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An enhanced fuzzy algorithm based on advanced signal processing for identification of stress

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ABSTRACT

Nowadays, it is crucial to promote and develop the autonomy of people, and specifically of individuals with some disability, in order to improve their life quality and achieve a better inclusion into socio-cultural life. Therefore, the identification of stress situations can be a suitable assistive tool for improving their socio-cultural inclusion. This work presents important enhancements and variations for an existing fuzzy logic stress detection system based on monitoring and processing different physiological signals (heart rate, galvanic skin response and breath). First, it proposes a method based on wavelet processing to improve the detection of R peaks of electrocardiograms. Afterwards, it proposes to decompose the galvanic response signal into two components: the average value and the variations. In addition, it proposes to extract information out the breath signal by analyzing its frequential composition. Finally, an improved response in detecting stress changes is shown in comparison with other previous works.

1. Introduction

Emotional Intelligence is an alive field of research, where some studies deal with human emotion measuring. These tendencies are within the approach of the assistive technologies, which have the target of improving people's life quality. Several research tendencies try to improve the autonomy of people with disabilities by focusing on improving their inclusion in socio-cultural life. Physiological signal measurements by non intrusive sensing systems, signal processing and analysis with Soft Computing techniques, identification and classification of emotions and stress situations, are some of the approaches that are being studied in a high number of significant research groups as [9,21,29].

Applying these studies to emotional blockage situations induced by a high stress levels is a field of huge interest as presented by Sharma and Gedeon [26]. A prompt detection of blockage situations is a powerful assistive tool for elder people and persons with disabilities. It is normal for people with special needs to have a caregiving person to help them when needed. For instance, a device capable of detecting blockage situations could be useful to inform the caregiver about a blockage taking place, helping them to give a quick assistance so the care-dependant person can overcome that difficult situation as fast as possible. This work presents an extended solution to the system presented in [23], which proposed enhancements for the work of [7], where such situations are detected and identified with the intention to be used in cases as the presented above.

Multiple studies analyze the influence of human emotions in people's everyday life, from qualitative studies based on human behavior as developed by López et al. [14], to quantitative analysis of measured physiological variations that emotions elicit in each person, e.g. in [25]. In particular, there are very specific physiological changes related to stress, as the phylogenetic substrates study made by Porges [20], or the activity study of the autonomic nervous system shown in [11]. As pointed in Cannon's research works, [3], when a person has to face a dangerous situation, the person's body prepares to confront that situation and generates a physiological response known as "fight-fly". This response increases the activity of the sympathetic nervous system producing changes as the increase of the heart rate frequency in order to provide more blood to the body. This change also produces the respiratory system to activate as a bigger blood flow requires more oxygen, [19]. Moreover, some other changes take place in the body such as the dilation of eye pupils to improve the vision or the increase of sweat secretion, [17].

Some proposals measure physiological signals using intrusive devices, as the work of [4] using cameras or electrode grids, to analyze and classify human emotions. Other lines are based on working with non-intrusive devices, as those having electrodes integrated in wearable devices or clothing accessories, [27]. This work is based on using physiological signals that can be measured with

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hidden devices, as the electrocardiogram (ECG), the galvanic response of the skin (GSR) and the movement produced by the subjects breathing (RESP).

Currently, processing and analyzing real physiological signals is a very interesting challenge in Biomedical Engineering. The complexity of such variables is remarkable, being higher than it seems a priori, as discussed in [15]. Such difficulty comes from the large amount of the data generated by analyzing the captured time series and from the countless noises and artifacts that appear in data entries. To solve these kinds of problems Soft Computing techniques have been highlighted considerably, as developments presented by Lee et al., Wozniak et al., Calvo-Rolle and Corchado [2,13,30].

In the study of human emotional changes, and specifically in stress situation labeling, some Soft Computing approaches have a special applicability, as [7], and [22]. These allow researchers to add undefined indexes that can be detected looking at physiological data time series during blockage situations. Due to the complex equilibrium between parasympathetic and sympathetic nervous systems, [18], at the present time it has not been possible to define the exact link between blockage situations and their associated physiological changes. But, as presented below, the measured ECG, GSR and RESP signals allow to see such changes in data time series.

The objective of this work is to continue developing an enhanced identification system for blockage situations based on the measurement of non-intrusively obtained human physiological signals. The work proposes to enhance the Matlab® based system presented in [23] by improving the processing of the input signals and adding a new input variable, based on the RESP signal. Three main improvements are proposed. First it proposes to increase the robustness of ECG processing using wavelet techniques, [10], for a more accurate R peak detection, recently appeared in works as [6,16,24,28]. The second is to decompose the GSR signal into its average and variation components to improve the efficacy of the Fuzzy strategy. The last improvement proposes process the RESP signal in order to get the frequential composition of the breath and to use its standard deviation as an input of the detection system. This combination of advanced signal processing and the addition of a third signal gives the system a higher immunity to false detections and implies an innovative approach to the strategy followed by the previous works where only two input signals were used.

2. Experimental stage

When humans are involved, the design of an experimental stage has to be performed with special care, considering and respecting all laws and each individual's rights. Eliciting of emotional blockage situations is a very specific work line considered within the human emotions study. In the present work, a particular experimental stage was designed based on the previously established by authors as [5,8]. These experiments consist on proposing a challenge of dexterity for solving a 3D puzzle in a limited period of time, in order to elicit a stress situation which will lead to an induced emotional blockage. In each experiment, each subject was previously informed about the elicitation process, and all the legal rules for testing on human beings were fulfilled. At the end of the experiment they were asked to fill a questionnaire where they explained how they had felt during the experiment.

During the experiment, volunteers were connected to the electrodes needed to collect the ECG and GSR as shown in Fig. 1. In addition, a chest band was used to measure the movements produced by the breathing, the RESP signal. Regarding to these signals two main states can be distinguished in Fig. 1: Relax State (RS) and Stressed State (SS). These states are directly linked with the three main parts of the experiment. During the relaxing phases (RS) of the beginning and ending of the experiment the three variables acquire values and tendencies that show that the subject is relaxing. In these two phases, the heart beats at a normal pace, the sweating is low and the breathing is harmonic. On the other hand, while solving the puzzle (SS), the GSR increases (the subject sweats more), the ECG beat period is reduced and the RESP tends to be faster and more irregular. These changes prove that the subject is getting stressed.

Unfortunately, using electrodes has disadvantages that difficult the extraction of information. The movements of the person can produce different artifacts in the ECG that make it difficult to extract the information. Moreover, as the gel of the electrodes gets drier the conductivity between the skin and the electrode reduces, and so, signal amplitude decreases and noises appear easily. Fig. 2 shows examples of these two possible problems.

As in [7] it is proposed to use the heart rate (HR) signal as an input to measure the stress level, this paper proposes to make the HR calculation more robust in order to strengthen a subsequent fuzzy stress detection. To accomplish the task this paper proposes to use median filtering and wavelet analysis for detecting ECG peaks. The signal that has been used to prove the effectiveness of the method is the shown in Fig. 2, which has been collected in the experiments for very significant as it has different artifacts and noises.

3. Enhancement of the R peak detection

3.1. Median filtering

When using electrodes, offset is one of the most common artifacts that appear in collected ECG signals. As stated in [24], one of the best methods to eliminate the offset produced by electrode movements is to apply a median filter to the ECG. 100 ms is a suitable length for the filter as artifacts normally do not last for much longer. Fig. 3 shows how the offset is successfully removed from the original ECG by applying this filter. Anyway, the median filter maintains the shape of the signal, enabling the identification of R peaks.

3.2. Wavelet analysis

Once the offset is removed from the signal, the next step is to remove the noise which will be done using a wavelet decomposition and reconstruction, [10]. Fig. 4 shows the diagram of how the wavelet processing is done (on the left and right sides of the diagram respectively).

In the left side of the diagram, decomposition is shown. In each stage, the signal is divided into two parts: A and D coefficients. The A coefficients have low frequency information and the D coefficients the high frequency information. These two parts are obtained by filtering and applying a dyadic downsample to the original signal. Depending on the desired coefficients a different decomposition filter has to be applied: the H high pass filter for D coefficients and the L low pass filter for A coefficients. On the right side of the diagram the reconstruction process is depicted, which is the opposite to what is done in the decomposition. Note that the reconstruction filters H' and L' are not the same as the H and L filters used during the decomposition.

The last decision is to choose the specific wavelet to be used in the analysis. Choosing the best is a tough task beyond this paper. Anyway, the use of a wavelet is considered to be correct if it enables the perfect reconstruction of the original signal. Thus, this paper proposes to use the third wavelet of the Coiflet family (with its correspondent filters), which allows the reconstruction of the ECG.