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Preliminary study on facial thermal imaging for stress recognition

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Abstract. It has been demonstrated that there is correlation between increased blood perfusion in the orbital muscles and stress levels for human beings. It has also been suggested that this peri-orbital perfusion can be quantified through the processing of thermal video. The idea has been based on the fact that skin temperature is heavily modulated by superficial blood flow. We have developed a high-definition thermal-imaging technique that can detect stress by recording the thermal patterns from people's faces. This technique has an accuracy comparable to that of polygraph examination by experts and has potential for application in remote and rapid security screening, without the need for skilled staff or physical contact. Although polygraph examinations, which have high precision when applied by experts, are good at identifying liars, they are impracticable for mass screening because skilled operators are needed, subjects have to be attached to instrumentation for several minutes, data analysis is time-consuming and the interpretation of data is delayed. We explored the possibility of using high-definition thermal imaging of the face for detecting deceit because it enables rapid automated analysis of changes in regional facial blood flow to be quantified. For stress recognition, support vector machines (SVM) and LDA are applied to design the stress classifiers and its characteristics are investigated. Using gathered data under psychological polygraphy experiment; the classifiers are trained and tested. The pattern recognition method classifies stressful from non-stressful subjects, based on labels which come from polygraphy data. The successful classification rate is 96% for 12 subjects. This means that facial thermal imaging because of its non-contact advantages, could be a remarkable alternative for psycho physiological methods.

Keywords. Thermal Imaging, Stress recognition, periorbital, polygraphy, SVM

Introduction

Affective Computing is a new area of computing research described as "computing which relates to, arises from, or deliberately influences emotions" [1]. It emphasizes the importance of adding new emotional features to the human-computer interaction [2]. Affective sensing, i.e., the development of mechanisms to make the computer aware of

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the user's affective state, is one key prerequisite to the development of affective computing systems. Our research attempts to explore a way to visualize and evaluate the emotional state identified with 'stress' of the users, through several physiological signals that can be measured non-invasively and non-obtrusively, and its results may support the possibility of Affective Computing applications.

Previous work has demonstrated the feasibility of detecting stress from physiological measurements. Such measurements can be acquired with minimal discomfort for the subject, and are useful in reflecting emotions [4]. One of the most relevant studies in this field was conducted by Healey and Picard [5], in which they presented methods for collecting and analyzing physiological data during real world driving tasks. They continuously recorded electrocardiogram, electromyogram, skin conductance, and respiration signals of drivers on a fixed route through Downtown Boston. Using Linear Discriminant Analysis [6], they showed that physiological measurements can predict mental stress with a high accuracy. Healey and Picard's study, however, did not address physical stress [7] which is another important stress category.

Pavlidis et al. have discovered a physiological signature on the face directly associated with stress levels [1]. This physiological response could be considered to be part of the 'fight or flight' syndrome triggered by the autonomic nervous system, whereby blood redistributes peripherally towards musculoskeletal tissue [3]. Specifically, Pavlidis et al. demonstrated that during stress produced by startle stimuli in the lab, subjects exhibited elevated blood perfusion in the orbital muscle area, which resulted in localized elevated temperature. They further suggested that such a heat signature can be captured by a highly sensitive thermal imaging system and analyzed using pattern recognition methods. Based on this principle, they have later developed an imaging system for quantifying stress during polygraph examinations. The system was compared with traditional polygraphy in an experiment designed and implemented by the Department of Defense Polygraph Institute (DOD PI). The accuracy of the two modalities was found to be equivalent (around 80%), thereby establishing the feasibility of the idea. In this paper we seek to achieve the following objectives:

1 - Identify the potential of thermal imaging as a means of detecting mental activity in human faces

2 - Proving the feasibility of facial thermal image analysis in order to explore the relationship between mental activity and it.

3 – Provide a physiological explanation for the observed thermal patterns that can reinforce the credibility and accuracy of the method.

4 - Evaluate the similarity of temperature signals and other psychophysiological signals such as blood pressure, electrical skin resistance and plethysmography.

In this study, we have used "peak of tension (POT)" test on 12 subjects and recorded polygraph and thermal signals. Then we extracted some feature from these signals and classified these using SVM into two levels. The remainder of this paper is as follows: Section 1 describes the methodology of our proposed approach, in section 2 we describe our experimental results, and finally section 3 summarizes and concludes the discussion with some comparison with other conventional methods of stress assessment.

1. Methodology

1.1. Experimental Results

In this project, we have used two devices for recording the database. The physiological signals were acquired using the CPS polygraphy system. The sampling rate was fixed at 256 samples for all the channels. PPG was measured from the ring finger of the left hand. GSR was measured from two Ag-AgCl electrodes attached to the index and middle fingers of the right hand. Appropriate amplification and band-pass filtering were also performed.

The second system used in this application is a TP8 thermal imaging model is made by China Guide Corporation. The system uses an uncooled thermal imager and some of the main characteristics are 384 * 288 resolution, sampling rate of 30 kHz, field of view of 22 x 16 and temperature sensitivity (NEDT) 1/0 ° C for 8-14 micrometer spectral range noted.

The protocol of recording was based on peak of tension (POT) test. In this case, one session of experiments took approximately 15 min. The first 2 min corresponded to the baseline measurement and were obtained without any stimulus. The subjects were requested to be as relaxed as possible during this period. Then, the subject were randomly shown pictures of 5 pieces of jewelry (ring, Czech Money, bracelets, coins and watches) and were asked questions about seeing or not seeing a desired object to determine if and when they would be lying. The first question was usually asked as a neutral question.

The temperature of the room was fixed around 25°C, humidity around 30%, and distance between imager and the subject was set at 1.5 meters. Moreover before each recording, subjects read and sign a text about their satisfaction to do this test.

Figure 1. Facial thermal images in stress condition.

1.2. Preprocessing and Noise Suppression

For every frame we compute the mean temperature of the 10% hottest pixels from within the periorbital region of interest. We have found experimentally that this represents the mean temperature on the vasculature in the inner corners of the eyes. This correlates with the portion of the periorbital region that has the highest blood flow rate (that's why it is the hottest) and is minimally affected in the imagery by blinking. Therefore, assuming that tracking is accurate, it provides a temperature signal that is indicative of blood flow perfusion in the eye musculature. We consider that the periorbital temperature signal, as defined above, consists of two components:

1. A low varying component indicative of the long term trend of blood flow levels, which is of high information value.

2. A mid frequency component, which is associated with temporary disturbances in blood flow caused by stress in specific Question and Answer (Q&A) sessions. This is also of high information value).

Different methods were used to improve the signal, and in the end, the smoothing method in MATLAB software was used with 200 window's length. The results of this approach can be seen in Figure 2. The results show this filtering (smoothing) can substantially eliminate noise of signal.

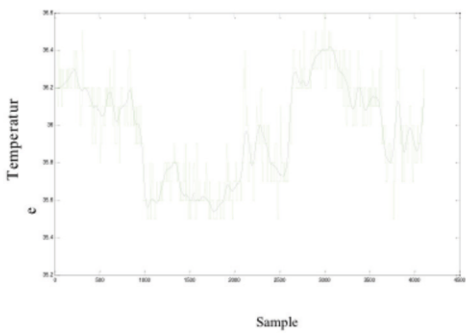

Figure 2. Periorbital temperature signal before and after noise suppression and smoothing

1.3. Feature Extraction and Selection

First, several features of the data set (signal mean, minimum and maximum temperature) extracted, Then we have used statistical algorithms to select the optimal features.

For labeling of the data set, different states can be considered for use: start of asking, end of asking and end of answer. Each of these times could be considered for feature extraction. It was shown that the first and third times are more legitimate. Further analysis of the periorbital signal indicating temperature, in a time of questions and answers on the subject indicates there are two stages of physiological responses. It is also observed that when subjects respond to questions, temperature curve for some of the subjects with a balanced gradient increases, but in some subjects there is a steeper increase. According to previous studies in [8] this type of slope is indicative of stress level. Thus, a steep periorbital curve indicates the subject is lying.

Therefore, the slope of the temperature changes from the beginning to start asking the next question is measuring and calculating as 10 features which are selected to represent thermal facial images.

In order to evaluate and select optimal features which are extracted we used paired T-test with SPSS 17 software. This technique helps to optimize the feature or set of features which would be used for the classifier input. As shown in Fig 3, The results of T-test on our feature set indicates that there is no good separation between two class and the highest value of T reached to 2.

1.4. Pattern Recognition

1.4.1. Linear Discriminant Analysis

The aim of LDA (also known as Fisher's LDA) is to use hyperplanes to separate the data representing the different classes [5] [32]. For a two-class problem, the class of a feature vector depends on which side of the hyperplane the vector is.

LDA assumes normal distribution of the data, with equal covariance matrix for both classes. The separating hyperplane is obtained by seeking the projection that maximize the distance between the two classes means and minimize the inter-class variance [32].

This technique has a very low computational requirement which makes it suitable for real time applications. Moreover this classifier is simple to use and generally provides good results.

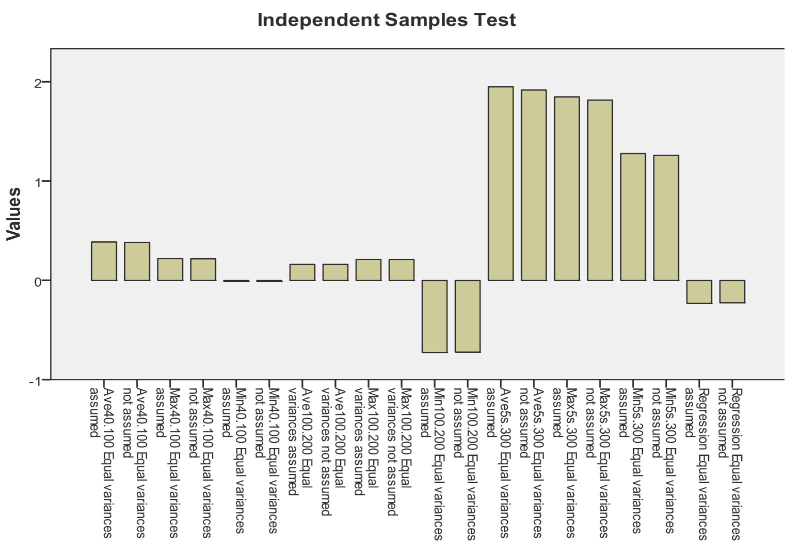

Figure 3. Results of paired T-Test on features. It has been used for optimal feature selection

1.4.2. Support Vector Machine

Support Vector Machines (SVM) are the computational machine learning systems that use a hypothesis space of linear functions in a high dimensional feature space to perform supervised classification. The support vector machine (SVM) tries to construct a discriminant function for the data points in feature space in such a way that the feature vectors of the training samples are separated into classes, while simultaneously maximizing the distance of the discriminant function from the nearest training set feature vector. SVM classifiers also allow for non-linear discriminant functions by mapping the input vectors into a different feature space using a mapping function $\Phi: xi \rightarrow \Phi(xi)$, and using the vectors, $\Phi(xi)$, $xi \in X$, as the feature vectors. The corresponding kernel function used by the SVM algorithm is

$$K(x_i, x_k) =< \varphi(x_i). \varphi(x_k) > (1)$$

The SVM used in this classification implements John Platt's sequential minimal optimization algorithm for training a support vector classifier. The practical interest of these methods is their capacity to predict the class of previously unseen samples (test set). The original data samples in any given data set are typically divided into a training set and a test set. This is done to have samples available for testing that were never presented to the system during the training phase. Such a strategy for dividing input samples into training and test sets is used in k-fold cross validation techniques. This strategy allows us to train and test on different samples and obviates the need to test on unknown physiological signal samples whose labels (targets) may be uncertain.

2. Results

In this paper, we used MATLAB software to classify data into two classes of stress and non-stress. The classifier which have been used are LDA and SVM. From each subject, there are 4 chart and in each chart there are 6 questions. In each question, features are extracted from a max and mean temperature signal. This operation is performed for 12 selected subjects. The labels of data are obtained from the polygraph data analysis. It means that, Firstly, we accept the output of polygraphy as the classic device for stress recognition and by using it, we labeled our thermal data.

The prediction performance was evaluated using 10-fold cross validation: 10% of samples were pulled out as the test samples, and the remaining samples were used to train the classifiers. To evaluate the predictive ability of the classifiers, the total prediction accuracy, which is the number of correctly predicted samples divided by the number of total samples, was calculated for each class. The goal was to develop and train a system that accepts the various physiological variables as input and predicts the participant's affective state. The Linear Discriminant Analysis (LDA) algorithm and SVM were trained to build the model independently, which could be used to predict the unknown affective state. The overall accuracy reached in each case is listed in Table 1. In our study, the SVM had the better prediction accuracy than LDA.

Table 1. Stress prediction accuracies

LDA	SVM
Accuracy percentage	Accuracy percentage
76.32%	96.00%

2.1. Correlation Analysis

The following conclusions can be taken from the below diagrams: It seems that the thermal signal has the highest correlation with blood pressure signal. The physiological reason for this could be due to rapid temperature changes in the body's autonomic nervous system function by increasing blood flow to specific regions of the body. As can be seen, changes occur in the four signals except that, the temporal dynamics are different.

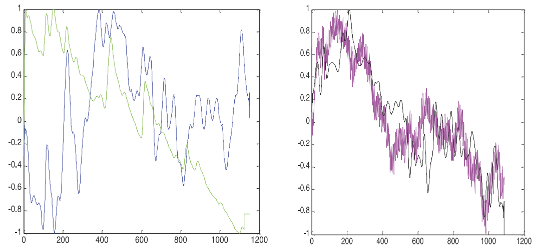

Figure 4. (a) Simultaneous display of GSR and periorbital temperature signal. (b) Simultaneous display of blood pressure and periorbital temperature

3. Discussion and Conclusion

We have presented a novel methodology for non-contact stress detection. It is based on facial thermal imaging. The results from the research outlined in this paper reinforce the belief that non-invasive, non-intrusive real time assessment of the affective state of a computer user is likely to become attainable in the future.

First, we convert the thermal images to periorbital temperature signal. Noise suppression removes the high frequency components from the signal. We have used polygraph psychophysiological signals (GSR, Blood Pressure, Respiration and PPG) for labeling the thermal data.

Some features are extracted from temperature signal and evaluated with paired T-test and 10 features have been selected to be input into a classifier. Two classifier were used for this purpose: LDA and SVM. The recognition rate for LDA and SVM are 76.32% and 96% respectively. It is clear that SVM gives a better prediction performance than the LDA.

It can be pointed out is that the temperature signal derived from the imaging had a resolution of 0.1 degrees Celsius. This means that the temperature changes of less than 0.1 degree were not available. It seems that the dynamic thermal response of tissue contains information subject to the separation of temperatures which are less than a few hundredths of a degree would provide greater detail which could be interpreted to assess a user's affective states. Despite the excellent features of this method a requirement is that the subject should not wear glasses during the test run. Glasses acts as a filter for infrared imaging and will prevent waves from reaching the imager. Also, the high price of the Thermal imager is another problem of this method that prevents its wide applicability.

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