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A comparative evaluation of neural network classifiers for stress level analysis of automotive drivers using physiological signals

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ABSTRACT

Automotive driving under unacceptable levels of accumulated stress deteriorates their vehicle control and risk-assessment capabilities often inviting road accidents. Design of a safety-critical wearable driver assist system for continuous stress level monitoring requires development of an intelligent algorithm capable of recognizing the drivers' affective state and cumulatively account for increasing stress level. Task induced modifications in rhythms of physiological signals acquired during a real-time driving are clinically proven hallmarks for quantitative analysis of stress and mental fatigue. The present work proposes a neural network driven based solution to learning driving-induced stress patterns and correlating it with statistical, structural and time-frequency changes observed in the recorded biosignals. Physiological signals like Galvanic Skin Response (GSR) and Photoplethysmography (PPG) were selected for the present work. A comprehensive performance analysis on the selected neural network configurations (both Feed forward and Recurrent) concluded that Layer Recurrent Neural Networks are most optimal for stress level detection. This evaluation achieved an average precision of 89.23%, sensitivity of 88.83% and specificity of 94.92% when tested over 19 automotive drivers. The biofeedback inferred about the driver's ongoing physiological state using this neural network based inference engine would provide crucial information to on-board safety embedded systems to activate accordingly. It is envisaged that such a driver-centric safety system will help save precious lives by way of providing fast and credible real-time alerts to drivers and their coupled cars.

1. Introduction

Safe-driving requires a relaxed mind and good concentration on part of the driver apart from a good reflex response [1]. Unacceptable levels of stress, fatigue and on-road distractions deteriorate driver's performance and may lead to temporal loss of concentration, risk assessment capability and vehicular control, often inviting road accidents. Researchers have identified that this issue of ever increasing fatality rate and economic losses can be addressed through development and deployment of context-aware driver assistant systems capable of predicting accidents and alert the driver proactively [2]. In 2010, European Union in the Information and Communication Technology for Mobility (ICT for Mobility) programme for Intelligent Vehicle Systems identified the Strategic Research Agenda for future research on Intelligent Vehicles "...should focus on highly integrated and price worthy solutions for driver assistance systems to reach wide deployment and achieve increased traffic safety and efficiency and reduce environmental impact..." [3].

Researchers in the past have extracted parameters from biosignals to measure emotion [4,5], stress level [2], fatigue [6] and the affective state [7] for driver assistance. They have interchangeably used the term "affective state" or "emotional state" or the "sentic state" to assess the mental and physical stress experienced by vehicular drivers [8]. For instance, [2] envisaged the development of an integrated vehicular or body-worn sensor configuration which might be able to calculate in real-time the driver's stress level, which can improve his safety and manage in-vehicle information systems cooperatively with him. In an approach towards affective state recognition in automotive drivers using on-road experimentation they investigated the use of bioelectric signals to give dynamic indications of driver's internal state. During driving, drivers are prone to instantaneous stimuli which arise due to various distractions like unanticipated pedestrian crossing, abrupt lane change by another vehicle, etc. Schmidt et al. [9] in a study on electrodermal activity based techniques for para-psychological analysis

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presented that syntactic features extracted from GSR signals make a good indicator for distress and mental exhaustion. Linder et al. [10] investigated into the morphology of PPG signal and concluded the usefulness of extracted structural features in the study of body-postures.

Continuous monitoring of driver affective state in a real-time driving scenario has been a challenging task that involves physiological data collection, preprocessing, feature extraction coupled with selection/transformation and finally classifying these features to a related stress/fatigue state using classification methods. Healey and Picard [2] developed an automatic stress recognition algorithm using linear discriminant analysis (LDA) with the features extracted from physiological data as inputs. They achieved over 97% recognition rate and a good correlation rate with the video stress metric developed for their application. Ji et al. [6] developed a real-time non-intrusive fatigue monitor based on information collected from physiological sensors and the subject's environment. Their Bayesian dynamic network accounted for both temporal and dynamic aspects of human fatigue. Katsis et al. [5] designed a wearable system for assessing the emotional state of car racing drivers using physiological signals collected in simulated environments. The maximum predictive ability of their system was 79.3% when they used support vector machine (SVM) for classification. Lisetti and Nasoz [4] and Haag et al. [11] successfully employed ANNs in classification of emotions, valence and arousal states of subjects with over 90% classification rate. To optimally model the associated decision making system using non-linearities observed in the extracted features accurately it is required that we perform a comprehensive analysis of the machine learning paradigms available and choose the one with optimal predictive ability and sensitivity. Solutions derived for driver safety related problems using such soft-computing methodologies offer high degree of sensitivity and specificity required over other heuristic decision making approaches.

Researchers at University of California, San Diego, while investigating the human centred design aspects of driver monitoring systems identified that there is a need to develop an algorithm capable of understanding the driver's intent and attention [12]. It is to be noted that if a human centric design approach is not adopted the system runs into the risk of ending up as a product that is not only unusable but also potentially dangerous. The human centric factors which should be considered while designing such driver assist systems include the driver's social environment, the country's norms, driver behaviour, etc. It can also be concluded that in such systems if the decision making modules were trained on the basis of naturalized data collected from real-time driving scenarios the above complex human centric factors may be incorporated into it. This work is a part of the BITS-LifeGuard research initiative at the Birla Institute of Technology and Science, Pilani, India which aims to enhance driver safety by designing a custom wearable computing fabric which can save loss of precious lives by the way of providing fast yet credible real-time alerts to the drivers and their coupled cars [13].

In this paper, we present our analysis based on the statistical, structural and spectral features extracted from the collected GSR and PPG signals using soft computing techniques. These features have been used to model the relationships between the inferred physiological state of the subject and his stress proneness using Neural Network classifiers. The outcome of this analysis will in turn be used to train the wearable driver assistance system to identify alarmable situations online. The following are the primary contributions of the paper (i) an annotated physiological signal database from 19 Indian automotive drivers was created for stress level analysis containing relaxed and real-time driving data, (ii) 39 features (statistical, structural and spectral) were extracted and subsequently a 30 features were selected using feature selection methods, (iii) a minimal mean squared error based model was developed using artificial neural network (ANN), and (iv) a comparative analysis was performed using 7 Neural Network configurations which were trained using the selected features for stress level classification and evaluated to find the most optimal configuration for further deployment.

In rest of this paper, Section 2 gives a glimpse of the techniques for physiological data acquisition, driving scenario design and corresponding labelling of stress level of drivers. Section 3 discusses the physiological signal processing methods adopted. Section 4 deals with the feature extraction routines for the collected signals and the statistical significance of features. A comparative analysis and evaluation of Neural Network classifiers towards stress level recognition has been discussed in Section 5 and results of this analysis has been presented in Section 6.

2. Data collection and pre-processing

We have collected data from drivers, majorly belonging to Pilani located in the semi-arid zone of Shekhawati region in the desert state of Rajasthan, India using body-mounted physiological sensors during multiple fixed route segmented on-road driving experiments [14]. Majority of the studies by researchers were based on simulated environments, but advantages of real-time data collection with respect to classifier training and accurate correlation of stressful events is required for the present application. As emphasized in the introduction, the driving environments of developed countries over developing countries like India differ significantly in road structure, driving style, the degree of adherence to traffic rules and most importantly on the emphasis on road safety. The drivers considered were predominantly male because of non-availability of female professional drivers in Pilani who consented for the study. This is partially justified due to the fact that the driver workforce of professional female drivers and their exposure to roads in India is less than 3%, which is very low [15]. The experimental protocol and the associated stress level analysis on female subjects will be incorporated upon availability in future experiments. For successful deployment of any decision making system onto a particular traffic environment, it needs to be trained using data collected from that particular environment. Therefore, we chose to train and test our algorithms by using physiological data collected from drivers practising in the intended area of deployment (in our case: Semi-Urban India). It however must be emphasized that the proposed methodology can be adapted to any country if the initial training data is representative of driver population in that particular country.

2.1. Sensory configuration and experimental setup

In a real-time driving scenario, it is important to detect the incremental changes in the emotions as well as the fatigue and stress level of the driver. For such sensitive situations, a carefully designed multimodal sensor-compute infrastructure is required. The setup used for data acquisition for the present work (shown in Fig. 1) involved a body-worn clip-on Nonin Pulse Oximeter (Device B) for PPG and SpO2 signals, Abdominal Respiration belt (Device C) and GSR Velcro electrodes (Device D). GSR signal is an induced signal that is triggered as a result of occurrence of stressful events [16]. Morphological changes were existent during the duration of stimulus and the signal gradually decade baseline subsequently [9]. However, PPG, in contrast to GSR, is a permanent signal [16]. It exhibits versatility because of its ability to extract multiple parameters like HR, SpO2, Respiration Rate, etc. [17]. It must be noted that despite the applicability of ECG and RSP in such applications the drivers reported discomfort due to sticky nature of electrodes