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Stress Detection in Automobile Drivers using Physiological Parameters: A Review

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Abstract
In past few decades there is a steep increase in road accidents and loss of life was experienced mainly due to the increase in driver drowsiness, fatigue and mental stress. In order to minimize human error while driving, we can monitor stress and fatigue by measuring physiological parameters like ElectroCardioGram (ECG), ElectroMyoGram (EMG), Skin Conductance (SC) also called as Galvanic Skin Response (GSR) and Respiration Rate (RR) continuously over a period of time. The studies show that in most drivers' skin conductivity and heart rate parameters are more closely related to drivers stress level. Autonomic Nervous System (ANS) primarily depends on emotional responses of the human body to the dynamic surrounding. Further it also controls the smooth muscles, heart muscle and secretion of the glands in human body. As a result of this fact, bio-signal recordings reflecting the operating condition of the physiological systems including the circulatory, respiratory, muscular and endocrine systems can provide useful information representing the dynamics of the internal states in human body. Therefore, it would be expected that the dynamic stress level of an automobile driver can be derived from those recordings.
Keywords: Automobile driver, stress, electrocardiogram, electromyogram, galvanic skin response, respiration rate, review.

1. Introduction

Driving is a complex task, requiring full concentration and a vital balance between alertness and a calm attitude. Stress and strong emotions can affect this balance whether they result from the driving task itself, or some unrelated matters. The job of operating public transit vehicles in urban centers may be among the most stressful and unhealthy modern occupations.

Many studies conducted over the last four decades in cities on almost every continent show that bus drivers, when compared to workers in other jobs, are more likely to experience, death from heart and blood vessel disease. Further they suffer from conditions such as chest pain and high blood pressure, digestive disorders, musculoskeletal problems, especially of the back, neck and shoulders. Bus drivers frequently report mental overload fatigue and sleeping disorders. Bus drivers also have more frequent absences from work and of longer duration than workers in other occupations.

Driving is one of the most stress causing activities. And stress is mainly caused by change in environment. Whenever we are behind the wheel we are exposed to unbelievably fast changing circumstances like road conditions, vehicular traffic, speed limits, traffic lights, on road obstacles etc. In addition we are supposed to take into consideration all of them in order to avoid penalties/accidents. In the worst case scenario any negligence may have fatal consequences. Driving also requires several decision-making operations involving complex information processing. These operations often lead to high mental stress. A stressed out driver gets easily irritated and may have what's commonly known as "Road Rage". In fit of this rage, a driver can cause lot of harm, not only to himself or his passengers, but also to the fellow road travellers. It is therefore very important to measure stress level in automobile drivers.

In efforts to improve overall safety and comfort, a number of vehicular technologies have been developed and deployed in the market over the last few decades. A major drawback of available vehicular systems, however, is that they do not include the driver in the loop of decision-making processes. For example, even if the driver is heavily cognitively loaded or distracted, the decision threshold of safety systems as well as the human-computer interface's information exchange protocol remains the same. Little research is done in designing the human-computer interface of a high end that also includes stress monitoring of the automobile driver.

Stress is a physiological condition in which the body becomes excited to face an emergency situation. A number of physiological changes including increase in heart rate, breathing rate, pupil dilation, muscle contraction, sweating etc. occurs during a high stress state. When the brain perceives a stressful situation like high traffic driving, it send messages to a section of nerves called the Autonomic Nervous System (ANS) which then activates the adrenal glands in the kidneys to secrete hormones, such as adrenaline and noradrenaline. This adrenaline hormone secreted by the adrenal glands initiates the process of "Fight or Flight syndrome" that leads to a number of physiological changes in the body. These hormone triggered changes makes the body alert to face the situation. This is mainly due to the activation of Sympathetic Nervous System (SNS). After a short period of time, body returns to normal state by the activation of the Parasympathetic Nervous System (PNS). Meditation techniques can also decrease the elevated stress level of a person to normal level [1]. Thus, it may be concluded that stress is a natural mechanism to cope up with the changes in the surroundings. These physiological changes in the body can be recorded and analysed for precise detection of stress in an automobile drivers.

A survey by Brake and Green Flag found that 12% of drivers said they had driven while feeling stressed, angry or annoyed at the behavior of other road users several times a week. Further 15% reported this feeling once a week, 16% once a month and 4% at least once a day [2]. There are many stressful situations associated with driving such as traffic jams, tailgating and generally dealing with other driver's risk-taking. All drivers are exposed to stressful driving situations from time to time, even if they do not generally suffer from stress in everyday life. Research has shown that angry drivers are more likely to take risks such as speeding, rapidly switching lanes, tailgating and jumping red lights which are very common scenario in Indian driving conditions [3]. It may be pertinent to add here that tailgating means; to drive so closely behind another vehicle that one cannot stop or swerve with ease in an emergency.

Though health check-ups are done periodically for bus drivers, there are not many facilities for stress reduction. If a person drives while stressed they run a much greater risk of being involved in a crash that kills or injures them or another road user. At this point it is important to find positive and productive ways to deal with stress. One of the simplest and most effective ways to deal with stress is its continuous monitoring. Many Stress Management Labs (SML) are working in India whose aims is to improve well-being in Education, Industry, Healthcare, Medicine, Stress etc. by proper counseling to develop Physical, Neural, Emotional, Cognitive, Social, Spiritual and Organizational Quotients for individuals and organizations [4].

Timely detection of the stress in human beings provides a helpful way for people to better understand their stress condition and provides physicians with more reliable data for intervention and stress management.

Existing studies have shown that stress can be recognized by recording and analysing the physiological parameters of the subject. The physiological parameters like an ECG, GSR, EMG, and RR of an automobile driver can be acquired for continuous monitoring of stress level.

2. Literature Survey

Driver's stress is an important factor in a large number of accidents. There has been much work done in driver stress detection. This paper presents a comprehensive survey of research on driver stress detection and provides structural categories for the methods which have been proposed. The methods of stress detection mainly focused on measures of the driver's state, driver performance and the combination of the driver's state and performance.

George Rigas *et al.* proposed a method based on a Dynamic Bayesian Network for the estimation of car driver's stress produced due to specific driving events. They also monitored driver's stress using selected bio-signals and provided a probabilistic reasoning-based framework and inferred results that indicate a strong correlation between the level of the stress as reported by the driver and the outcome of their model [5].

Li Shiwu *et al.* proposed a system that can actively monitor the driver's fatigue level in real time for the prevention of accidents. For that they used Support Vector Machine (SVM) technique to identify driver's fatigue based on psychological features, such as EEG and ECG. Driver's fatigue levels obtained were used as output variables of SVM model and that resulted in a model that can recognize driver's fatigue levels [6].

In Cheol Jeong *et al.* intended to develop a device which would detects the electrocardiogram (ECG) signal of driver in real time and provided Autonomic Nervous System (ANS) information and degree of stress through analysis of Heart Rate Variability (HRV) [7].

Rajiv Ranjan Singh *et al.* presents a comprehensive analysis of extraction and signal processing techniques of features from physiological signals. They adopted Self-Organizing Map to cluster data into topographically distinct clusters of low, medium and high stress states and developed cumulative sum-based stress metric, capable of detecting over-stress conditions, using Page's Technique [8].

Jennifer A. Healey and Rosalind W. Picard collected and analysed physiological signals like electrocardiogram, electromyogram, skin conductance, and respiration continuously during real-world driving tasks to determine a driver's relative stress level. Their findings indicated that physiological signals can provide a metric of driver stress in future cars capable of physiological monitoring [9].

Yong Deng *et al.* proposed a feature selection method based on Principal Component Analysis (PCA) and evaluated their effectiveness in terms of correct rate and computational time using five classification algorithms namely, Linear Discriminant Function (LDF), C4.5 induction tree, Support Vector Machine (SVM), Naïve Bayes and K Nearest Neighbour (KNN) [10].

Yuan Shi *et el.* built a personalized stress detection model based on Support Vector Machines, and evaluated it on the collected data and result showed that their model can detect stress with high precision [11].

Barreto & Zhai monitored and analysed galvanic skin response (GSR), blood volume pulse (BVP), pupil diameter (PD) and skin temperature (ST) to differentiate affective states of stress in a computer user [12].

3. Physiological Parameters

Although several possible physiological parameters have been considered within the literature to detect stress as discussed in the previous section, Table 1 gathers a summary on the signals involved in stress detection within literature.

Table I
Literature Review on physiological parameters involved in stress detection.

Physiological Parameters	References
BVP (Blood Volume Pressure)	Healey & Picard (2005) [9]; Barreto & Zhai (2006) [12]
PD (Pupil Dilation)	Barreto & Zhai (2006) [12]
GSR (Galvanic Skin Response)	Barreto & Zhai (2006) [12]; Singh. R.R. *et al.* (2012) [8]; George Rigas *et al.* (2008) [5]; Healey and Picard (2005) [9]
ST (Skin Temperature)	Barreto & Zhai (2006) [12]
ECG, EKG (Electrocardiogram)	George Rigas *et al.* (2008) [5]; Healey and Picard (2005) [9]
Respiration Rate (RR)	Healey and Picard (2005) [12]
EMG (Electromyogram)	Healey and Picard (2005) [12]

In this paper we propose the use of four main parameters and their derivatives, namely, Heart rate (HR), galvanic skin response (GSR), electromyogram (EMG), and respiration rate (RR). These four parameters are selected based on their properties regarding non-invasivity when being acquired and because their variation is strongly related to stress stimuli [9].

An electrocardiogram (ECG) is a cardiac measure that shows sensitivity towards variations in workload. Heart rate variability (HRV) (a measure of electrocardiographic activity) has been widely accepted in the literature for the assessment of mental workload [13]. HRV can be easily derived from the variation in R-R interval of ECG..

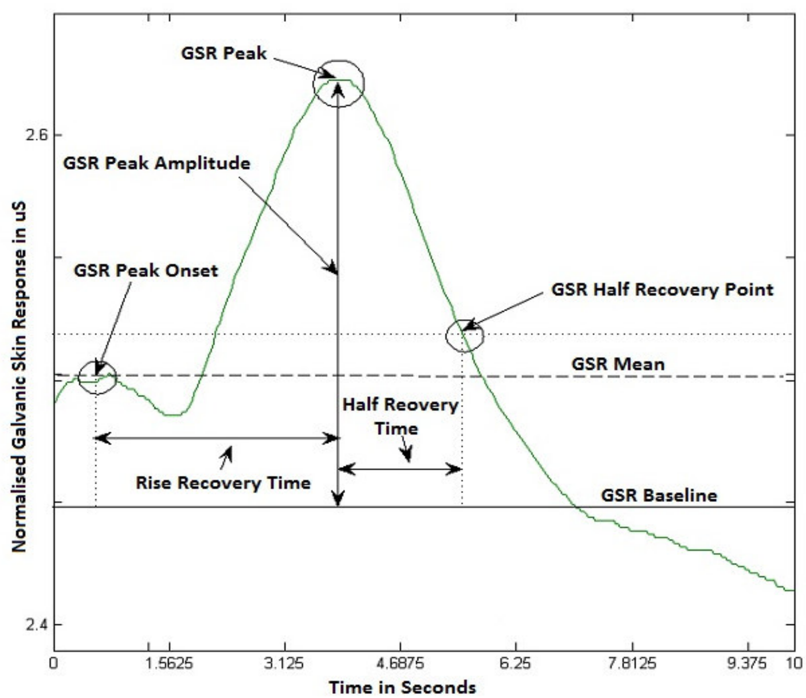

Fig. 1. Shows GSR Statistical features.

Galvanic Skin Response (GSR), known also as electrodermal activity (EDA), is an indicator of skin conductance [12], [14]. There are specific sweat glands (eccrine glands) that cause this conductivity to change and result in the GSR. Located in the palms of the hands and soles of the feet, these sweat glands respond to psychological stimulation rather than simply to temperature changes in the body. Some of the features that can be extracted from a GSR signal segment corresponding to busy driving scenario are shown in Fig. 1

GSR is a linear correlate to arousal and reflects both emotional responses as well as cognitive activity. The GSR signal comprises of two components: tonic (Frequency Range: 0.0Hz to 0.16 Hz) and phasic (Frequency Range: 0.16Hz and above).GSR can be obtained by different methods, but the device proposed to acquire signals is based on an exosomatic acquisition [9]. In other words, extracting skin conductivity requires a small current passing through the skin. GSR is typically acquired in hand fingers and its measure units are µSiemens ($\mu\Omega^{-1}$).

Electromyography (EMG) measures muscle activity by detecting surface voltages that occur when a muscle is contracted. In isometric conditions (no movement) EMG is closely correlated with muscle tension, however, this is not true of isotonic movements (when the muscle is moving). When used on the jaw, EMG provides a very good indicator of tension in an individual due to jaw clenching. On the face, EMG has been used to distinguish between positive and negative emotions. EMG activity over the brow (frown muscle) region is lower and EMG activity over the cheek (smile muscle) is higher when emotions are mildly positive, as opposed to mildly negative. EMG signal measured from the upper trapezius muscle can be used to calculate stress level. The results show significantly higher amplitudes of the EMG signals during stress compared to rest and fewer gaps (periods of relaxation) during stress. The differences in EMG features between rest and stress conditions indicate that EMG is a useful parameter to detect stress [15].

Respiration Rate (RR) can be measured through chest cavity expansion using an elastic Hall effect sensor strapped around the driver's diaphragm [9] or it can be measured by installing a thermistor based sensor in the nasal passage [16]. Respiration can be measured as the rate or volume at which an individual exchanges air in their lungs. Rate of respiration (RespRate) and depth of breath (RespAmp) are the most common measures of respiration. Emotional arousal increases respiration rate while rest and relaxation decreases respiration rate. Although respiration rate generally decreases with relaxation, startle events and tense situations may result in momentary respiration cessation. Negative emotions cause irregularity in the respiration pattern. Because respiration is closely linked to cardiac function, a deep breath can affect cardiac measures. Respiration is most accurately measured by gas exchange in the lungs, but the sensor technology inhibits talking and moving. Instead, chest cavity expansion can be used to capture breathing activity using either a Hall Effect sensor, strain gauge, or a stretch sensor [17].

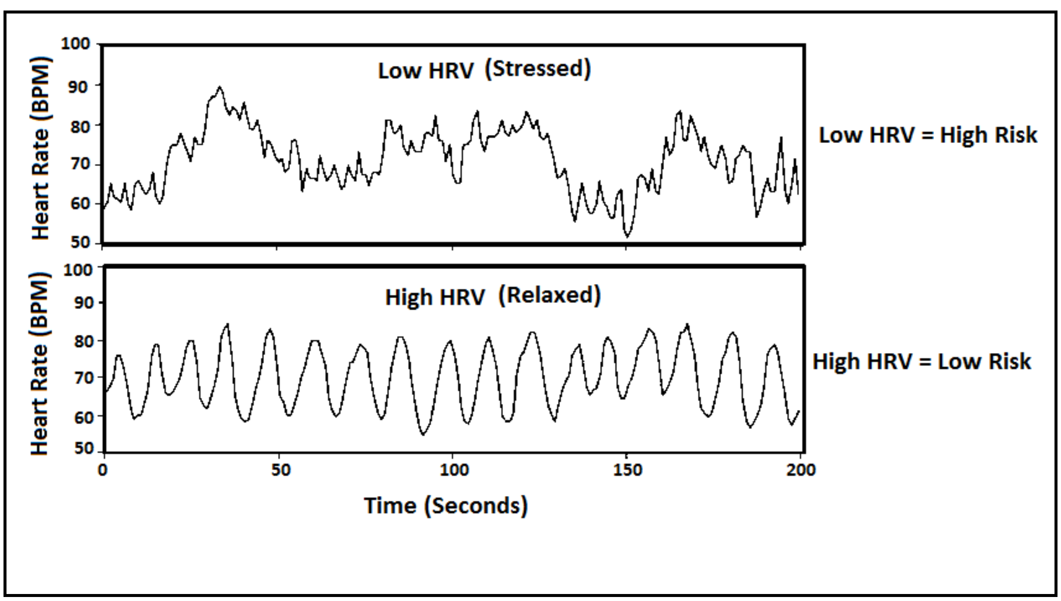

Fig. 2. Shows an original HR signal notice the different arousal of this signal, depending on the stressing stimulus.

On the other hand, Heart Rate (HR) measures the number of heartbeats per unit of time. HR can be obtained at any place on the human body, being an accessible parameter to be easily acquired. HR describes the heart activity when the Autonomic Nervous System (ANS) attempts to tackle with the human body demands depending on the stimuli received [9]. HRV refers to the oscillation of the interval between consecutive heartbeats. When subjects are under stress, HRV is suppressed and when they are relaxed, HRV emerges as indicated in Fig. 2. Similarly, HRV decreases with mental effort, but if the mental effort needed for a task increases beyond the capacity of working memory, HRV will increase [18]. Concretely, ANS react against a stressing stimulus provoking an increase in blood volume within the veins, so rest of the body can react properly, increasing the number of heartbeats.

4. Gaps in Research

Much work has been done on recognizing the stress level of automobile driver's by extracting features from the bio-signals acquired by physiological sensors. However, little work has been focused on the feature extraction, feature selection and finding the corresponding correlation between selected features and the traffic conditions. Also, the database acquired from Healey and Picard's [9] experiment was very valuable but lacks proper recording time for different driving segments like initial rest, city1, highway1, city2, highway2, city3 and final rest.

5. Conclusion

Autonomic Nervous System (ANS) control all the vital involuntary muscles in human body like glands, blood vessels, heart, lungs, intestine etc. Whenever an automobile driver is subjected to fast changing environment (e.g. driving scenario) the ANS activity of automobile driver also changes according to it. As a result, the physiological parameters like galvanic skin response (GSR), electrocardiography (ECG), electromyography (EMG) of the trapezius muscle, and respiration rate (RR) also changes. This change in Heart rate (HR), EMG, GSR and RR can be recorded via sensors to detect the dynamic stress level of the driver in real-time.

Based on our literature survey, we propose that GSR, ECG, EMG and RR and their derivatives will be sufficient to provide us the best possible feature set to identify stress of an automobile driver. HR can be computed easily from ECG signal, while instantaneous respiration rate (IRR) can be computed from the raw respiration data. Thus stress detection systems can detect stress by using physiological signals like HR, EMG, RR, GSR etc. providing a precise output indicating to what extent an automobile driver is under a stress.

In order to develop a suitable stress level monitor, the following tasks need to be accomplished:

i. Finding correlation of individual physiological parameters like GSR, ECG, EMG and RR with the traffic condition like highway, city, rest, traffic jam etc.
ii. Analysis of the correlation will identify the physiological parameters best suited to detect stress level.
iii. A function of the selected/identified physiological parameters may be derived that gives better correlation with traffic conditions, as compared to any one physiological parameter taken in isolation.
iv. Based on this function or otherwise a classifier may be developed that may indicate the stress level of the driver as: a) Low, b) Moderate, c) High.

6. Future Scope

In future, we may want vehicles to be more intelligent and responsive, managing information delivery in the context of the driver's psychological state. Physiological sensing is one method of accomplishing this goal. Drivers could be allowed to make safe errors while talking on the cell phone or using visual navigation aids. But if a high-stress condition were detected using the algorithm on data, the driver distractions could be turned off until the driver recovered to a medium-stress level. These sensors can be tested in the laboratory and embedded into wearable and automotive systems to measure affective signals in the natural ambulatory environment. Finally, these findings may contribute toward progress in developing machines which can respond intelligently to human affect while simultaneously understanding human mental condition.

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