Mental Fatigue, Human Computer Interaction, Behavior Biometrics, Monitoring, Pattern Recognition.

1 Introduction

Fatigue is regarded as one of the main causes of human error. Its symptoms are frequently ignored, as well as its importance for a good mental and physical condition, key for human performance and health. Mental fatigue is usually characterized by a lack of mental energy, a feeling of tiredness and drowsiness [1], mental exhaustion, loss of initiative and difficulties concentrating. This lack of focus is also often the source of errors that would easily be avoided in a normal situation [2]. In more objective terms, a person affected by mental fatigue also faces a performance loss as well as an increase in the number of errors and increased difficulty processing information. Thus, mental fatigue must be taken into serious consideration, especially in critical scenarios such as the ones of operating vehicles and machines, or in jobs of high risk/responsibility.

Mental Fatigue can occur at any moment and its effects may persist from only a few hours to several consecutive days. Depending on its duration and intensity, fatigue can make the carrying out of daily tasks increasingly difficult or even impossible [3]. In severe or prolonged cases it can cause illnesses such as depression or chronic fatigue syndrome.

There are many possible causes for mental fatigue: excessive and prolonged brain activity, poor nutrition, significant changes in one's environment and irregular or inadequate sleep patterns have the power to cause fatigue of the mind and the body. Other possible causes for fatigue include recreational drugs, alcohol, and specific medications. However, aspects such as the accumulation of physical exercise, monotony, prolonged discomfort or stress peaks should also not be despised as chief causes of acute mental fatigue [4].

Very often fatigue is simply ignored and seen as yet another effect of our busy and active lifestyle. It is not recognized by people as a medical issue. However, people who suffer from fatigue should remember that it may be a sign that a more serious underlying health problem is occurring. People who experience continued or chronic fatigue should discuss their symptoms with an expert: medical evaluation is often recommended for these patients, as fatigue could be an indication of chronic fatigue syndrome or other serious health problems [5, 1].

Given this problem and its context, an approach to detect and monitor fatigue is proposed. It aims to detect different degrees of mental fatigue of an individual in a non-invasive and transparent way, focusing especially on acute mental fatigue in which the loss of performance and increase of errors are more significant. Specifically, a set of features extracted from the individual's interaction with the computer that can be affected by fatigue are studied. These features describe the way the individual uses the computer's peripherals and include the velocity and acceleration of the mouse, the typing rhythm, the distance travelled by the mouse, among others. A similar approach has already been employed successfully in previous work to study the influence of stress on such behaviours [6, 7].

Undeniably, the detection and classification of fatigue will be based on notion of Behavioural Biometrics, depicted further ahead. Specifically, it relies on keystroke and mouse dynamics. A simple logger application was developed that acquires information about each mouse and keyboard event (e.g. mouse button down, mouse button up, key down, key up, mouse movement), with the detail needed to generate the features pointed out below. Following this approach it is possible to collect data that will allow to learn the behavioural patterns of interaction with the keyboard and mouse of each user, in a non-intrusive way [8].

This non-invasive and transparent approach on the analysis of fatigue will open the door to the development of better and intelligent working environments, that are sensitive to their users' mental states. This may improve the decision-making of team managers and increase the productivity of the team as well as the quality of its work. This will also have a positive effect on the quality of life of the members of the working community which should not be despised.

1.1 Human-Computer Interaction

Personal computers are increasingly present in our lives. They are used daily in our workplace, in our homes, for entertainment or to get informed. As they gradually take over the space of other objects such as the television, the radio or books, they start to become an irreplaceable part of our lives. In this transformation, intuitive and natural interaction mechanisms between humans and computers are fundamental. This is the main goal of Human-Computer interaction (HCI): to improve the interaction between users and computers by making computer interaction mechanisms adapt to the users and the tasks instead of the other way around. In a more long-term perspective, HCI aims to design systems that minimize the barrier between the Human's cognitive model of what they want to accomplish and the computer's understanding of the user's task, as well as help in solving real world problems [9].

An especially interesting topic in HCI is affective computing: the branch of artificial intelligence that aims to design computer systems that are capable of recognizing, interpreting and processing human emotions and behaviours. Under this approach, interaction can be driven by (among other issues) the emotional state of the user, resulting in computer systems that are sensitive to stress, tension, satisfaction or fatigue and are able to deliver better and contextualized services.

Affective computing essentially aims to make human-computer interaction closer to human-human interaction [10]. In human-human interactions factors such as emotions, body language or signs of stress are taken into consideration. Often, these factors influence the decisions and the course of action of an person. The inclusion of these issues in computer models will allow to develop systems that care for the user's problems, that understand the motivation of the users and that communicate in a more appropriate manner. While computers will never learn to care or feel *for real* [11], the modelling and simulation of some of these traits could result advantageous.

1.2 Behavioural Biometrics

Behavioural Biometrics is the science that seeks to identify individuals based on their behaviour while carrying out daily tasks. Its underlying assumption is that each individual behaves differently and that these behaviours are unique enough to identify us with a satisfiable degree of certainty.

Just like physical biometrics look at the size of the hand, the fingerprint or the iris, behavioural biometrics look at features like the way we talk, the way we look at a screen or the way we walk. Moreover, such behaviours tend to vary with factors such as mood, fatigue or stress [12]. Thus, behavioural biometrics allow to, not only identify the individual, but also identify specific states of an individual. This analysis of behavioural patterns may be conducted in a non-intrusive and non-invasive way, by the mere observation of the user.

2 A Framework for Monitoring the Effects of Mental Fatigue

The main aim of the proposed framework is to detect symptoms of mental fatigue and, through notifications or other actions on the environment, prevent eventual errors or accidents that frequently result from fatigue. To assess the level of fatigue, the framework looks at the interaction patterns of the user with the keyboard and the mouse. This process is implemented using a background application that captures the events fired by the keyboard and mouse in an entirely transparent way. This way, individuals are able to carry out their tasks as usual, without being influenced by the monitoring. The features considered are used by or inspired in behavioral biometrics. In what concerns the keyboard, the features considered in this work are:

- Keydown time: the time during which a key is pressed down while typing; Units: Milliseconds (ms)
- Time between keys: the time between the release of a key and the pressing of the following one; Units: Milliseconds (ms)
- Errors per key: the number of times that the backspace or delete keys are used in comparison with the remaining keys;

Concerning the mouse, the features considered in this work are:

- Mouse Velocity: the velocity at which the cursor of the mouse travels in the screen; Units: Pixel/Milliseconds (px/ms)
- Mouse Acceleration: the acceleration of the cursor of the mouse at a given time; Units: Pixel/Milliseconds^2 (px/ms^2)

These features were selected from a wider group in a previous study [13], given the statistically significant effects that fatigue produced on them.

2.1 The Architecture

The architecture of the proposed system includes not only the simple acquisition and classification of the data, but also a perception of the environment. Users may interact with devices, that are integrated into the environment and provide information about users, their interaction patterns and their surroundings and context.

This system is organized into several layers that separate the acquisition and the data processing tasks:

- Data Sensing - The Data Sensing layer is responsible for acquiring data that characterizes the user in terms of the features studied, that describe their behavioural patterns;
- Data Processing - This layer processes and transforms the data to be sent to the next layer, synchronizing data from different sources and constructing the appropriate software objects. It also filters outlier values that would have a negative impact on the analysis (e.g. a key pressed for more than a certain amount of time);
- Classification - This layer is responsible for interpreting data from the mental fatigue indicators and build the meta-data that will support decision-making. To do it, this layer uses the machine learning mechanisms detailed below;

– Data access - This layer is responsible for providing structured access to the data of each user and managing their complete information. It provides, not only, access to this data in real-time but also provides access to a behavioural historic and profile of each user, allowing studies within longer time frames;
– Presentation - This layer includes the mechanisms to build intuitive and visual representations of the users' state.

The classification of the mental state of a user is achieved through the use of the k-Nearest Neighbour algorithm (k-NN). It is a method of classification based on closest training samples in the feature space. The data used to train the model used by the k-NN were acquired from the study detailed in the Case Study section. The classification model uses the following features: Mouse Acceleration, Mouse Velocity, Keydown Time, Time Between Keys and Error per Key. These are the features that showed more statistically significant differences due to fatigue in the studies conducted.

The process of analysing and classifying the behaviours is detailed in the work flow depicted in Figure 1. It starts with the acquisition of data from the mouse and the keyboard and continues with its processing and filtering in real time. The results of this classification are depicted graphically in real-time through the interfaces developed and are also stored in a database for future use.

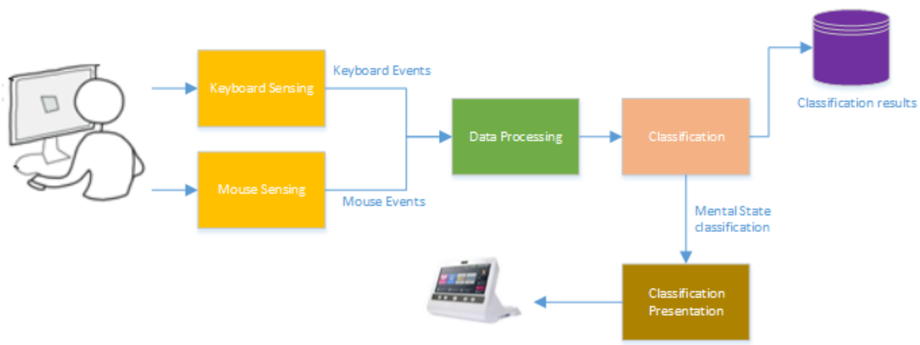

Fig. 1. The flow of data in the Mental Fatigue Monitoring Framework

It was also an objective to make these interfaces intuitive and simple to read. Indeed, the analysis of the information compiled should not constitute, in itself, a drawback. Despite the complexness of the information compiled, the it is shown, in a first instance, in a very minimal and intuitive interface. There is also no explicit or conscious interaction with the system: the events fired by the use of the mouse and the keyboard are stored and analysed entirely in background. The whole system runs in background, and only the output (classified mental state) is shown, through an icon depicting the mental state, as detailed in Figure 2.

It is possible to observe the current mental state of the user as well as the historic. For this purpose, it was developed a second graphical interface that shows the history of the user's fatigue, its current value, as well as the intensity of previous values. Both the mental states and their intensity are the result of the classification process. An example of a monitoring session is shown in Figure 3, where it is possible to observe the current mental state and respective intensity of the user, as well as its historic.

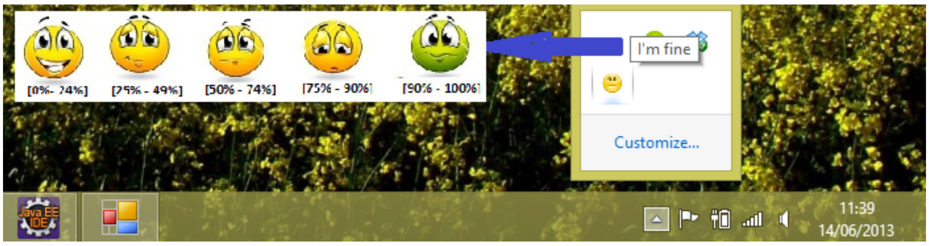

Fig. 2. Icon located on the taskbar of the Operating System, showing the current state of the user with a minimal interface. The arrow points to all the icons used to characterize the state.

3 Case Study

For the work detailed in this paper, the system was installed and used in a real working environment with the objective of monitoring in acute mental fatigue. This type of fatigue is common in nowadays working environments, in which the pressure of timelines, competition and challenging objectives results on short peaks of mental fatigue, with real-time visible effects on the behaviour of the individuals.

To study these behavioural differences due to acute mental fatigue, a study was conducted with collection of data in two different moments, for each one of the twenty participants. The described monitoring framework was installed in the computers of the participants and kept running in the background, having no effect on the normal behaviour and carrying out of the work of the participants. The participants were volunteer researchers from the University of Minho, performing their regular tasks at their laboratories, aged between eighteen to fifty. All these individuals were familiar and had previously used the computers.

The first moment of data collection took place in the morning, when participants were fully rested and starting their regular day of work. The second moment took place at the end of the day of work. Both collection moments took place in the same day for each participant. At the end of the day the user feels the effects of fatigue due to a full day's work [14]. In this work we argue that these effects are also felt and measurable in the user's interaction patterns, as described in the Results section.

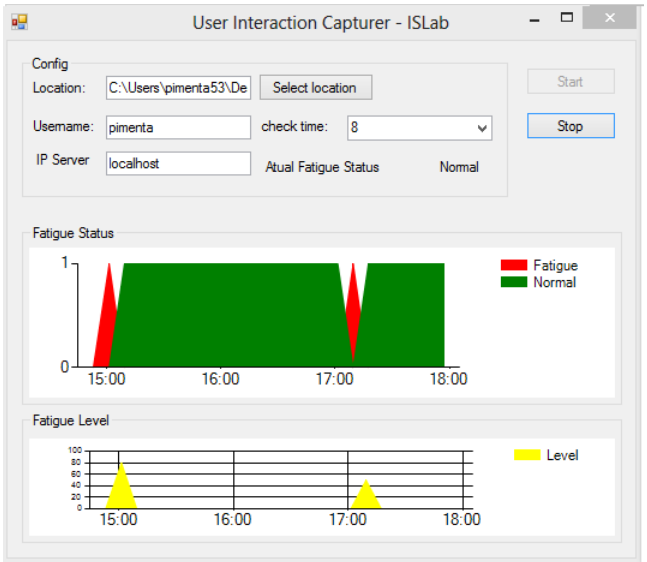

Fig. 3. The monitoring system displaying the current mental state and respective intensity, as well as the historic of the current monitoring session. It is possible to see peaks of mental fatigue around 15:00 and 17:00 hours.

4 Results

To check if there really is an effect on the behaviour of the participants between the two moments of data collection, a statistical analysis of the data was carried out.

First, it was determined, using the Pearson's chi-squared test, that most of the distributions of the data collected are not normal. In that sense, the Mann-Whitney test is used to test the hypothesis described ahead. This test is a non-parametric statistical hypothesis test for assessing whether one of two samples of independent observations tends to have larger values than the other, and thus prove the existence of distinct behaviours. The null hypothesis considered is: H_0 represents the equal medians of the two distributions. For each two distributions compared, the test returns a $p-value$, with a small $p-value$ suggesting that it is unlikely that H_0 is true. Thus, for every Mann-Whitney test whose $p - value < \alpha$, the difference is considered to be statistically significant, i.e., H_0 is rejected. In this work, a value of $\alpha = 0.05$ is considered.

The results obtained through this approach show that the handling of the keyboard and mouse in a normal state (without fatigue) and a state of mental fatigue are different. A significant difference between the data collected in the two different moments was observed which proves the existence of different behaviours. Figures 4 and 5 show that the use of mouse and keyboard is in generally slower. In these images, data from the first moment of data collection is depicted in green and the from the second moment is depicted in red. Figure 4 depicts an increase in the *keydown time* feature, which quantifies the time, in milliseconds, that a key is pressed down while typing. Figure 5 shows a decrease in the velocity of the mouse, measured in pixels/milliseconds. This velocity is computed between each two consecutive clicks. Both features show a statistically significant decrease in performance.

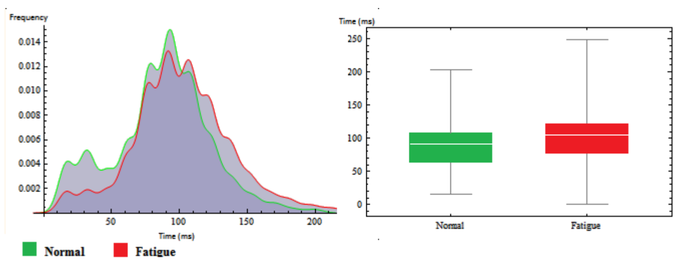

Fig. 4. Histograms and Box Plots comparing the data of the two distributions for the feature Keydown Time: fatigued individuals tend to write slower.

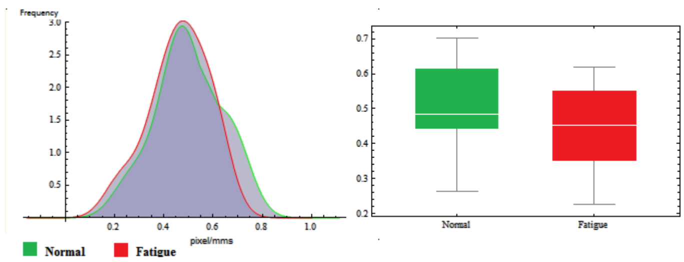

Fig. 5. Histograms and Box Plots comparing the distributions of the data collected in the two moments for the feature Mouse Velocity: fatigued individuals move the mouse slower.

Table 1 depicts the results of the Mann-Whitney test for each of the features, when comparing the distributions of the data in the two collection moments. It also shows the trends observed in the participants (e.g. 100% of the participants evidence an increase in the keydown time due to fatigue) and the values of the mean and medians for each of the features.

In a first instance these results prove, once more, that the presence of mental fatigue is accompanied by a loss of performance and an increase in errors. This is not surprising nor was it the main objective of this work. More important in this scope is the fact that it is indeed possible to detect mental fatigue through

Table 1. Results of the statistical analysis of the data for the 20 participants. Only the features that have shown significant differences are included. The "trend" column depicts the percentage of participants that have a given trend. For example, the mean value of the velocity of the mouse decreases for 90% of the students, when fatigued.

Metric		Normal	Fatigued	Trend	p-value
Keydown Time	Mean:	79.827	87. 119	Increases in 100%	$0.7 * 10^{-4}$
	Median:	77.601	81.502	Increases in 60%	
Time between keys	Mean:	469. 193	1040.26	Increases in 100%	$1.23 * 10^{-144}$
	Median:	215.75	386.55	Increases in 90%	
Mouse Acceleration	Mean:	0.4238	0.3829	Decreases in 90%	$3.01 * 10^{-11}$
	Median:	0.2202	0.2010	Decreases in 100%	
Mouse Velocity	Mean:	0.5002	0.4401	Decreases in 90%	$5.03 * 10^{-15}$
	Median:	0.2680	0.2537	Decreases in 100%	
Time between Clicks	Mean:	3081.35	3257.61	Increases in 50%	$5.8 * 10^{-4}$
	Median:	1733.30	1863. 15	Increases in 50%	
Error per key	Mean:	7.643	9.002	Increases in 90%	$2 * 10^{-2}$
	Median:	7.444	8.598	Increases in 90%	

the way people use the keyboard and the mouse. Moreover, this detection can be carried out using non-invasive tools, in real-time.

5 Conclusion

This paper detailed a framework for the detection and monitoring of fatigue based on pure Human-computer Interaction. It configures a process that is non-invasive and transparent to the users, relying on the sheer observation of the behaviour. Through the use of mouse and keyboard and the respective behavioural biometrics, keystroke dynamics and mouse dynamics were observed and used to analyse the different patterns of interaction of a user with the computer.

The results obtained evidence not only an already known and expected effect of fatigue on the user's performance throughout the day but also, and more interestingly, that it is possible to measure and classify these effects, in real time. This work opens the door to the development of leisure and work environments that are sensible to their user's level of fatigue. From this point on we envision the creation of decision-support systems that will improve the performance and quality of life of the individuals by suggesting better time-management strategies that optimize the work schedule. Additionally, within the context of the CAMCoF project, the long-term goal is to develop environments that are autonomous and take actions concerning the management of the environment towards the minimization of fatigue and the increased performance of a group of individuals, by adjusting aspects such as work schedules, ambient sound, pauses or individual musical selection.

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