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Quantifying Driver Stress: Developing a System for Collecting and Processing Bio-Metric Signals in Natural Situations

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Abstract

A system for quantifying the physiological features of emotional stress is being developed for use during a driving task. Two prototypes, using sensors that measure the driver's skin conductance, respiration, muscle activity, and heart activity are presented. The first system allows sampling rates of 200Hz on two fast channels and 20Hz on six additional channels. It uses a wearable computer to do real-time processing on the signals and has an attached digital camera which was used to capture images of the driver's facial expression once every minute. The second system uses a car-based computer that allows a sampling rate of 1984 samples per second on eight channels. This system uses multiple video cameras to continuously capture the driver's facial expression and road conditions. The data is then synchronized with the physiological signals using a video quad-splitter. The methods for extracting physiological features in the driving environment are discussed, including measurement of the skin conductance orienting response, muscle activity, pulse, and respiration patterns. Preliminary studies show how using multiple modalities of sensors can help discriminate reactions to driving events and how individual's response to similar driving conditions can vary from day to day.

1 Motivation

The problem of modeling, quantifying and detecting emotional stress response remains an open challenge to researchers. Many medical experts agree that stress is an important factor in disease prevention and recovery, yet no reliable method exists to monitor an individual's response to stressors from day to day. Previous work in physiological monitoring has focused on either sparse episodic diagnoses or on short term experiments in which the reported data is averaged over large populations (30-50 subjects)[Fah96]. The variations in individual reaction patterns over time have not been adequately modeled. To build statistical model's of an individual's response, a system must be developed to gather data during normal daily tasks. This research presents a system for use during the driving task. The driving task provides a real world situation in which repeated types of stressful events naturally occur and in which the driver is physically constrained from most activities that could mask the effects of emotional stress.

2 Capturing Context

To infer a relationship between features of the physiological signals and the affective state of the driver, information about the context of the driving situation was collected and synchronized with the signals from the physiological sensors. Several methods were considered for this task. The idea of using an observer was initially rejected because it was predicted that this would create confounding social interactions and inhibit natural expression of emotion toward driving events. However, pilot studies were conducted both with and without observers as passengers, considering the value of the observer's annotations. The method of directly prompting a response from the subject using either a keypad or audio recording diary was not used because it might have distracting the driver's attention at a critical time and endangered their safety.

In the first study, the context of the driver's state was captured using a digital camera focused on the driver and an audio recording. The physiological data was correlated with the digital images from the camera by a time stamp from the wearable computer. The audio tape was coded and correlated separately. Problems with this method of capturing context included the poor quality of the digital images (shown in Figure 1), the lack of documentation of driving events and the ambiguity of the driver's commentary.

In the second study, more reliable recording methods were used to capture context. To capture facial expression, a small video camera was mounted on the steering column, behind the release for the airbag, as shown in Figure 3. A second camera was placed on the center of the dashboard pointing out towards the road, using a .42 wide

Figure 1: In the wearable system, a digital camera temporarily mounted on the dashboard recorded the facial expressions and actions of the driver. Shown left, the driver attending to passing traffic at an intersection and right the driver attending to the road ahead.

Figure 2: The four video inputs are displayed simultaneously. Shown are images from the camera mounted on the steering column (upper right), the dashboard (lower right) and the sensor system (lower left).

angle lens to capture road and traffic conditions (as shown in Figure 4). Also, an observer rode as a passenger to record driving events. The video signals from the cameras were synchronized with the video signal from the physiological monitoring system using a quad splitter, as shown in Figure 2. This allows for an unambiguous record of physiological response to driving events. A fourth input to this system can be used either to display annotations from the observer or to show input from a video camera capturing the road behind the car.

3 The Physiological Sensors

In both pilot experiments, the drivers wore physiological sensors under his or her clothing while driving. The sensors were placed so as not to restrict the motion of the arms, the hands or the foot responsible for control of the gas and the brake. The placement of the sensors in the first pilot is shown in Figure 5. For the second pilot an EKG was placed on chest as shown in Figure 6 and the BVP was instead placed on the middle finger.

4 The Signals

Four types of signals were measured during the driving task: skin conductance, respiration, muscle activity and heart activity. Heart activity was measured using both a blood volume pulse (BVP) sensor and an electrocardiograph (EKG) sensor. These sensors were chosen because they are minimally invasive and can provide a continuous record of the subject's response to driving stressors.

4.1 Skin Conductance

The skin conductance is one of the fastest responding measures of stress response and has been previously used to measure the difficulty of driving tasks[Hel78]. It has been found to be one of the most robust and non-invasive physiological measures of autonomic nervous system activity[CT90]. Selye and others have linked skin conductance response to stress and autonomic nervous system arousal[Sel56].

A characteristic orientation or "startle" response occurs in the signal whenever a person is forced to attend to

Figure 3: A small camera is placed on the steering column to capture facial expression while driving. The camera is placed behind the airbag release point to ensure the driver's safety.

Figure 4: A camera placed on the front dashboard with a .42 wide angle lens captures context information from the road. An observer can note driving events and monitor sensors using a laptop.

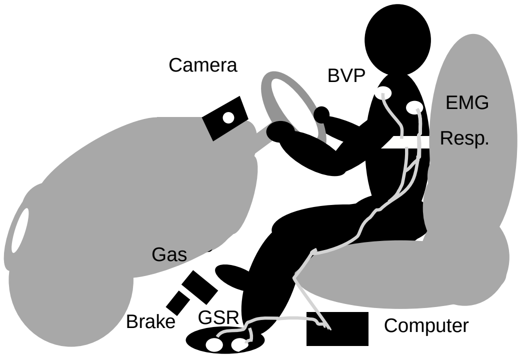

Figure 5: A diagram showing how the physiological sensors were worn by the driver in the first pilot study. The skin conductance sensor (GSR) was placed on the arch of the left foot. The respiration sensor was placed over the diaphragm. The electromyogram (EMG) was placed on the trapezius muscle on the left shoulder. In the first pilot, the BVP was paced on the driver's torso to avoid motion artifacts as shown. In the second pilot, an EKG was worn on the chest and the BVP was carefully placed on the driver's finger.

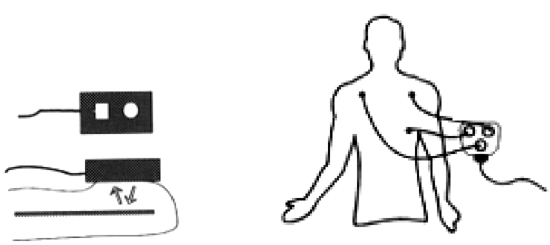

Figure 6: A diagram showing the BVP (left) and EKG placement (right) The BVP uses a backscatter method in which light from the sensor source is reflected by the volume of blood in the capillary and measured by the adjacent photo-detector. The EKG placement on the torso was chosen so as to minimize motion artifacts. Both diagrams are from the Thought Technology User's Manual[Tho94].

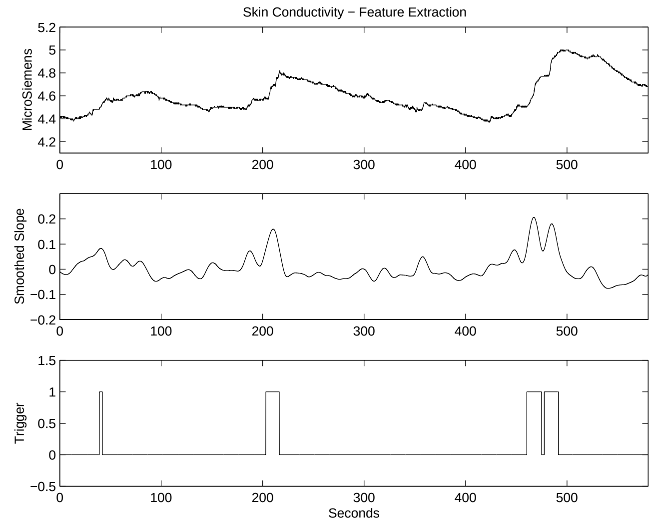

Figure 7: The skin conductance response is first smoothed with a low pass filter (top), then the first forward difference is calculated (middle). A threshold is then applied to trigger detection of the orienting response (bottom).

a change in their environment, either external or internal[Dam94]. Signal processing algorithms were developed to detect these responses. First the raw GSR signal, sampled at 20Hz, was convolved with a smoothing filter, then the first forward difference was calculated and a threshold was applied. The feature triggered by this threshold indicated the steep slope associated with the rising edge of the startle response. An example of this algorithm is shown graphically in Figure 7.

4.2 Heart Activity

Heart activity is a valuable indicator the individual's overall activity level, for example, heart rate accelerations occur in response to exercise, loud noises, sexual arousal, mental effort[Fri86]. Lower heart rate level is generally associated with a relaxed state or a state of experiencing pleasant stimuli[Fri86]. However, heart rate also accelerates upon inhalation and decelerates on exhalation. To assess an individual's stress response in real time this arythmia should also be modeled.

In the initial pilot, heart rate was measured using the BVP and sampled at 20Hz. To detect heart rate, an algorithm was developed to detect the rising edge of the signal a threshold. The inter-beat interval (IBI) was calculated as the time between detected rising edges, and the inverse of the IBI was recorded as the heart rate for that interval. An example of the BVP signal and the result of this algorithm are shown in Figure 8.

4.3 Respiration

Emotional excitement and physical activity are reported to lead to faster and deeper respiration. Peaceful rest and relaxation lead to slower and shallower respiration[Fri86]. A state of stress would therefore be indicated by frequent respiration; however, sudden stressors such as a startle, tend to cause momentary cession of respiration[Fri86].

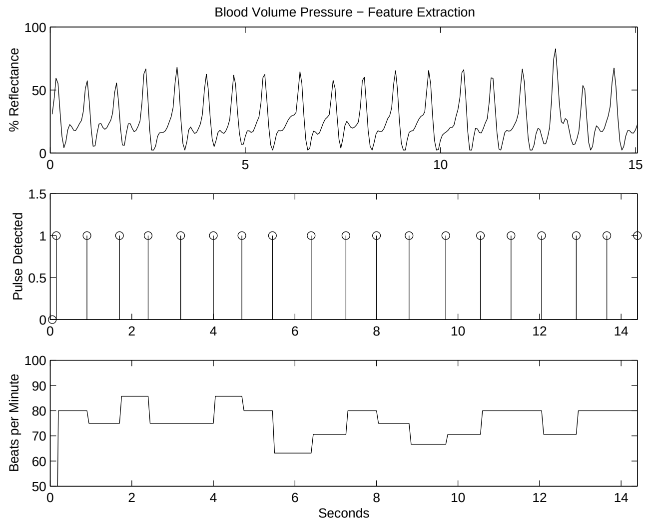

Figure 8: The BVP signal is processed using a threshold and a trigger to detect the pulse (middle). The reciprocal of the inter-beat interval is calculated and reported as the heart rate (bottom)
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Respiration is currently measured by a Hall effect sensor which detects the amount of expansion of the chest cavity as the wearer breathes in and out. This signal, sampled at 20Hz, is processed by first convolving with a low-pass filter and then taking the first difference. A threshold is applied to the smoothed slope and the rising and falling edges are detected. The time between breaths is calculated using the trigger for successive inhalations. Breathing rate is then recorded as the inverse of the inter-breath interval for that period. A heuristic for detecting the confounding activity of talking was also developed. If thresholds for the both the inter-breath interval and the average value of the raw signal during that interval exceeded certain thresholds, a flag indicating talking was triggered. Figure 9 shows the respiration signal and the results of the algorithms detecting inhalation, exhalation and talking.

4.4 Muscle Activity

Muscle activity has been shown to increase during stress[CT90]. People may unconsciously clench their muscles in a state of mental stress even when no physical activity is required[DEM88]. Firing from this muscle could indicate either unconscious clenching due to stress or firing due to motion, such as turning the car. Data from the context sensors can be used to differentiate these reactions. In the pilot experiment, the EMG was placed on the trapezius muscle. The EMG signal was sampled 20Hz in the first experiments which resulted in signal aliasing. Therefore, only a rough approximation of the muscle activity could be extracted. The muscle activity trigger first smoothed using a low-pass filter, then applied a threshold. Figure 10 shows the raw signal, the smoothed signal and the results of the threshold trigger.

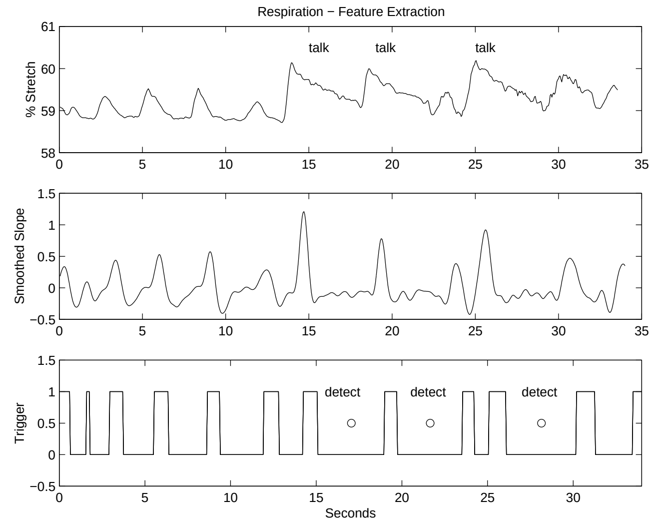

Figure 9: The respiration sensor measures the expansion and contraction of the chest cavity around the diaphragm (top), this signal is smoothed using a low pass filter and its slope, using a first difference is calculated (middle), a threshold is applied to this slope feature and inhalation and exhalation are detected (square wave - bottom). Additional processing of the length between breaths and the average of the raw signal between breaths allows the computer to detect the signature breath pattern for talking (circles - bottom).

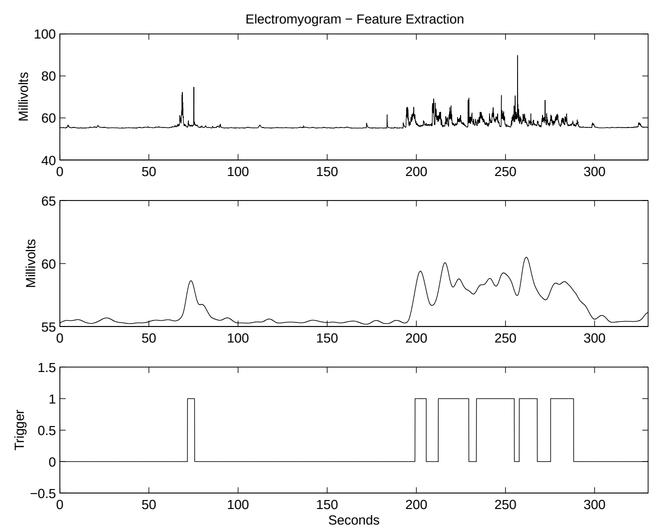

Figure 10: The electromyogram measures muscle activity. The raw signal (top) is first smoothed with a low pass filter (middle), then a threshold is used to trigger the feature indicating muscle activity (bottom).

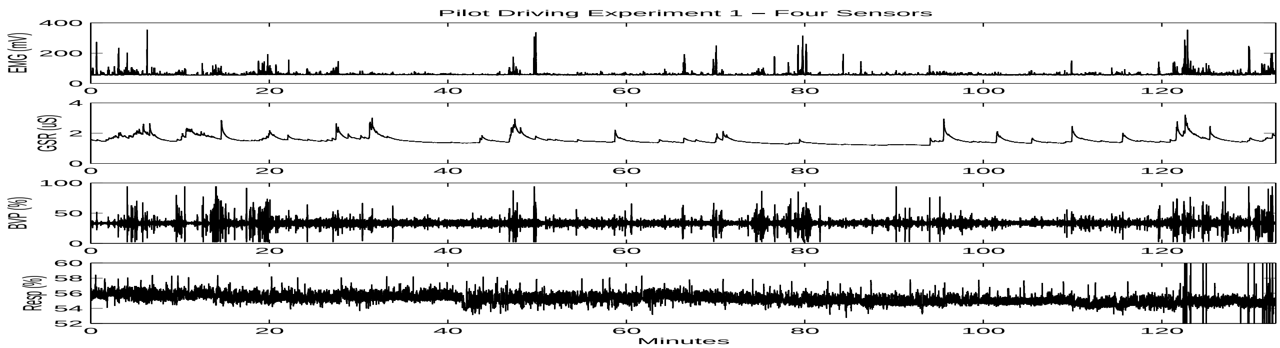

Figure 11: Data collected from the first pilot experiment using the wearable system.

5 Pilot Driving Experiment

Preliminary data from the first pilot experiments are presented to illustrate features of interest. Figure 11 shows the data collected by four sensors during two hours and twenty minutes of driving. Some events which were recorded from the audio record were the driver merging onto the highway at 31 minutes, the driver establishing cruise control from 38 to 47 minutes and the driver turning off the highway at 122 minutes. Looking across multiple sensor data suggests that events which involve both physical and mental stress such as turning can be distinguished from events which involve primarily mental stress such as merging or little stress such as driving under cruise control.

One confounding difficulty, however, is that the frequency of responses also appears to vary for the same driver on different days. Figure 12 shows the same driver's response to similar driving tasks. To account for variations due to gel and sensor placement the data is normalized by subtracting off the minimum and dividing by the range (maximum - minimum)[SF90]. In the first experiment, many responses occur, but in second experiment shown, only one strong reaction occurs when the car nearly collides. However, the strength of this reaction, may have also skewed the normalization process, by providing a larger range than the first experiment.

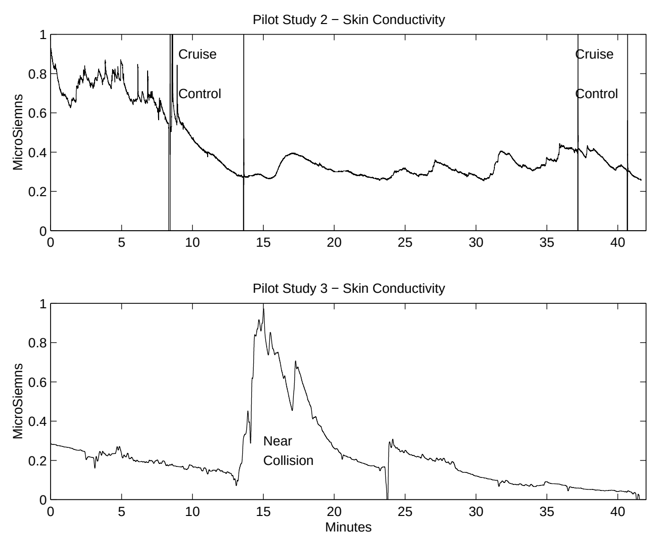

Figure 12: Normalized skin conductivity reactivity for the same driver on different days. The driver shows more responses on in the first pilot than the second at similar driving tasks.

6 Summary

Inferring the significance of physiological events in the natural environment is difficult and requires using many sensors to capture context. Stress reactions can occur from both physical and mental stressors. To understand the factors involved in the stress reaction, a model must be developed to interpret an individual's reaction in context. Using multiple sensors and context data, we hope to develop algorithms to distinguish between mental stress, physical stress and a relaxed state. The results of these algorithms could be used to help make people aware of how daily tasks effect their stress level. Real-time stress detection algorithms could also be used to monitor driver stress and determine if it is advisable to interrupt the driver with cell phone calls or navigation assistance.

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