METHODOLOGY AND SYSTEM OF EVALUATING THE DRIVER'S VIGILANCE LEVEL IN AN AUTOMOBILE TRANSPORTATION EXAMINING BOTH PHYSIOLOGICAL AND MECHANICAL DATA

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Abstract: This paper deals with the methodology followed in order to design a new intelligent system to improve the driver's safety in an automobile transportation and the actual realization of a first prototype. The results of the study are reported. A simulator system has been developed at the Robotics Laboratory of the "Politecnico di Milano". A description of the necessary hardware and architecture is made in detail. Driver's physiological data, acquired from sensors on the wheel, is correlated, using statistical multivariate analysis, with his/her vigilance level evaluated using polysomnography. This statistical model is applied on the data off-line in order to define a controller, to be applied on real time acquired data. The platform's mechanical data is also acquired and studied. All the elaboration of the data results in one vigilance level index for the current driver and situation. Future steps and possibilities are also discussed.

1 INTRODUCTION

Many projects in European Union (EU) programs are devoted to the increase of safety in automobiles, in order to reduce deaths and accidents down to 50% in the next few years (Istat, 2001) Project PSYCAR (Psycho physiological Car) funded by EU in a Regional plan, starting from Lombardy Italian Region and Austrian Region, is one of these projects. The "Politecnico di Milano" university, along with the Linz Kepler University cooperated in the development of the project.

Apart from these EU programs, almost all automobile industries are studying new methods to improve active safety. Most of these methods are based on examining the engine's mechanical and the car's dynamical parameters or on camera vision systems continuously monitoring the driver (Citroen, 2007, Seat, 2006). Nevertheless, the greatest disadvantage of such systems lies on the fact that a possible driver's head turning or lowering can be a huge problem for the camera's view and so can put the whole system out of order. In addition to that, the high complexity of vision software can add financial and technical obstacles in the system. Such systems have been proposed by BMW and SEAT. Mercedes-Benz is also working on the same direction according to a recent article (Omniauto, 2006).

The methodology presented by this paper is innovative for the field of automotive safety. Its innovation lies on the fact that all the driver's physiological parameters are acquired using sensors on the wheel, which are continuously in contact with the driver's body. The driver does not have to do anything in particular or, in any mode, different from what he is used to do when entering and driving his/her vehicle, as in other safety systems (Saab, 2006, Gizmag, 2005). Intelligent sensor placement is fundamental for the system's applicability. A possible loss of contact with the driver's body, is by itself a safety decrease information, because can only mean that the driver has taken his hands off the wheel. Several car's dynamical and mechanical parameters are also acquired and evaluated. This combination of the car's behaviour with the driver's physiological state is another innovation presented by this paper and the future of automotive safety may lie on this combination. The system also stores all the data acquired in order to self- improve with time, using

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neural network techniques which will be implemented in the next phase of the project.

The output of the system proposed by this paper is a vigilance level index, easily interpreted by the driver. Indices can be collected and can be sent to a centre of suggestions, in a tele-assistance shape (Rovetta, 1995).

2 SELECTION OF THE PHYSICAL PARAMETERS TO BE MEASURED

Since the number of parameters to measure in such a system is enormous, a very important part of the procedure is the selection of the right parameters to measure (Zocchi, 2005, Rovetta, 2005). The physiological parameters that can be measured and that can determine the driver's condition and ability to drive are not so categorically determined.

A large scale research has been done through years by numerous universities and research teams, to define the physiological and neurological parameters that can determine a possible drop in the person's vigilance level. Using the results from these researches, a selection of the necessary sensors is made. Based on that, blood pressure, cardiac and respiratory frequencies, hand trembling, galvanic skin resistance, heart rate variability, body temperature, blood alcohol and oxygen concentration and cerebral waves are physiological parameters that can possibly detect a person's neurophysiologic state (Rovetta, 2001).

Two different sets of parameters are chosen to be measured. The discrimination is made because of the fact that some parameters are measured only to determine the driver's attention level and are used only in the research phase as an index to which the second set of the parameters is correlated. The second set consists of the parameters that will continue to be used on the real cars, and that obviously are only the signals from the sensors on the wheel.

The first set consists of the polysomnography parameters along with the driver's reaction time. A medical team is assisting the Robotics Laboratory of the Politecnico di Milano team in acquiring all these parameters and also in their interpretation. The polysomnography parameters acquired are presented in the table (Table 1) and they are used as an index of the driver's attention, to which all the other acquired parameters are correlated.

The second set of measured parameters consists of the driver's Galvanic Skin Resistance (GSR), Heart Rate Variability (HRV) and body temperature (THE), which are measured using sensors on the wheel.

Table 1: The physical parameters acquired with the medical equipment.

Polysomnographical parameters acquired
Electro- Cardio- Graph (EKG)
Electro- Encephalo- Graph (EEG), 4 channels
Electro- Oculo- Graph (EOG), 2 channels
Chin Electro- Myo- Graph (EMG)
Peripheral Body Temperature (THE)
Nasal Pressure
Blood Oxygen Concentration
Respiratory Frequencies, 2 channels

3 SIGNAL ACQUISITION, CONDITIONING AND DATA STORING

In order to collect the GSR (Galvanic Skin Resistance), THE (Peripheral Body Temperature) and HRV (Heart Rate Variability) signals from the steering wheel, a portable system has been developed by the ELEMAYA Company, on demand. For the GSR, two silver plates are used and the skin's galvanic resistance is measured across them. For the HRV signal a photoplethysmographic sensor is used, while for the THE a simple thermocouple is used. All these signals are filtered and amplified by the same ELEMAYA system. The A/D converter is a National Instruments DAQ-card 6062E. All electronic board aspects were studied (Klaassen, 1996, O'Dell, 1991, Sangwine, 1994, Doebelin, 2004). The digitization of the signals is made at a sampling frequency of 200Hz, following the Nyquist criteria.

The data from the mechanical platform is acquired using a PC and a C program. The program is the same that simulates the road and the car movement. The sampling rate was set to 65 Hz. The data analysis was concentrated on the straight parts of the road, since the turning highly depends on each driver's ability to drive and in addition to that it highly unlikely that someone falls asleep when turning. In addition to that, the data acquired during the driver's attempt to avoid the appearing obstacles was also neglected.

Especially for the calculation of the error in the car's position, the ideal position that the driver had to follow was the right lane of the circuit that corresponded to constant y position in the Cartesian coordinates space. Based on this, the error that the driver made was calculated as the difference from the ideal position. The error data was normalized for each driver separately to eliminate as much as possible the interference of each person's driving capacity and style. In this way, the final available data for analysis were vectors containing for each driver the normalized error in the car's position.

The polysomnographical hardware used consists of a portable medical apparatus capable of acquiring all the necessary signals. The analysis of these signals determines the driver's status. In total, these signals are 37 and are presented in Table 1. The software for this polysomnographical acquisition is the Madcare's Somnological Studio. The software is capable of saving all the acquisition session data in one and only European Data Format file (.edf), which then is converted into a simple ASCII text file, using the NeuroTraces edfAsc program. These text files are loaded and examined in MATLAB. The sampling rate frequency is set to 200 Hz.

The polysomnographical and mechanical platform signals are automatically filtered, while the signals from the steering wheel are first filtered by the acquisition system, using hardware, and then by software because of their specific needs. In particular, for the HRV signal the cut off frequency has been set to 10 Hz, for the GSR to 0.1 Hz and for the THE to 0.8 Hz. For determining the correct cut-off frequencies for every signal, medical advises has been followed and Fourier analysis has been made.

Steering wheel signals data storing is made using MATLAB data acquisition files (.daq). These files are easily handled by MATLAB and also allow storing the exact acquisition start time and date. All the data is stored in one matrix, where every column array corresponds to one sensor and every row array corresponds to one sampling session (1/200 sec.). The data from the mechanical platform is stored in simple text files.

4 PROTOCOL FOR THE SIMULATION SYSTEM

The simulations are made on two different driver conditions. In the first part, the driver has slept during the last night, while in the second he/ she has been awake for twenty-four hours. In the first state the nominal conditions of the person are evaluated, while in the second the altered ones. During the tests made with the driver not having slept, when sleep is detected while he/she is undertaking the simulation, the driver is waken up. In this way, the transition phases are better examined. The simulations are always made in dark and noiseless conditions in order for the person to have much more possibilities to fall asleep or to lose attention.

Before starting the data acquisition, a questionnaire is completed by the person responsible for the simulation, on which the date, the time and environmental conditions are written. The car at the start of every simulation session is always positioned at the same point of the virtual circuit. Each subject, before driving on the simulation for the first time is also trained to use the simulator and to always follow the same pre-defined route.

After these initial procedures, the driver starts the simulation and the data acquisition is also initialized. During the procedure and in pre-defined times that the subject does not know, an obstacle appears on the screen and the driver has to push the brake. In this way, his/her reaction time is measured and stored among all the other parameters acquired. This response time along with the data from the polysomnography signals (Rovetta, 1997, Pinelli 1998) determine his/her attention level.

5 OFF-LINE ANALYSIS. STATISTICS ON THE ACQUIRED DATA

At the end of every simulation data from both the sleepy subjects and the control group is divided in three categories, as shown in table 2.

The purpose of the statistical analysis is to find a relation between all the measured parameters and the driver's vigilance level decrease. The index of the driver's vigilance is measured by studying the EEG signals and the driver's reaction time to the appearing obstacles. These analyses focus on two different directions. First, the general behaviour of the signals as the driver moves towards sleepiness is studied. Then, the behaviour of the same signals the exact minute before a sleep-attack is studied. The exact time of a sleep-attack is determined, using EEG Power Spectral Density (PSD) analysis and medical experience.

For the EEG PSD analysis, after studying all the possible solutions, the $\alpha+\beta$ (Eoh, 2005) cerebral waves method is chosen as the most appropriate method. After determining the exact time of the sleep-attack, all the data from the minute before this

Table 2: The signals acquired during the driving simulations for evaluation and statistical analyses.

Physiological data from the steering wheel	Mechanical data from the simulator	Reference data
HRV	Steering wheel position	Polysomnographical signals
GSR	Accelerator pedal position	Reaction time
THE	Brake pedal position	
	Car's position on the road	
	Car's speed	

sleep-attack is divided in ten-second intervals and analyzed statistically. This procedure is necessary for also studying the exact time interval before the sleep-attack in which some interesting phenomena occur.

The stored data is statistically analyzed using MATLAB (ver. 7, rev. 14). The observed phenomenon is not linear and so a standard linear analysis is not adequate. Multivariate analysis is used in order to identify categories of input that are related to a certain output index.

Different analysis types are used to determine all the necessary statistical parameters. First an analysis is made based on simple mean value and variation observation for every signal acquired and every different driver condition status. In addition, correlation and cross-correlation matrices are calculated to determine a possible correlation of one acquired parameter to another, but also to correlate all the acquired parameters with the driver's safety index, derived from the polysomnographical data.

Furthermore, a cluster analysis is made on the data, in order to investigate grouping in the data, simultaneously over a variety of scales, by creating a cluster tree that is not a single set of clusters, but rather a multi-level hierarchy, where clusters at one level are joined as clusters at the next higher level. This allows deciding what level or scale of clustering is most appropriate in the application. Discriminant analysis, also used and applied on the data, determines one ore more parameters that better discriminate two populations.

The data from the mechanical platform is also analyzed in the same way. The results of these analyses are presented on the appropriate section of this article.

6 REAL-TIME PROCEDURE

The off-line statistical procedure is useful for setting up the real-time system prototype. In this prototype, the only parameters acquired are the non-invasive ones (GSR, THE, HRV) with the sensors on the steering wheel and also the data from the mechanical platform (Table 2). Together with the data, the driver's ID is also stored. In this way, the system becomes personalized and will be in a later phase trained based on the driver's personal characteristics. The driver's ID is obtained by his key, in a real car, or by a password, on the simulator. The saved data is in this phase also used for calculating the mean values of the heart beats number and the steering wheel's standard deviation values, needed for normalizing the data.

All the parameters enter a Fuzzy logic classifier that, based on the statistical results made off-line, determines if the driver has a high possibility of being sleepy. Practically, the classifier continuously monitors the acquired data in order to determine a possible movement of the driver versus sleep. If the driver is found to be probably sleepy, then the system is put into alertness in order to focus on detecting a possible sleep attack and alert the driver.

The simulator system program uses a MATLAB function to call the fuzzy system and calculate the safety index as well as for retrieving the important parameters for every signal. This is because the signals do not enter directly the Fuzzy classifier, but first need a small elaboration. For example, in order to retrieve the heart beats per minute number from the HRV signal.

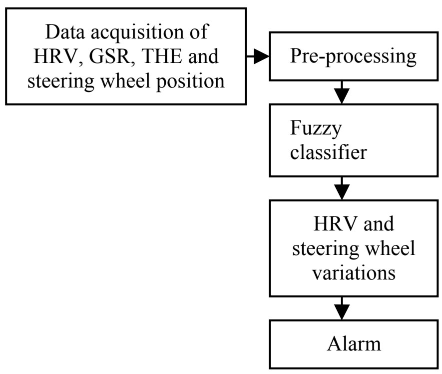

Figure 1: Real-time procedure flow diagram.

As shown in figure 1 (Fig.1), if the classifier detects a high possibility of sleepiness, then the system stays alert for monitoring the heart beats number variations as well as the steering wheel position variations. If high standard deviation values are detected in the heart beats signal or very low standard variations in the steering wheel position signal, the system alerts the driver with a sound. The thresholds were chosen to be 10 beats for the heart beats number and 0.5 in the normalized steering wheel position standard deviation. This procedure was chosen according to the results reported in section 7.

7 RESULTS

By observing the data acquired during simulations made with persons that did sleep during the night before, some interesting facts on their mean GSR value can be noticed. The more difficult the driving conditions, the lower the GSR values. The skin's galvanic resistance is inversely proportional to its perspiration and so this result means that the driver skin's perspiration is higher when the driving conditions are difficult (curved circuit, fast car speed). This also means that the driver is more vigilant when the simulation conditions are difficult, because of the fact that the skin's perspiration is inversely proportional to the person's relaxation (Hancock, 1996). Examined from another point of view, the lower the GSR value, the more vigilant the driver. The raise of the GSR can be quite important, even ten times higher than the normal value for every person.

In addition to that, the number of heart beats per minute decreases in sleepy subjects. Generally, as a driver moves towards sleepiness his/her number of heart beats decreases, something that was expected as this phenomenon is common knowledge in medicine. Finally, the THE value tends to drop slowly as the subject get sleepy, but only of a few decimals.

Using this information the fuzzy logic classifier was designed and trained. Afterwards, some driving simulations were made and the output of the classifier was compared with the actual vigilance level of the driver, defined by the medical analyses. The results show a success of 60,68% to 79,61% and are shown in figure 2 (Fig.2).

Apart from these observations concerning the general behaviour of the chosen parameters towards sleepiness, the most important results concern the analysis of the data the minute before a sleep attack. In these analyses the heart beats number and the steering wheel position signals presented some very interesting behaviour.

So, the heart rate generally tends to drop but the most important thing noticed is that it presents some significant variations twenty to thirty seconds before the microsleep (Fig.3). At least in 76% of the cases these variations were present. The percentage can improve using a lower threshold value.

Finally, very small standard deviation values were observed in the error in the car's position (Table 3) as well as in the steering wheel position. The error the driver is making was calculated as the difference from the ideal position of the car on the road. Each driver has his/her own driving style and so his/her own mean error values. The data were normalized using these values. The important thing noticed is that during the minute before the microsleep the standard deviation value of the error made is much lower that usual and so is the standard deviation value of the steering wheel's position. This implies that, even if the driver is driving far from the ideal position he/she is not moving the wheel as usually does. This phenomenon was observed in 87,5% of the cases and can be augmented by lowering the threshold value by only a little.

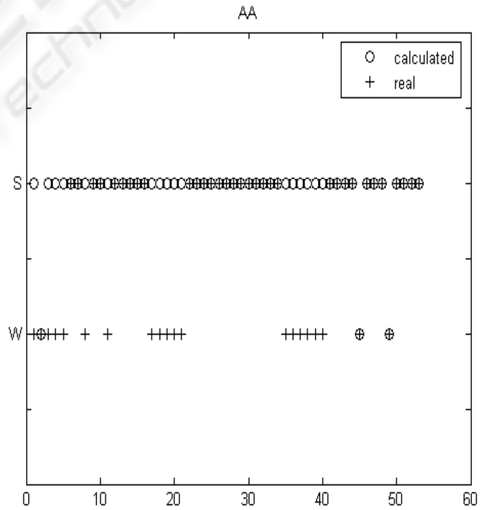

Figure 2: Confrontation between calculated and real sleepiness level for 52 epochs with two sleepiness levels. The '+' symbols present the real sleepiness level while the 'o' ones present the calculated value for every epoch. For every epoch, when the '+' and the 'o' symbols coincide the result is considered successful.

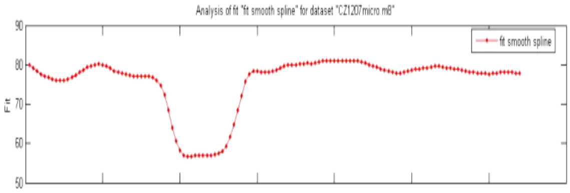

Figure 3: High variations in the heart beats number 40 seconds before a sleep-attack. The plot shows a B-spline polynomial fit for a subject's heart beat data. The number of beats per minute vary from 55 to 80.

Table 3: A subject presenting very low standard deviation values in the steering wheel's movement, in respect to his usual value. The six cells correspond to the six 10-second intervals before the sleep-attack. The 6th interval are the final 10 seconds before the sleep attack.

	1	2	3	4	5	6
Mean	2.9958	1.1638	1.1764	0.9943	1.0264	1.1572
Std_var	2.8497	*0.2137*	*0.0908*	*0.0822*	*0.2035*	*0.1555*

8 FUTURE STEPS

A study on the applicability of neural networks to the system described is in progress at the Politecnico di Milano's Laboratory of Robotics. The idea is to use all the data acquired during a driving session along with the current driver's identity in order to adapt the system to each particular driver. This will be made at the end of every driving session, when the engine stops, in order to ensure that the system's real time speed is not affected by this procedure. The neural network shall be used to re-train the fuzzy logic controller and make the system better with time.

9 CONCLUSIONS

The results of the research here discussed are promising. A control strategy based on the fuzzy classifier and a controller that monitors the heart beats number and the steering wheel position could be applied for determining a high risk of sleep attack and alert the driver.

The decrease in the heart beats number and the peripheral body temperature, as well as the increase in the GSR value are indicators of sleepiness that could set the system into a general alert status. These phenomena have a quite slow progress and so they can only be used as pre-cursors of sleepiness and not of an actual sleep-attack, which is a very fast phenomenon (3-15 seconds). On the other hand, the standard deviation values of the steering wheel position and the heart beats number occur very fast and permit an early notification of the driver, since the phenomenon occurs usually 20- 30 seconds before the sleep-attack. The standard deviation value of the error in the car's position cannot be used in an actual car, as the ideal position is unknown but is a useful parameter in simulated driving sessions (For example if using this system in driving licence exams).

The methodology discussed and proposed by this paper among with the constructed simulation prototype is innovative for the field of safety in automobiles and is used in a daily basis to acquire more data for the statistical analysis and the fuzzy controller set-up. The final tests on a real car will prove the applicability of the safety system discussed and its capability to cover with the maximum safety the drivers all over the world.

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