EVALUATION OF MULTIPLE LEVELS OF PSYCHOLOGICAL STRESS USING ONLY ELECTRODERMAL ACTIVITY DATA

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This study presents a method for extracting a variable stress level by using a Kohonen neural network. The used physiological parameters were extracted only from the electrodermal activity signal. A very strict recording protocol was used to ensure an artefact free signal.

1. INTRODUCTION

Due to current research made in psychological and physiological fields, a connection was made between human stress and various health disorders like diabetes, heart disease, asthma, obesity and other disorders. Even though methods for detecting stress and other human emotions are being researched and satisfying results are being obtained, one major problem is the high number of sensors or electrodes that are required for successful emotion detection.

Real world scenarios were studied in [1–2] where driver’s stress was detected by using electrodermal activity (EDA), electrocardiogram, respiration rate and electromyogram data. Computer users’ stress can be detected as described in [3], where features were extracted from EDA, blood volume pulse, pupil diameter and skin temperature. Also, human emotion recognition is another researched field where some emotions can be associated with stress and encouraging results in emotion recognition were obtained in [4–6].

“Monitoring the electrodermal activity is increasingly accomplished in agent-based experimental settings as the skin is believed to be the only organ to react only to the sympathetic nervous system. This physiological signal has the potential to reveal paths that lead to excitement, attention, arousal and anxiety” [7]. Also, in [7] a lack of feature extraction methods is described and the study supports the idea that new, more complex methods are needed in emotion recognition research. In

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this idea is emphasized and a new method for feature extraction from EDA data is presented which was used along with other parameters to obtain an acceptable recognition rate for emotions.

A few conclusions can be drawn from previous research. All developed methods until now can provide a simple true or false statement about a specific emotion and there is no information about the level of said emotion that influences the subject. New complex methods are needed when analyzing physiological signals and almost all studies that involve emotion recognition have one physiological signal in common, the electrodermal activity data, but all of them use extra signals in the detection process.

The EDA data can be easily acquired with two electrodes placed on the subject’s skin. The effect of the subject’s psychological and physiological state on the eccrine sweat glands, signal acquisition methods and measuring sites are described in [9–11]. Because there are only two electrodes needed for recording, signal acquisition can be made very easy and the subject’s state won’t be influenced by a high number of attached electrodes.

2. INDUCING STRESS

A method used in previous studies to induce a state of stress or relaxation is described in this chapter. One of its main advantages is that the method can be applied multiple times in laboratory conditions and similar results are expected every time. The two completely different states (relaxation and stress) are needed for comparison purposes.

For the stress inducing part, a modified version of the Trier social stress test [12] is used. The subject’s task is to solve a series of mathematical equations with solutions from zero to nine in a variable period of time. This time interval varies according to the last three answers given by the subject: three consecutive correct answers will decrease the period by a fraction and three consecutive incorrect answers will increase the period by a fraction. At the beginning of the test, the subject is instructed that the time allowed to solve each equation is constant. To avoid situations where the subject gives too many correct answers and the period of time allowed for each question decreases to a point where the subject won’t be able to read the equation, a lower limit of four seconds was introduced. This limit will allow the subject to read the equation and at least try to solve it. By using this type of stress method, the minimal amount of time for solving an equation by the subject is reached. A stress level will be obtained because the subject won’t be able to solve even trivial equations or mistakes will be made because the amount of time given is not enough. After subject input, a message is displayed on the screen with big green characters for a correct answer and big red characters for an incorrect answer. This message is intended to further increase the subject’s stress level.
The relaxed state was obtained by playing a musical sequence into a pair of noise-cancelling earphones and displaying a slowly panning panoramic image. A classical musical sequence was used based on the results obtained in [13] where the effects of music on the subject’s state were studied. The slowly panning panoramic image was chosen because it kept the subject focused on the screen. This prevented the subject’s mind to wander to other thoughts or personal issues that could result in a stressed state instead of a relaxed state.

A software program that includes these two methods was designed, and after each test, a log file was provided that contained, for the stress part, time stamps with the moment when each equation was displayed, the moment when the subject gave an answer and the type of answer given (correct/incorrect). For the relaxation part, only the beginning and the end time stamps were logged. The software program is divided into three parts:

- relaxation inducing part: for two minutes, a classical music sequence is played and a slowly panning panoramic image is displayed;
- stress inducing part: for approximately ten minutes, the subject must solve 50–100 equations;
- relaxation inducing part: for two minutes, a classical music sequence is played and a slowly panning panoramic image is displayed.

By using these two methods, two different patterns were noticed when visually inspecting the resulting EDA signals. The relaxed state was characterized by a slowly decreasing trend and a low variability and the stressed state was characterized by a slowly increasing trend and a high variability. The three parts of the test are displayed on an entire recording in Fig. 1.

![Fig. 1 – Recording obtained after using the software program.](image-url)
In this study, recordings were acquired from subjects with ages between 25 and 65 years old. The signals were recorded with a Varioport device produced by Becker Meditec (Karlsruhe, Germany). The recorder is a 16 bit digital skin conductance amplifier that applies a constant 0.5 V across two Ag/AgCl electrodes with a contact area of 4 mm in diameter with a sampling frequency set at 250 Hz. Room temperature was maintained around 25 ºC and humidity was kept at 50–60 %.

The two electrode sites were chosen on the thenar and hypothenar eminences as indicated in [14] and Fig. 2. Electrode detachment during recording was avoided by washing the electrode sites with neutral soap and water. An isotonic conductive paste was used to obtain a good connection between the electrode and the subject’s skin.

Before the experiment was started, each subject had to wait at least 20 minutes with the electrodes attached to allow the electrode paste to form a good connection with the skin. Also, the EDA signal can be influenced by sudden noises in the room or other people walking around the subject, therefore the subject had to wear noise-cancelling earphones (through which the musical sequence was played) and the subject was left alone in the room. By taking these measures, influences generated by the environment or the recording equipment are minimized.

4. FEATURE EXTRACTION

In this study, five parameters were extracted from the EDA signal and used to evaluate stress that would best describe the subject’s reaction to stressed and relaxed states characterised by slow trend changes and fast variations in the EDA. These parameters are the skin conductance level (SCL) gradient, skin conductance...
response (SCR) frequency, skin conductance response signal power, response rise time and response amplitude (extracted from the EDA).

Before any features were extracted, signal normalization was required because each subject will react with a different SCL to stimuli. Because each subject reached a minimal SCL during the relaxation stage and a maximal SCL during the stress stage in the experiment (therefore each subject has a recorded maximum and minimum value that borders the EDA signal), a simple normalization was obtained by applying the equation (1):

\[ p_{\text{normalized}} = \frac{(p_i - \bar{p})}{\text{std}(p)}, \]  

where the mean value of \( p \) is

\[ \bar{p} = \frac{1}{n} \sum_{i=1}^{n} p_i, \]  

and the standard deviation of \( p \) is

\[ \text{std}(p) = \left( \frac{1}{n} \sum_{i=1}^{n} (p_i - \bar{p})^2 \right)^{\frac{1}{2}}. \]  

After signal normalization, a feature extraction window must be established. In previous studies, adjacent windows were used for feature extraction that returned a simple binary result: the subject was either stressed or relaxed. Also, in the subjects’ recordings, two frequent patterns emerged: short responses to external stimuli (noises, images) during the relaxation period and short periods of relaxation during the stress period. These reactions were noticed during clear stress or relaxed periods therefore a 15 second window would simply ignore these reactions. Another problem occurs when the subject’s response spans across two 15 second windows and two different evaluations are given. These problems were solved by using a 10 second overlapped window that was shifted by five second increments. In this way even the subject’s minor reactions to external stimuli were detected and, by averaging three successive windows an intermediary level of stress was obtained.

The SCR signal was obtained by using differentiation and a subsequent convolution with a 20-point Bartlett window on the EDA signal [15].

The SCL signal is obtained by low pass filtering electrodermal activity data with a sliding averaging ten second window.

Because the EDA signal ascending or descending trend offers information about the subject’s stress level, the SCL gradient was extracted by using the slope formula (4) from the simple linear regression theory [16], where “x” and “y” are the coordinates for each sample in the electrodermal activity signal.
Response rise time and amplitude were extracted from the normalized EDA data by using a peak detection algorithm. For each feature window, these values were summed and divided by the total number of samples in the window.

Parseval’s formula was used to compute the SCR signal power, which is the sum of the squared amplitudes in the feature window and divided by the number of samples in that window.

5. DATA CLASSIFICATION

After each recording, an expert observer was asked to analyze the EDA signal and mark the stressed and relaxed signal patterns. Because the subject’s recording presented some anomalies during the relaxed or stressed state, the observer received feedback from the subject and marked these anomalies accordingly. These anomalies appear when the subject is in a relaxed state and its mind wanders or it is distracted by an audio or a visual stimuli. The same thing occurs during the stress test, when trivial equations are presented and the subject relaxes. By gathering this information about the recording, a step signal with two values (“0” – relaxed, “1” – stressed) was generated. This signal provides a subjective testing and evaluation instrument for the classification method used in this study.

Because the evaluation method is a subjective observation made by an observer, a unsupervised classification method was preferred for the extracted features. More specifically, the chosen classification method was the Kohonen neural network [17–18] (self-organizing map). This type of network was successfully used in other research fields [19–20] and it represents a general model with a superior organizing capacity that can compress the input dimensions [21].

Network training was performed by using two thirds of the recordings that were chosen at random, while the rest were used to test the network outputs. Network size was set at four by four neurons and the training algorithm ran for 8 000 epochs.

After network training was finished, the whole training set was fed once again at the network input and the outputs were compared with the observer signal. The results were two neuron activation histograms associated with the stressed and relaxed state. For a better visualization, the histograms were scaled between 1 and 256 and a neuron activation histogram is displayed in Fig. 3 as a gray scale map for the both states. The neurons represented with a lighter colour have a higher activation rate than those represented with a darker colour.
In Fig. 3, the relaxed state is characterized very well by a single neuron that is positioned in the lower left corner. For the stressed state, multiple neurons have a high activation rate; therefore a decision must be made regarding which neurons will be associated with stress and which neurons will be ignored. This decision can be made by viewing the neuron activation rates according to their respective position in the Kohonen network in Table 1. Neurons with an activation rate equal to or larger than 5% were used as representative for the stressed state.

<table>
<thead>
<tr>
<th>Table 1</th>
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<tr>
<td>Neuron activation rates (%) for the stressed state in the neural network output layer</td>
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<table>
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<tr>
<th></th>
<th>4.96</th>
<th>7.27</th>
<th>0.99</th>
<th>24.8</th>
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<tbody>
<tr>
<td></td>
<td>2.86</td>
<td>0</td>
<td>19.62</td>
<td>7.16</td>
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<tr>
<td></td>
<td>0.99</td>
<td>1.43</td>
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<td>3.85</td>
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<tr>
<td></td>
<td>9.15</td>
<td>4.41</td>
<td>3.74</td>
<td>8.59</td>
</tr>
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By using the information presented in Fig. 3 and Table 1, a Kohonen network output label mask was generated where three labels were used: “1” for the stressed state, “0” for the relaxed state and neurons marked with an x were ignored. The ignored neurons were not considered when the Euclidean distance was computed to determine which output was corresponding to the presented network input. The generated mask can be viewed in Fig. 4.
After analyzing each recording from the test set with this mask, a comparison was made with the expert observer signal and a correct stressed or relaxed state average recognition rate of 85.1% was computed. This means that the Kohonen network will generate only two outputs for each type of state, but the purpose of this paper is to recognize multiple levels of stress.

For a gradual estimation in which rapid variation states are detected, a ten second window shifted by five seconds was used. For every three overlapped windows, the network output labels are summed and divided by three. In this way, four different levels were obtained: “0” (completely relaxed), “0.33”, “0.66” and “1” (very stressed). In Fig. 5 the variable stress level (A) and the binary state signal (B) were shifted for better viewing purposes.

In a previous study [22], a signal that describes a completely stressed or relaxed state was obtained (signal B in Fig. 5) which is used for comparison with the signal A obtained with the gradual evaluation method. In Fig. 5, the events E1 and E3 are two reactions to external stimuli while the subject was in a relaxed state (the signal around these events is characterized by a slowly descending trend and a low variability). A low level of stress will be generated because these short reactions occur during relaxation periods, which is correctly detected in signal A but in signal B a completely stressed state is reported. Also, the event E2 in Fig. 5 marks a short relaxation period during the stress task; therefore a lower stress level should be reported. Once more, for this event, the gradual evaluation method was
able to report a low stress level while the binary method reported a completely stressed state. The conclusion is that the gradual evaluation method will return a variable stress level that is influenced by the subject’s short reactions to external stimuli.

6. CONCLUSIONS

The method presented in this study can detect multiple stress levels while using two small electrodes for signal recording. It must be noted that current methodologies for stress detection require a large amount of electrodes and sensors used for recording multiple types of physiological signals. The existing methods can detect only two states: total relaxation or total stress.

The method used for signal normalization is also important because these physiological signals will vary in amplitude from one subject to another. By using this method, the analyzed signals will vary with the same amplitude for all subjects.

A strict recording protocol was used as described in [14] that provides recorded signals with minimal artefacts from the environment or the recording device.

From the two histograms in Fig. 3, an important conclusion can be drawn: there are two neurons specific to the relaxed state and stressed state that are placed in the far most extremities of the network (on the diagonal). This means that these two states are very well described by the network.

The recognition rate was computed for each recording in the training set by comparing the expert observer signal with the signal generated by the Kohonen network. An average recognition rate of 85.1 % was obtained on the entire test set.

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