Physiologic Instrumentation for Real-time Monitoring of Affective State of Computer Users

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Abstract: - This paper outlines the development and hardware - software integration of an instrumental setup designed towards the real-time assessment of the affective status of a computer user. This assessment is based on the measurement and digital signal analysis of three physiological variables that reflect dynamic changes of the Autonomic Nervous System (ANS): Blood Volume Pulse (BVP) measured with an infrared finger photoplethysmograph (PPG), Galvanic Skin Resistance (GSR) and the Pupil Diameter (PD). Real-time assessment of the affective status of a subject is an essential component in the development of the emerging field of Affective Computing.

Key-Words: - Physiologic Monitoring, Blood Volume Pulse, Galvanic Skin Resistance, Pupil Diameter, Affective Computing, Human-Computer Interaction.

1 Introduction

Since their emergence, computers have been used in continuously increasing areas of human activity. While computers were first devoted to highly sophisticated tasks, for very specific purposes, being accessed only by a small "elite" of highly trained users, now computers are present in many of the everyday activities of ordinary people. This dramatic shift in the proliferation and pervasiveness of computers has brought about a parallel shift in the means and reach of the human-computer interactions. Just a couple of decades ago users provided input to computer systems by means of perforated cards that represented cryptic codes, known only to the initiated. Still, if the sequence and syntax of such codes were not exactly as the rules would allow, the computer would simply drop the processing job, not giving it a second look, or allowing the user any real opportunity to amend the imperfect input. It was evident that computers were not designed to care about the users and their environment, and that almost the complete burden of the interaction had been placed on the human, forcing him/her to "think" as a machine and try to communicate with it in its native language.

These days, however, computers are much more user-friendly and accessible to relatively untrained operators. Human-computer interactions take place now in a synergistic framework in which users are frequently given ample opportunity to refine their input. Moreover, specialized interaction subsystems are now integrated in many computing systems so that at least part of the interaction can be performed in ways that are ordinarily used by humans, such as in the case of speech recognition and speech synthesis applications to human-computer interaction. Clearly, advances in Digital Signal Processing are being used to shift the "burden" of the interaction to the computer.

The emerging filed of Affective Computing strives to make computers aware of the affective or emotional state of the user, so that they can adjust their behavior appropriately, to enhance their interaction with humans [8, 9]. A specific example of the usefulness of this awareness would be in automated computer-based tutoring [3], where upon detecting user (trainee) frustration after the introduction of a new topic, the computer could slow down the pace of the instruction or provide additional explanations.

Of course, one of the major challenges towards this lofty goal is the definition of reliable mechanisms to detect and classify the relevant affective states of the computer user. This paper presents our instrumental approach to the detection of frustration episodes in a computer user.

2 Problem Formulation

In particular, when a person experiences an extraordinary emotional state, such as anger or frustration, the activation of the Sympathetic Division of the Autonomic Nervous System (ANS) will be reflected by the alteration of the physiology of a number of organs and systems. Sympathetic activation prepares the body for heightened levels of somatic activity that may be necessary to implement a reaction to stimuli that disrupt the “rest and repose” of the organism. When fully activated, this division produces a “flight or fight” response, which readies the body for a crisis that may require sudden, intense physical activity. An increase in sympathetic activity generally stimulates tissue metabolism, increases alertness, and, from a global point of view, helps the body transform into a new status, which will be better able to cope with a state of crisis [7].

A state of frustration will result in some level of sympathetic activation, which will simultaneously introduce variations in a number of physiological processes around the body of the frustrated individual, as the Sympathetic Division of the ANS is particularly divergent. Unfortunately, the human body is a highly dynamic environment, constantly undergoing variations due to a large variety of causes, in which the emergence of a frustration state is only one example. Therefore, the physiologic variations introduced by the user’s frustration may actually be small, compared to the background variations in those processes and in the physiologic signals that one can use to monitor them.

We propose that a key factor in achieving a reliable assessment of the affective state of the computer user is the simultaneous recording of several physiologic signals that are likely to present a synchronized modification when frustration sets in. Real-time assessment of the user’s affective state will require the comprehensive and global consideration of coherent modifications in many of these signals. On the other hand, the monitoring mechanism acting on the computer user cannot be invasive, and should not even be obtrusive. The instrumental setup we present aims to provide global monitoring of the sympathetic response that could be associated with frustration, without being invasive or obtrusive. For that purpose, the system monitors three physiological signals discussed next.

3 Physiologic Signals Monitored and Sensors Used

3.1 Galvanic Skin Response (GSR)

It is well known that the palms of the hands of a person experiencing stress or nervous tension tend to become moist. This is because sweat glands in these areas of the body are activated and fill with sweat (a hydrate solution of water and salt). Skin with higher water content will conduct an electric current more easily than dry skin. Increased activity in the sympathetic nervous system will cause increased hydration in the sweat duct and on the surface of the skin. The resulting drop in skin resistance (increase in conductance) is recorded as a change in electrodermal activity [5].

To record the Galvanic Skin Response we used a battery-operated GSR sensing module: the GSR2 (white device in Figure 1), by Thought Technology LTD (West Chazy, New York). This affordable device efectively addresses some of the key issues in sensing skin conductance that are relevant to the system proposed here: The two elongated electrodes and molded plastic case are ideal to have the hand of the subject rest on it and achieve contact over large portions of the volar surfaces of the medial and distant phalanges in two of the subject’s fingers, as recommended by Dawson, et al [2]. Also, a 9V battery powers the device to guarantee that only safe levels of current will be sourced from one electrode and sinked into the other for the skin conductance measurement.

This device uses the resistance found in between its two electrodes as the resistive value to determine the frequency of oscillation of a square-wave oscillator. Originally, the square wave oscillation is fed to a speaker, creating a sound whose fundamental frequency is proportional to the skin conductance measured (for the purpose of biofeedback training). Fortunately, an earphone output is available, which we use to feed the square wave signal into an “frequency-to-voltage converter” integrated circuit (LM2917N), which then yields a voltage proportional to instantaneous skin conductance. This modified device was calibrated by connecting several resistors of known resistance to it and measuring the output voltage of the frequency-to-voltage converter in each case.

Figure 1. GSR and BVP sensors.

3.2 Blood Volume Pulse (BVP)

Sympathetic activation is known to cause changes in heart rate, stroke volume and peripheral cardiovascular resistance [7]. All of these effects can be sensed non-invasively by monitoring the amount of blood perfusion in a peripheral region of the body, such as the tip of a finger, which is proportional to the opposition presented by blood in the region to the passage of infrared light. In our instrumental setup, we have used UFI's Finger Clip Photoplethysmograph (Model 1020-FC), biasing it with +/-9V and amplifying the output approximately 100 times (black clip in Figure 1). An active, 2nd order low pass filter was also incorporated to minimize the noise from fluorescent lamps that may pollute the signal, in spite of the black metal enclosure provided with the clip sensor.

3.3 Pupil Diameter (PD)

It is well established that the ANS innervates some of the muscles that control the pupil size [4, 7]. More specifically, it is known that the radially-arranged dilator pupillae muscles, which cause the pupil to open when they contract, are activated primarily via alpha-adrenergic input from the Sympathetic Division [1]. In order to obtain real-time measurements of the diameter of one of the user's pupils, we used the ASL-504 Eye Tracker system by Applied Science Laboratories (ASL, Bedford, MA). This system utilizes a near-infrared light source that illuminates the eyes of the computer user, who sits in front of the computer screen, while a video camera, with an infrared lens, continuously captures images of one of the user's eyes. Using this infrared process, reflections at two particular points in the user's eye can be obtained: the first is the bright reflection of the illumination on the cornea, or "Corneal Reflection" (CR), and the second one is the bigger reflection observed in the pupil, the "Pupil Reflection" (PR). Using real-time image processing methods, such as edge detection, the location of both of these reflections, as well as the size of the pupil are determined and recorded 60 times per second. The relative location of both these reflections can be used by the system to estimate the direction of gaze of the subject.

4 Experimental Setup

In order to measure the changes in GSR, BVP and PD that take place when frustration sets in, a hardware / software system was developed to: a) Provide an appropriate stimulus, capable of eliciting frustration in the subjects participating in the experiment; b) Provide synchronization signals for the rest of the instrumental setup, so that the segments of the several signals recorded under the frustration state can be identified and analyzed as a whole; and c) Record the signals with all the necessary time markers.

4.1 Stimulus Software and Context

In this research, the stimulus for the subject should elicit a state of frustration at known times, so that the changes in the physiological variables monitored can be assessed. Lawson [6], after Rosenzweig, defined frustration as "the occurrence of an obstacle that prevented the satisfaction of a need.". The 'need', in this case, can be interpreted to mean either a need or a goal. So our objective for this work was to give the subject a goal, and prevent him/her from achieving that goal. To realize that, a protocol similar to the one used by Scheirer, et al. [10] was followed. A computer game was designed that consisted of a series of 30 similar visual puzzles, each on a separate screen, presented one after the other. In each puzzle, the subject's task was to use the mouse to click on the box at the bottom of the screen that corresponded to the type of symbol (circle, square, triangle or star) that was repeated the most times in the screen shown (e.g., Figure 2). This mouse-click also advanced the screen to the next puzzle.

To enhance the emotional responses of the subjects, the game was made into a competition. The subject who achieved the best overall score for accuracy and speed when data had been collected from all participants would receive a 5-CD stereo system.

To elicit frustration at known times during the playing of the game, the software was modified to intentionally make the screen cursor unresponsive to the movement of the mouse, during five seconds, in three different visual puzzles. These delays occured after the subjects clicked with the mouse on a box they had selected, therefore delaying their progress to the next puzzle. The stimulus sequence described, implemented with Macromedia Flash ®, was 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. The burst would be played out of the left channel only (binary 1 = 01_b) at the beginning of the game; through the right channel only (binary 2 = 10_b) when each of the three cursor-freezing delays took place; and through both channels (binary 3 = 11_b) when the user clicked on a stop button to end the game. These timing bursts were used to introduce synchronization marks in the recordings of GSR, BVP and PD.

The left and right channel signals from the stimulus laptop were connected to retriggerable monostable multivibrators to convert each one of those bursts (whenever they occurred) to TTL-level pulses of the same duration. Furthermore, both pulse signals were connected to a binary decoder, so that for any of the three active combinations described above, a negative digital pulse would appear in the corresponding output line of the decoder. These lines were used to activate analog switches connected in parallel with 3 individual keys ("1", "2" and "3") in the numeric pad of the keyboard controlling the eye gaze tracking system. This was done to emulate those keystrokes, which are accepted by the eye tracking system program to add timing markers in the eye gaze and pupil diameter file collected by the system. With the arrangement described above these markers would be automatically introduced when 1) the user starts the session, 2) each of the three intentional cursor delays takes place, and 3) the user concludes the session.

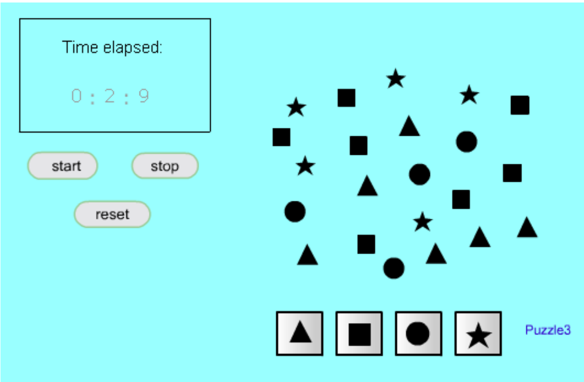

Figure 2. Stimulus Program Screenshot

4.2 Instrumentation Hardware

The complete instrumental setup used is illustrated in Figure 3. The stimulus program described above ran in a laptop PC. While solving the visual puzzles, the subject had the GSR and BVP sensors described attached to his/her left hand (Figure 1). Additionally, the eye gaze tracking system described had been calibrated and recorded PD data to a file on its own interface PC, at rate of 60 samples/second.

4.2.1 Conditioning and A/D Conversion of the BVP and GSR Signals

Both the GSR and BVP signals were converted, after appropriate conditioning described in the following paragraphs, using a multi-channel Data Translation DT2814 Analog-to-Digital Conversion board, as two independent channels, each at a sampling rate of 360 samples/sec. The acquisition of these signals to disk was initiated manually by the experimenter, a few seconds before the subject would effectively start to solve the visual puzzles, clicking the "start" button on the laptop program, which would send the first timing burst through its audio output. Similarly, the acquisition to disk would continue until it was stopped manually by the operator, after the subject had completed all the visual puzzles and terminated the session by pressing the "stop" button in the laptop program, which issued the corresponding timing burst through its audio output.

As mentioned before, the output of the photoplethysmographic BVP sensor was filtered by a 2nd order low-pass Butterworth active filter, with a corner frequency at 10 Hz. Moreover, the filtered BVP signal was not connected directly to the A/D board input. Instead, it was mixed with the TTL-level signal obtained from the left audio channel of the stimulus laptop, using a non-inverting, unity gain summing amplifier arrangement.

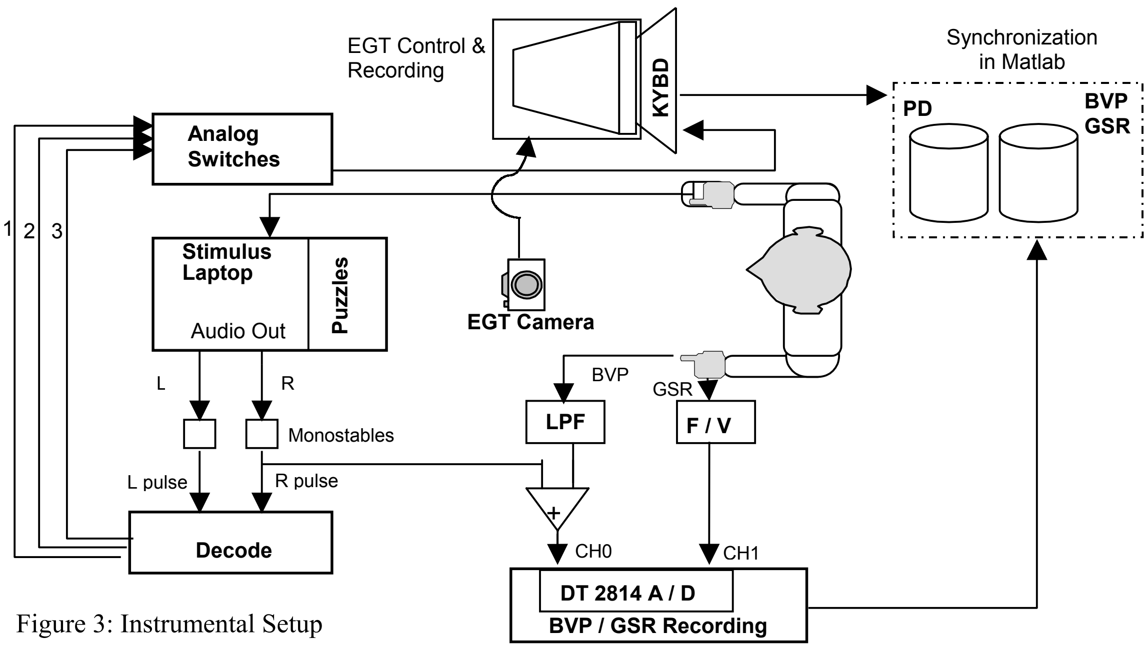

Figure 3: Instrumental Setup

Accordingly, when the user started or concluded the experimental session a large offset pulse would be added to the BVP signal, which allowed the easy identification of these timing marks in the digital record. Since these events (Start = event 1 = 01_b, and Stop = event 3 = 11_b) were also simultaneously recorded (as keystrokes "1" and "3") in the eye gaze and pupil diameter file, captured by the eye gaze tracking system's computer, it is possible, after the fact, to align both files. The need to fuse both files together is also the reason for our choice of sampling rate for the BVP and GSR signals: 360 samples/sec. The eye gaze tracking system records the pupil diameter 60 times per second. It should be noted that this "destructive" tagging of the BVP channel, to indicate the start and stop events, so that the BVP-GSR file could be aligned with the PD file, briefly distorts the BVP signal at the very beginning and at the very end of the session. These segments of the BVP signal need not be analyzed, anyway.

4.2.2 Pupil Diameter Recording

The values of the diameter of the subject throughout the experiment were collected at 60 samples/sec by the ASL-504 eye gaze tracking system. The software for this system allows the extraction of selected variables (in this case the pupil diameter and the marker channel) to a smaller file, which in turn can be read into Matlab ®, where it can be aligned with the BVP and GSR signals obtained through the Data Translation A/D board, thanks to their common timing marks for events 1 (start) and 3 (stop). At this point the pupil diameter data can be upsampled (interpolated) by six, to achieve a common sampling rate of 360 samples/sec, for all three of the signals measured.

5 Results

Figure 4 shows an example of the three synchronized signal traces, displayed in Matlab® for one of the subjects. The order of the signals is (from top to bottom): BVP, GSR and PD. The three stem marks, with circles at their tops, in each trace indicate the occurrence of events of type 2 (temporarily unresponsive cursor).

Measuring the intervals between peaks of adjacent BVP pulses, the instantaneous Heart Rate (HR) can be calculated (shown in Fig. 5). The Heart Rate Variability (HRV) can be approximated as the standard deviation in a sliding window, normalized by the window mean. Then, defining an interval of suspected frustration around HRV increases that surpass a given threshold, the "BVP suspected frustration intervals" shown in Fig. 5 are found.

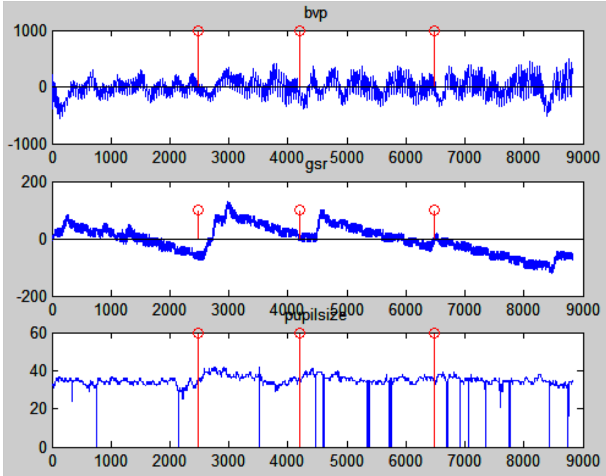

Figure 4: Synchronized BVP, GSR and PD data collected from subject #11 in our experiments.

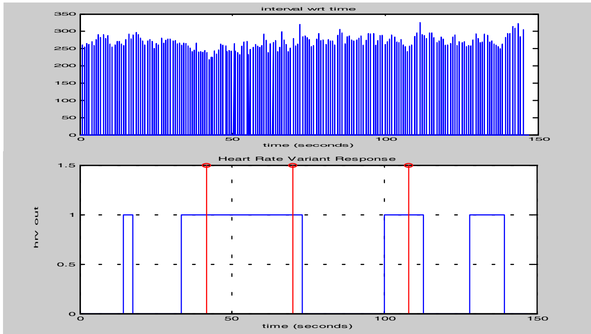

Figure 5: HR from BVP and BVP suspect intervals

Similarly, removing the trend and smoothing the GSR signal with a median filter yields the detection signal shown in Fig. 6, along with the "GSR suspected frustration intervals" that are defined from it, by thresholding.

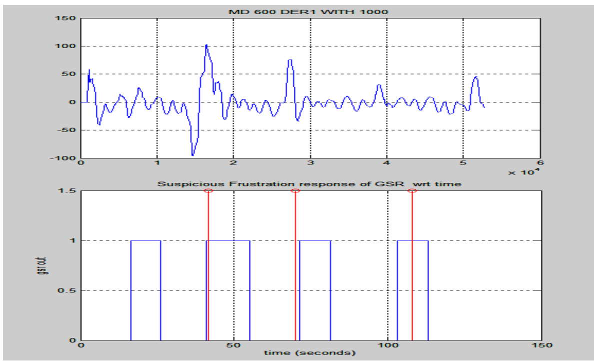

Figure 6: Processed GSR and suspect intervals

In the case of the PD signal, gaps due to blinking have to be filled by interpolation. A threshold is then applied to the amended sequence of PD values, to isolate increases in pupil diameter that may signal an affective shift, perhaps due to frustration. The resulting "PD suspected frustration intervals" are shown in Figure 7.

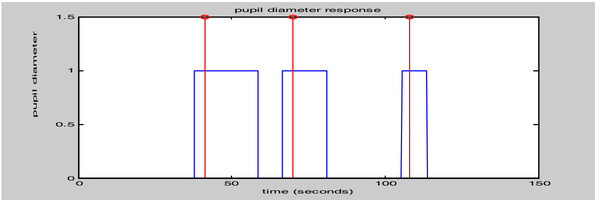

Figure 7: Suspect intervals from PD increase

When these detection signals are combined according to the following logic equation:

$$FR = (GSR \wedge BVP) \vee (GSR \wedge PD) \qquad (1)$$

the frustration suspected intervals determined by the overall system (FR) emerge. These are shown in Figure 8.

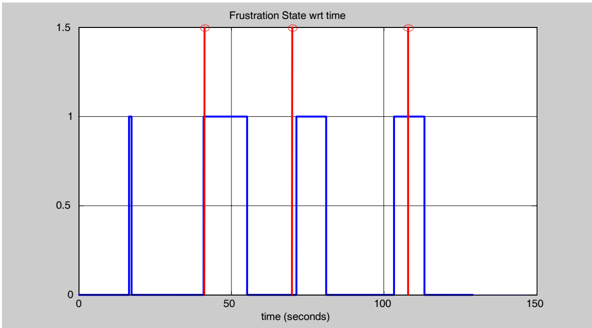

Figure 8: Overall frustration suspect intervals

6 Conclusions

The results indicating the suspicion of episodes of frustration, which are in good temporal agreement with the known timing of the cursor delays for the subject displayed, support the appropriateness of this instrumental setup for the comprehensive monitoring of the affective state of a computer user.

Other subjects from the pool of 15 that were tested with this instrumentation did not yield results that were as clear cut as the ones shown, with the simple processing used so far. This has encouraged us to seek the development of more complex and powerful algorithms, which will be tested with data that has been and will be collected using the instrumental setup described in this paper.

Once an appropriate algorithm is found, it will be implemented to process the real-time physiologic data that our instrumental setup produces.

7 Acknowledgements

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