Mental Stress Detection Based on Soft Computing Techniques

F. Mokhayeri
Biomedical Engineering Department
Islamic Azad University, Mashhad Branch
Mashhad, Iran
mokhayeri@ieee.org

M-R. Akbarzadeh-T
Electrical and Computer Engineering Department
Ferdowsi University of Mashhad
Mashhad, Iran
akbarzadeh@ieee.org

Abstract—**In this study, a novel approach is proposed for mental stress recognition through automatic analysis of eye video sequences. The proposed system consists of five stages: video capturing, fuzzy image processing, signal processing, feature extraction and, classification. The pupil parameters including Pupil Diameter (PD) and Pupil Dilation Acceleration (PDA) are measured using soft computing techniques wherein the eye region is detected using the genetic algorithm (GA), and a fuzzy filter is designed for noise reduction. Edge detection is performed based on fuzzy reasoning and linking is done using Hough transform. Then, signal processing technique is applied to the pupil parameters to extract their most relevant features. Extracted features are imported into the learning system to classify the affective states between "stress" and "relaxed". The Fuzzy SVM (FSVM) is applied to this classification process. In order to induce the stress in subjects, a Stroop color-word test is designed. Also, the results obtained from the pupil parameters are compared with two other physiological signals including Electrocardiogram (ECG) and Photoplethysmogram (PPG). The experimental results indicate the pupil parameters have great potential for stress recognition compared to the other two physiological signals and, proposed stress recognition system is promising.**

Keywords-mental stress recognition; fuzzy image processing; genetic algorithm; fuzzy support vector machine

I. INTRODUCTION

In recent years, a growing number of studies have investigated the relationship between the stress and physiological signals including electrodermal activity (EDA), heart rate (HR), various indices of heart rate variability (HRV), blood pressure (BP), muscle tension, and respiration, and pupil diameter [1-5].

This paper focuses on stress recognition based on pupil videos obtained from video camera that supports the reliable detection of subjects under mental stress levels. Use of video images is a reliable means of detection of stress as users are comfortable with video image capture due to the ubiquitous presence of video cameras in personal computers and it can be easily capture video of the eye of the user. In video-based sensing, effective image processing is needed. Many difficulties in image processing arise because the uncertain data. Fuzzy set theory and fuzzy logic offers us powerful tools for knowledge representation and uncertainty handling. Fuzzy image processing (FIP) is a relatively new field in which fuzzy set theory is applied to the task of image processing. This approach is valuable as fuzzy logic provides a mathematical framework that allows the application of expert knowledge to image processing problems. In this paper, a technique is presented for noise reduction and edge detection based on fuzzy logic reasoning.

This paper is organized as follows: Section.2 describes the data collection procedure. Section.3 presents the fuzzy-based image processing approach for computation of pupil parameters. Section.4 presents the physiological signal processing Section.5 describes the classification. Section.6 presents the simulation results. Finally, Section.7 explains the conclusion and future work.

II. DATA ACQUISITION

In this work, a multimodal database for the analysis of mental stress in computer user was constructed. It gathers the eye sequence videos and physiological data including the electrocardiogram (ECG) and photo-plethysmograph (PPG) under a mental stress state. In this dataset, sixty healthy male and female subjects in the 22-28 age range volunteered for the experiment. In order to induce mental stress in subject participating, a Stroop color-word (SCW) test is designed. The SCW test is a psychological test that involves focusing on one particular feature of a task, while blocking out other features to elicit mental stress in humans. Stimuli in the SCW test are mixed randomized in two groups of congruent and incongruent. Congruent stimuli are those in which the ink color and color name refer to the same word. Incongruent stimuli are those in which ink color and word differ. The SCW test in this work divided into three sections: 1.Congruent section 2.Incongruent section 3.Incongruent section with change of button position, and each section has four segments including 1.Initial segment, 2.Congruent segment, 3.Incongruent segment and rest segment. The change in the positions of the buttons in the third section is done to avoid subject's adaptation through repeated clicks. During this test, the subjects were asked to select one of the six buttons with the label that matched the font color of a word shown on the screen which named a color. Then they receive the correct answer with a sound feedback. Subject's pupil responses and two physiological signals were simultaneously recorded by video camera while performing Stroop test. The subjects were asked to sit comfortably and fix their head with a chinrest. To assure reliability of the changes of pupil size, during the experiments, the lighting condition and the temperature of the laboratory were held constant. Before the test started each subject watched a

978-0-7695-4574-5/11 $26.00 © 2011 IEEE
DOI 10.1109/BIBM.2011.80

relaxing video to set baseline relaxation. In this research, the pupil video was recorded by a video camera and PPG and ECG were recorded with the Powerlab system (ADInstruments). During the experiment, one video camera was placed in front of subject's eye, and three electrodes for a 3-lead ECG were placed on the subject's body and one PPG sensor placed on a subject's finger.

III. PUPIL PARAMETERS COMPUTATION

In this section, the fuzzy image processing approach is developed to compute the pupil diameter (PD) and pupil dilation acceleration (PDA). The proposed algorithm is composed of eight main stages including data capturing, video to image converting, preprocessing, edge detection using fuzzy logic, and calculation of PD and PDA using math operation.

A. *Pre-processing*

The purpose of this step is to eliminate the noise, remove the blink and, obtain the images with normalized intensity and similar size.

This paper presents a fuzzy filter for the noise reduction in pupil images. This employs the previous knowledge of the pixels for fuzzy smoothing. In the first step, all the pixels of images are adapted to estimate the noisy pixels of a pupil image and a fuzzy rule based system compute the degree to each pixel. In this step, a fixed threshold is used for a number of similar pixels in a neighborhood. In the second step, a secondary fuzzy rule based system is employed that uses the output of the previous fuzzy system to perform fuzzy smoothing by weighting the contributions of neighboring pixels [6].

Then blink detection is performed based on variance map calculations. The first frame is obtained and the variance map of the intensity values variations in the pixels of the sequence frames is created. The variance map (σ_1^2) and mean image (μ_1) of the first frame are initialized according to the (1) and (2) equations.

$$\sigma_1^2(x, y) = 0 \tag{1}$$

$$\mu_1(x, y) = I_1(x, y) \tag{2}$$

Then, the next frame is obtained. It is updated recursively according to the following formula that is given in equation (3) and (4).

$$\mu_{j+1}(x, y) = \frac{j\mu_j(x,y)+I_{j+1}(x,y)}{j+1} \tag{3}$$

$$\sigma_{j+1}^2(x, y) = \left[1 - \frac{1}{j}\right]\sigma_j^2(x, y) + (j + 1)\,(\mu_{j+1} - \mu_j)^2 \tag{4}$$

After each updating, a threshold value of the variance map is computed. The threshold value used in this work is 255. If the ratio of the number of threshold variance pixels to the total number of pixels in the eye exceeds from a certain threshold, a blink is detected [7].

Images captured from different people have different sizes and they are affected by illumination conditions and other factors. Hence we normalize the pupil images before feature extraction. Image intensity was normalized using the histogram equalization.

B. *Edge Detection*

In this work, a fuzzy image processing (FIP) method is performed for edge detection in pupil images without determining the threshold value. In this method, distinguished pixels are imported to the floating matrix by a fuzzy inference system. The fuzzy set was used to represent intensity and these sets were associated to the linguistic variables black, white and edge. The membership functions for the input and output fuzzy sets were Gaussian, and Mamdani method was used as the defuzzification procedure. Finally, the output membership functions is designed to distinct the values of the black, whites and edge of the image. The inference rules depends on the weights of the neighbors gray level pixels that neighbors weights are degree of blacks or degree of whites. In this method, all the pixels of the image assign by appointment the situation of the neighbor pixels and the condition of each pixel is defined by the 3x3 mask. The six rules were employed to compute the direction lines of gray level values around the centered pixel of each mask. In these rules, if the grays represented in one line were black and the other grays were white then the marked pixel is an edge. Another six rules compute the eight neighbors with depending on the values of the gray level weights, if the weights of the four sequential pixels were degrees of black and the weights of the other four neighbors are the degrees of white, then the center pixel represents the edge. Another group of rules are for detection the white pixels, black pixels and the edges [8].

C. *Edge Linking*

Hough transform is considered as a very powerful tool in edge linking and curve detecting. Its main advantages are its Insensitivity to noise and its capability to extract lines even in areas with pixel absence. The Standard Hough Transform (SHT) proposed by Duda and Hart is widely applied for line extraction in natural scenes, while some of its modifications have been adjusted for geologic lineament extraction purposes. Ellipse detection algorithm consists of three steps: 1. each pixel in the pupil image is transformed into a parameterized curve, 2. valid curve's parameters are binned into an accumulator, 3. a curve with a maximum score is selected from the accumulator to represent a curve in the pupil image [9].

D. *Pupil Diameter and Pupil Dilation Acceleration calculation*

First, the ellipse equation was formulated from the points located on the obtained outline of the ellipse. An ellipse equation can be shown in the form of expression (5).

$$Ax^2 + Bxy + cy^2 + Dx + Ey + F = 0 \tag{5}$$

The X- and Y-coordinates of the ellipse center (x_0, y_0) can be shown, respectively, using parameters A-F of expression (5), as shown below:

$$X_0 = BE - 2CD/4AC - B^2 \tag{6}$$

$$Y_0 = BD - 2CD/4AC - B^2 \tag{7}$$

Points A-F from expression (5) are calculated from the five points. The coordinates of the ellipse center are solved using expressions (6) and (7). These coordinates are compared with the coordinates solved using parallelograms. If the two points are not same, then five new points are chosen because the possibility exists that an incorrect point was included. If two points are same, the major axis and the minor axis are calculated using equations (8) and (9), which show the major and minor axes, respectively:

$$a = \sqrt{\frac{2(Ax_0^2 + Bx_0y_0 + Cy_0{}^2 - F}{(A+C)^2 - \sqrt{B^2(A-C)^2}}} \tag{8}$$

$$b = \sqrt{\frac{2(Ax_0^2 + Bx_0y_0 + Cy_0{}^2 - F}{(A+C)^2 + \sqrt{B^2(A-C)^2}}} \tag{9}$$

The obtained length is considered to be equivalent to the pupil diameter. Then Pupil Dilation Acceleration (PDA) is computed. First, PD deviation (PDD) is defined such as equation (10) and the measurement criterion according to expression (11) is defined to distinguish between the dilation and constriction of the pupil.

$$PDD = \frac{d\,(Secondary\ PD - Primary\ PD)}{dt} \tag{10}$$

$$Pupil\ Condition = \begin{cases} dilation & if\ PDD > 0 \\ fix & if\ PDD = 0 \\ \text{constriction} & if\ PDD < 0 \end{cases} \tag{11}$$

Then, Pupil Dilation Acceleration (PDA) is computed according the expression (12).

$$PDA = \frac{d\,(PDD)}{dt} \tag{12}$$

IV. SIGNAL PROCESSING

In this section, the signal processing technique is applied to the pupil parameters to extract the most relevant features. Mean value of PD (MPD) and Maximum value PDA (MPDA) is extracted from pupil parameters.

Also, the other two physiological signal including ECG and PPG are analyzed and Heart Rate Variability (HRV) and Blood Pressure (BP) are computed. These signals are often used to evaluate stress stage in studies of affective sensing and reflect user's affective state. Four features are extracted from the ECG and three features from the PPG. The full lists of all the features are given in Table I.

TABLE I. THE FEATURES EXTRACTED FROM THE SIGNALS

Signal	***Feature***	***Definition***
Pupi Video	MPD	Mean Value of Pupil Diameter Ration
Pupi Video	MPDA	Maximum Value of Dilation Acceleration
ECG	MHR	Mean Value of the Amplitude of each HR Response
ECG	RHR	Rising Time of each HR Response
ECG	HER	Energy of HR
ECG	DHR	Standard Deviation
PPG	MPPG	Average Value of the BP Samples
PPG	DPPG	Rising Time of each BP Response
PPG	DPPG	Standard Deviation

V. CLASSIFICATION

In this work, the Fuzzy SVM (FSVM) classifier is used to classify the features into different categories and differentiate the stress state from the relax state.

FSVM was proposed to deal with unclassifiable regions when using one versus the rest or pair-wise classification method based on binary SVM for n(>2)-class problems. FSVM is an improved pair-wise classification method with SVM; a fuzzy membership function is introduced into the decision function based on pair-wise classification. For the data in the classifiable regions, FSVM gives out the same classification results as pair-wise classification with SVM method and for the data in the unclassifiable regions, FSVM generates better classification results than the pair-wise classification with SVM method. FSVM method defines fuzziness among inputs and assigns membership values to each input. For a two class problem, the input dataset can be represented as the following:

$$(y_1,s_1,x_1),\ldots,(y_n,x_n,s_n)\ \forall\ x_i \in R^N,\ \forall\ y_i \in \{1,-1\}\ ,\ \forall\ s_i \in \{0,1\}$$

Where x_i is the input, y_i is the class label and s_i is the membership value. FSVM provides a solution for the following problem which is the Lagrangian form of the optimization problem:

$$\text{maximize } w(\alpha) = \sum_{i=1}^{n} \alpha_i - \frac{1}{2}\sum_{i=1}^{n}\sum_{i=1}^{n} \alpha_i\, \alpha_i\, y_i y_i k(x_i\,, x_j)$$

$$\sum_{i=1}^{n} y_i \alpha_i = 0 \quad 0 \le \alpha_i \le s_i C \quad i= 1,\ldots\ldots n \tag{13}$$

Where α_i is the Lagrangian coefficient, $K(x_i,x_j)$ is the kernel function and C is the cost parameter.

FSVM method introduces the concept of membership values into SVM. Hence, it needs to define the membership functions. A membership value provides a degree of the representativeness of the input for its class. Therefore, the membership function has to be formed to measure this representativeness. For calculating the degree of membership, classical membership functions can be used as well as data specific membership functions. In this study, the Distance to One Class Mean (DTOCM) function is used for assigning the degree of membership. A target class exists in this membership method; the distance measurement for the membership function is calculated due to the center of the target class.

$$fmf\,(x_i) = 1 - [dist(x_t\,, x_i\,) / (r_t\,, \delta\,)],\ x_i \in s\,,\ \delta > 0 \tag{14}$$

In the equation 14, dist is a distance function in the feature space, x_t is the center of the target class and r_t is the maximum radius [10-11].

VI. SIMULATION RESULTS

In order to evaluate the performance of the proposed algorithm, a database of pupil videos and physiological signals were constructed and an algorithm was tested on them. In this dataset, each participant generated data under two states in the Stroop test: relax state (Congruent Segment) and stress state (Incongruent Segment). The Stroop experiment sequence is composed of two sections which each section contains four segments including: 1) Initial segment (I), 2) Congruent segment (C) - in this section, the font color and the meaning of the words presented to the user is match and the subjects are not under mental stress. 3) InCongruent segment (IC) - in this section, the font color and the meaning of the words presented are different and, the subjects are under the mental stress. 4) Resting segment (S) - the subjects are relaxing in this section. Table II shows interval of each segment in the dataset [12].

TABLE II. THE INTERVAL OF THE EACH SEGMENT.

Section	*Approximate Interval (second)*
Initial segment	10
Congruent segment	40
InCongruent segment	80
Rest segment	20

The proposed algorithm is performed on the pupil images in each interval. Table III shows the recognition rate of the features.

TABLE III. THE RECOGNITION RATES USING FSVM CLASSIFIER

Feature		***Recognition Rate using FSVM***	
		Stress (%)	Relax (%)
MPD	Stress (%)	80.3	15.7
	Relax (%)	14.6	81.4
MPDA	Stress (%)	63.5	33.5
	Relax (%)	34.2	60.8
MHR	Stress (%)	73.2	22.8
	Relax (%)	20.8	75.2
RHR	Stress (%)	71.4	24.6
	Relax (%)	23.7	72.3
EHR	Stress (%)	72.5	23.5
	Relax (%)	21.8	74.2
DHR	Stress (%)	68.5	27.5
	Relax (%)	26.8	69.2
MPPG	Stress (%)	63.7	32.3
	Relax (%)	30.2	65.8
RPPG	Stress (%)	61.8	34.2
	Relax (%)	31.3	64.7
DPPG	Stress (%)	62.3	33.7
	Relax (%)	30.8	65.2

VII. CONCLUSION

In this paper, a stress recognition system based on soft computing methods was developed. In order to compute the pupil parameters, a novel algorithm was proposed which uses the fuzzy technique for uncertainty handling. In the proposed algorithm, the pupil region was detected using the genetic algorithm (GA), and a fuzzy filter was design for noise reduction. Edge detection was performed based on the fuzzy reasoning. The other two signals including ECG and PPG are analyzed using the signal processing method. Feature extraction was applied to the signals and, the extracted features were imported to the FSVM for classification of the user's states. The proposed method was tested on the dataset. The Experimental results indicate that stress significantly influences on the pupil parameters. The results confirm the ability of the proposed method to perform the comfortable and non invasive stress recognition system. Therefore, the proposed approach can be considered as a good option for improving the performance of the affective computing systems.

REFERENCES

[1] J. Healey and R. Picard, "SmartCar: detecting driver stress," Proc. Proc. 15th International Conference on Pattern Recognition, vol.214, pp. 218-221, 2000.

[2] T.G.M. Vrijkotte, et al., "Effects of work stress on ambulatory blood pressure, heart rate, and heart rate variability," Hypertension, vol. 35, no. 4, pp. 880-886, 2000.

[3] U. Lundberg, et al., "Psychophysiological stress and EMG activity of the trapezius muscle," International Journal of Behavioral Medicine, vol. 1, no. 4, pp. 354-370, 1994.

[4] L. Bernardi, et al., "Physical activity influences heart rate variability and very-low-frequency components in Holter electrocardiograms," Cardiovascular Research, vol. 32, no. 2, pp. 234, 1996.

[5] J. Zhai and A. Barreto, "Stress detection in computer users based on digital signal processing of noninvasive physiological variables," EMBS '06. 28th Annual International Conference of the IEEE, pp. 1355–1358, 2006.

[6] H. Vahdat Nejad, H. Pourreza, H. Ebrahimi, "A novel fuzzy technique for image noise reduction", Transactions on Engineering, Computing, and Technology, V14, 2006.

[7] T. Morris, P. Blenkhorn and F. Zaidi. "Blink detection for real-time eye tracking". Journal of Network and Computer Applications, Vol. 25, num. 2, pp. 129-143, 2002.

[8] Abdallah A. Alshennawy, and Ayman A. Aly, "Edge Detection in Digital Images Using Fuzzy Logic Technique", World Academy of Science, Engineering and Technology 51, 2009.

[9] Lim, S.,Lee, K., Byeon, O., Kim, T, "Efficient Iris Recognition through Improvement of Feature Vector and Classifier", ETRJ Journal, Vol. 23, Number 2, pp. 61-70, 2001.

[10] Inoue T, Abe S. Fuzzy support vector machines for pattern classification. In: Proceeding of International Joint Conference on Neural Networks. Washington DC, pp.1449–1454, 2001.

[11] N.Ozlem Ozcan, Fikret Gurgen, "Fuzzy Support Vector Machines for ECG Arrhythmia Detection", International Conference on Pattern Recognition, pp.2973-2976,2010.

[12] J ing Zhai, Armando Barreto: Stress Recognition Using Non-invasive Technology. FLAIRS Conference, pp. 395-401, 2006.