Front-end Analog Pre-Processing for Real Time Psychophysiological Stress Measurements

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ABSTRACT

Every day computers become more influential in our daily lives. In an attempt to improve our interaction with computers, the emerging field of Affective Computing strives to provide the necessary mechanisms that will make machines aware of the affective state of their users. This paper explains the challenges in pre-processing psychophysiological signals, including Blood Volume Pulse (BVP) , Galvanic Skin Response (GSR) and Skin Temperature (ST) for the determination of the emotional state of a computer user, particularly, as he/she experiences emotional stress. These signals are appropriate because they are non-invasive, non-obtrusive and their variation under stress is predictable. The Galvanic Skin Response measures the change in electrodermal activity (increase in conductance) as sweat glands are stimulated to produce a hydrate solution. The Blood Volume Pulse waveform reflects modifications in heart rate, stroke volume and peripheral cardiovascular resistance modulated by the sympathetic nervous system. The acral Skin Temperature experiences short term changes that originate from vasomotor activity in the arterioles. The following sections describe the instrumentation setup that has been developed to monitor these three variables as computer users experience varying levels of stress, elicited by the completion of a series of "Stroop Test".

Keywords: Affective Computing, Psycho-physiological, Blood Volume Pulse, Galvanic Skin Response, Skin Temperature, Electrodermal, Sympathetic Nervous System, Stroop Test.

INTRODUCTION

The role of computers has changed from number crunching tools used by a small group of scientist, to everyday tools that help organize and accomplish daily activities for people in fields as diverse as medicine, engineering, law, transportation, logistics, etc. Computers have revolutionized the way we perform tasks, and the efficiency we achieve in them. This is possible because of the evolution in interactions between humans and computers. At first we could only communicate by means of perforated coded cards. Now we can use the keyboard, mouse, microphones, cameras, and we have sophisticated Graphical User Interfaces that allow people with no knowledge of computer programming to use them for their particular interests.

Affective Computing strives to take this interaction to new heights, by providing the necessary input for the computer to react to the emotional state of the computer user. This is a major challenge given the difficulties defining a trustworthy method of classifying and detecting emotions. This paper describes the development of the hardware for data acquisition that would allow determination of the affective state of a computer user.

PHYSIOLOGY OF EMOTIONS

Galvanic Skin Response (GSR), also known as electrodermal activity (EDA), is very popular in psychophysiological studies since Carl Jung and his students (1907) described it as a mean to enter the "sea of the unconscious" because "every stimulus accompanied by an emotion produced a deviation of the galvanometer" directly proportional to the strength of the emotion aroused. Eccrine sweat glands are intimately involved in EDA because they are concentrated in the palms of the hands and the soles of the feet and respond primarily to "psychic" stimulation, from the Sympathetic Nervous System (SNS), rather than ambient temperature changes. We used the exosomatic method to find the skin conductance, in which a small current is passed through the skin and measured.

The cardiovascular system is in charge to keep us alive by maintaining the vital blood flow throughout the body, providing nutrients and oxygen to our cells. The SNS controls this system by shifting the flow in response to exercise, temperature, postural and emotional changes. Blood Volume Pulse (BVP) is the most common measure of vasomotor activity because it reflects the phasic pumping of the heart, the vasodilation of vessels that changes in the amount of acral blood delivered. [1] In our instrumentation setup we measured this variable through finger photoplethysmography, which shines light against the finger and measures how much is reflected to a photo transducer.

The temperatures of peripheral limbs vary as a consequence of changes in blood flow [2]. In our instrumentation setup Skin Temperature variations are measured through a solid-state temperature transducer attached to the finger of the subject.

EQUIPMENT AND METHODOLOGY

We used the GSR2 module by Thought Technology LTD (West Chazy, New York) to record the Galvanic Skin response (Figure 1). This is a battery-operated device consisting of two elongated electrodes molded in a plastic case which makes them ideal for the shape of the hand. The index and middle finger (of left hand) are placed on the electrodes achieving contact over a large portion of the medial and distal phalanges. The apparatus finds the resistance between the two electrodes and determines its value to then output a square wave with a frequency that is proportional to the skin conductance measured. Its output is then fed into a frequency to voltage converter (LM2917) integrated circuit (IC) yielding a voltage level representative of the EDA.

To measure the Blood Volume Pulse we used UFI's Finger Clip Photoplethysmograph Model 1020-FC (Figure 2). We amplified the output 100 times and filtered with a low-pass 2^{nd} order filter to minimize noise from fluorescent lamps. The photoplethysmography clip was placed on the left hand's annular finger (distal phalange).

The subject's skin temperature is gauged with an LM34 IC that provides a linear output between -50 and 300 degrees Fahrenheit. Since our range of interest is between 75 and 100 degrees [3], the output of the sensor is buffered and fed to a differential amplifier (with a gain of 31V/V). The sensor was attached to the distal phalange of the left thumb finger with the help of Velcro (Figure 3).

Our three signals: GSR, BVP, and ST were converted using a Multi-channel National Instruments DAQPad 6020E Analog-to-Digital Conversion system, with each of the three independent channels sampled at 360 samples/second (Figure 4). Two more channels were used to digitize timing signals embedded in the program and generated by the laptop PC used for stress elicitation. The DAQPad system transmits the digitized signals to a PC host over a USB connection. A Matlab program was developed to receive the sampled signals and store them to the PC's hard disk.

Figure 1: GSR2 Module by Thought Technology LTD

Figure 2: UFI Finger Clip Photoplethysmograph Model 1020FC

Figure 3: Temperature Sensor LM34

Figure 4: Multi-channel National Instruments DAQPad 6020E Analog-to-Digital Conversion System

One challenging aspect of this research is to provide adequate stimulation to reliably elicit mental stress in a human subject. In the context of human-computer interaction, the stress experienced by the user is most likely to be mental (as opposed to physical), and moderate in intensity. Therefore, our experimental protocol sought to produce moderate mental stress in the participating subjects, at pre-determined times. Accordingly, a computer game based on the well-known 'Stroop Test' was designed and adapted to elicit the mental stress while the subject was interacting with the computer.

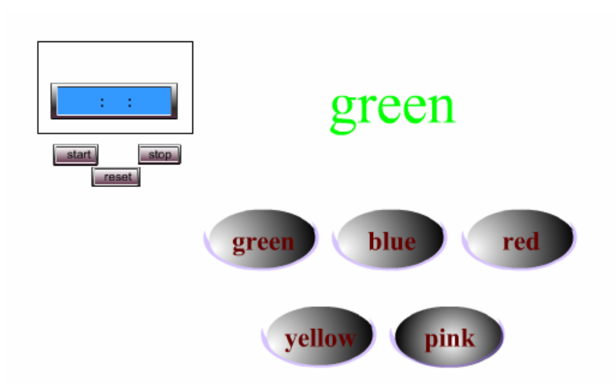
In the classical version of the Stroop Color-Word Interference Test [6] the subject is required to name the font color of a word designating a different color. Although there is controversy concerning the exact mechanisms responsible for the Stroop effect, this task has been widely utilized as a psychological or cognitive stressor to induce emotional responses and heightened levels of physiological, (especially autonomic) reactivity[5]. For our research, an interacting environment needed to be established to let the subjects experience a similar effect. To accomplish this, the classical Stroop Test was adapted into an interactive version that requires the subject to click the correct answer, which is one of the five buttons shown on the screen, rather than stating it verbally. One typical example of this test interface is shown on Figure 5 a).

This modified version was implemented with Macromedia Flash® and also programmed to output bursts of a sinusoidal tone through the sound system of the laptop used for stimulation, at selected timing landmarks through the protocol to time-stamp the recorded signals at those critical instants. These sinusoidal burst signals from the audio output of the stimulus laptop were thresholded and fed into retriggerable multivibrators to obtain a single pulse in each signal, every time a given channel (left or right) was activated. These two pulses could then express any of the four binary combinations of two bits: 00, 01, 10, 11 to provide 4 different types of event markers through the protocol. Figure 5 b) is the audio output schedule in this experiment from the beginning to end of the protocol. The complete experiment comprises three consecutive sequences. In each sequence, there are the following segments:

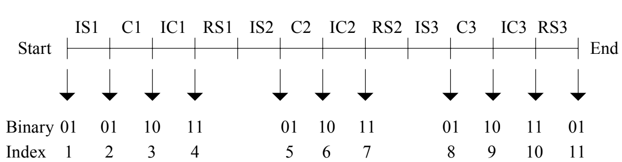
- 'IS' - An introductory section to let the subject get used to the game environment, in order to establish an appropriate initial level in the psychological experiment, according to the law of initial values (LIV) [1].

- ‘C’ - A congruent segment, in which the font color and the meaning of the words presented to the user match. The subject is expected to be in a baseline state of “comfort” during this segment
- ‘IC’ - An incongruent segment of the Stroop Test in which the font color and the meaning of the words presented differ. This is the segment in which stress is effectively elicited in the subject.
- ‘RS’ - A resting section to let the subject relax for a certain time.

The binary number shown in Figure 5b is the de-multiplexed output of the audio signalling used in the system to time-stamp the three physiological signals, BVP, GSR and TS. ‘01’ represents a burst in the left channel audio signal, ‘10’ represents a burst in the right channel and ‘11’ represents simultaneous bursts in both channels.



a) Sample screen of the Macromedia Flash version of the Stroop Test used



b) Audio output schedule used to time-stamp critical points through the testing protocol

Figure 5: Computer Implementation of the Stroop Test for stress elicitation: Appearance and timeline

RESULTS

Five healthy subjects (three females and two males) volunteered to compete the stress elicitation protocol described above while having their GSR, BVP and ST signals monitored and recorded by our instrumental setup. Their ages ranged from 25 to 32 years.

Our instrumental system was able to record the three signals with the level of accuracy desired, throughout the complete protocol and with a minimum or instrumental noise. The timing channels from the computer displaying the Stroop test were also recorded.

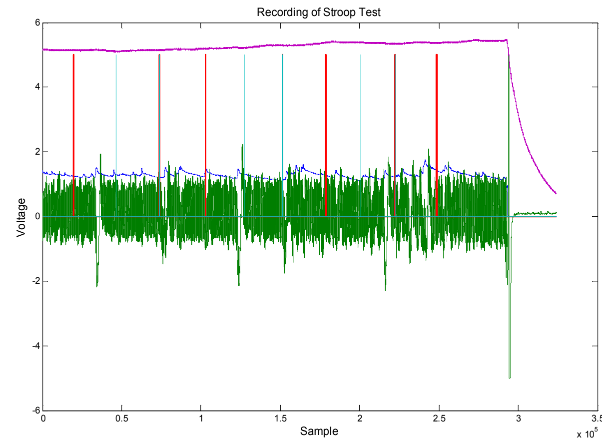


Figure 6: Affective State Recording Matlab Plots (subject 3)

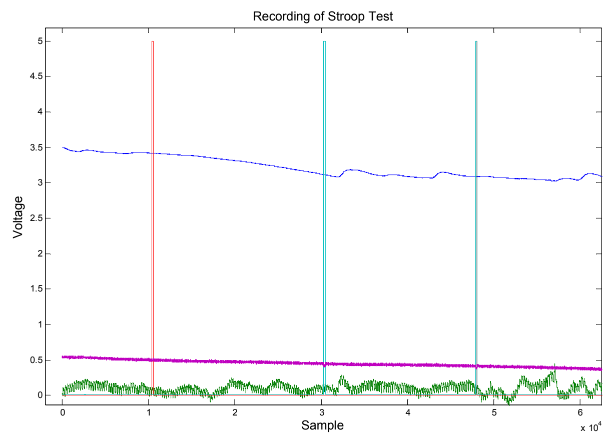


Figure 7: Affective State Recording Plots (subject 5, zoomed in)

Figure 6 shows the Matlab generated plots corresponding psychophysiological signals recorded from one of the subjects tested (subject #3). The long vertical lines are time landmarks derived from the timing channels recorded to help us recognize the exact location of key instants of the test. The first vertical line represents the start of the test. For the first period (spanning between the first and the second vertical lines) the Stroop test is designed to allow the subject to remain in a comfort state. During the second period (from second vertical line to the third) the test provides the stimulation designed to elicit the emotional stress response we want to quantize and analyze. The third period is a resting period, and then the same cycle is repeated two more times, that is: comfort state, stress elicitation and relaxation.

Figure 7 shows a selected segment (zoomed in) of the response of a different subject. In this figure, for example, changes in the GSR signal recorded reflect the effective elicitation of stress in the subject. For the first period (comfort state) we see no alteration or sudden increase of the GSR. However, when the stimulation is provided during the second period we see three peaks representing a change in electrodermal activity due to a change in stress state. A second feature that may be observed when comparing Figures 6 and 7 is the variability of the resting state levels for different subjects. Particularly we see that GSR resting state is low for the first subject (just over 1 V) while his temperature was high (reading almost 6 V). For the second volunteer we see that her average temperature was much lower (0.5 V) but her GSR was high (between 3 and 3.5 V).

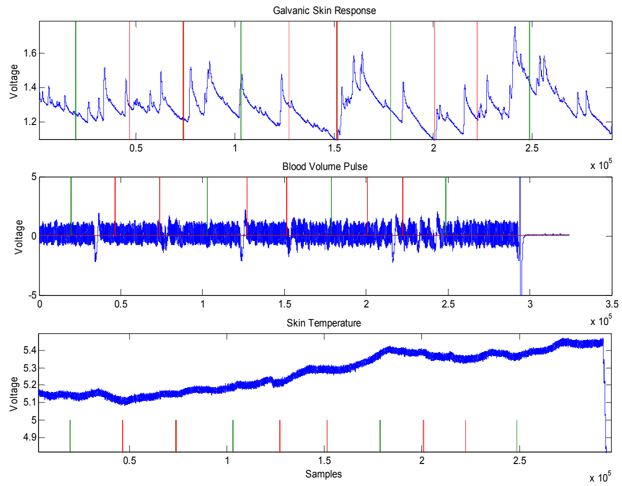


Figure 8: Affective Recordings Independent Plots (subject 3)

Figure 8 is the plot of the three recorded signals independently drawn with the timing marks. The changes in the signals are much more noticeable at each stage of the Stroop Test.

CONCLUSION

A hardware and software instrumental setup has been developed for the monitoring and recording of three key psycho-physiological signals: Galvanic Skin Response, Blood Volume Pulse and Skin Temperature, towards the automated assessment of affective state in computer users. The hardware consisted of the sensors and analog pre-processing stages for each of the three signals, as well as the use of a multi-channel analog-to digital conversion system. The software for this monitoring setup consisted in the Matlab programs for the acquisition and storage of the digitized signals, and a stimulus program, developed with Macromedia Flash®, to elicit mental stress at predetermined times in the testing protocol, through the 'Stroop Effect'.

The monitoring setup has been validated by recording data from five volunteer subjects. All three physiological signals were correctly recorded throughout the testing protocol, for each of the subjects. In addition, time-stamp data was gathered simultaneously with the physiological variables, to facilitate off-line analysis of time windows when the stimulus Flash program was expected to elicit stress in the subjects.

Visualization of the data collected verified our expectations that the instrumental system would be able to capture physiological changes that correlate with the elicitation of stress. In particular, some clear modifications of the GSR signal under the stress condition were observed in the data collected. Similar observations were made with respect to the ST signal of some subjects. The integrity of the BVP signals measured was verified, although no clear response features could be defined in this signal by mere visualization. All of these signals (and similar sets from more subjects to be monitored) will be used to develop a suite of digital signal processing approaches that may, eventually, provide robust classification of the affective state of the computer user from GSR, BVP and ST signals measured in real-time.

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