METHODOLOGY OF EVALUATING THE DRIVER'S ATTENTION AND VIGILANCE LEVEL IN AN AUTOMOBILE TRANSPORTATION USING INTELLIGENT SENSOR ARCHITECTURE AND FUZZY LOGIC

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Abstract— *This paper deals with the methodology of creating a new intelligent system to improve the driver's safety in an automobile transportation. 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 and the safety belt, is correlated, using statistical multivariate analysis, with his driving performance and attention level evaluated using polysomnography. This statistical model is applied on the data off-line in order to define a fuzzy logic system, to be applied on real time acquired data. 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.*

Keywords: automobile safety, fuzzy logic, sensors

I. 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 [1]. 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 cooperate in the development of the project.
Apart from these EU programs, almost all automobile industries are studying new methods to improve safety. Most of these methods are based on examining the engine's mechanical and the car's dynamical parameters or on camera vision systems [2, 3]. 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.
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 and on the safety belt, 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, like in other safety systems [4, 5]. 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 off his safety belt or that he took his hands off the wheel. The car's dynamical and mechanical parameters will be also evaluated in the next phase of the project. This combination of the car's behavior 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 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 teleassistance shape [6].

II. 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 [7, 8]. 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 attention and vigilance. 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

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neurophysiologic state [9].
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 and the safety belt. Some parameters belong to both sets.
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 : Electrocardiogram (EKG), Electroencephalogram (EEG), 4 channels Electrooculogram (EOG), 2 channels Chin Electromyogram (EMG), Peripheral Body Temperature (THE), Nasal Pressure, Blood Oxygen Concentration and 2 channels Respiratory Frequencies 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 and of the driver's respiratory frequency, measured using sensors on the safety belt. Especially for the respiratory frequency, two different frequencies are measured. One is the respiratory frequency on the thorax and one the frequency on the abdomen. The phase angle between these two signals is very important for determining the driver's vigilance level.
At this phase of the PSYCAR project, all the above parameters are measured, evaluated and correlated with the driver's vigilance level. As the project is still active and evolving every day, parameters of low correlation with the driver's attention level will be dropped.

III. Signal acquisition, conditioning and data storing

One of the innovations presented by the system described in this paper is the idea of collecting all the sensory signals into one acquisition board. In this way, the board, having all the signals available, is in the position to make a calculation of the driver's vigilance level index. For this to be achieved, several aspects should first be considered [10- 13].
In order to avoid wrong signal interpretation and to maintain homogeneity, all sensory output signals are transformed into voltage. Afterwards, the signals are digitized. To do that, the sampling rate of the analog to digital converter (ADC) is chosen, in order to avoid aliasing and noise problems. The Nyquist criterion is the basis of the sampling rate choice.
The digital value that results after the A/D conversion is checked in order to ensure that the sensor is properly working. The error free digital value is translated into the physical quantity it represents, if this quantity is not voltage. This procedure, known as signal scaling, allows saving data ready to be evaluated by the system.
The data storing is fundamental and the use of simple binary or text files ensures that the data will be easily interpreted by every application. The continuously dropping price of computer memories, allows also the saving of all the necessary data in an inexpensive way. Nevertheless, as the project evolves with time, data compression techniques will be used to ameliorate the memory use.
All the saved data, during this phase of the project, is elaborated off-line, as described in the next section. The speed of computation in this off-line elaboration is not a key factor. On the other hand, the system's speed is essential when the data is used in real time. To ensure that the necessary computational speed is available in every moment, the real time system only computes the corresponding vigilance level index and stores the data for later use. This later use will be a self-adaptation procedure, implemented using neural networks, in order for the system to better adapt to each driver. This implementation is currently studied and will be incorporated in the system in the second phase of the project.

IV. Off-line and real-time data elaboration. Fuzzy logic controller.

A drop in the driver's attention and vigilance level is possible to lead to a sleep-attack. Sleep-attacks are one of the most dangerous in-car situations and are one of the most important situations that the system described in this paper is trying to detect. Since a sleep-attack has very small time duration and has no clear signs that precede it, the continuous monitoring of the driver's attention/ vigilance level is the only way to detect an elevated sleep-attack risk.

Main goal of the PSYCAR project is to define the right parameters for the driver's psycho-physical status monitoring inside the "Car System". Besides that, the correlation between these parameters and the driver's safety is crucial.
Statistical methods are used for this purpose. Multivariate analysis permits in a proven way to correlate all these parameters to an independent index, which for the application described in this paper, is the driver's vigilance index. Every signal is elaborated in order to obtain only its necessary properties. The data obtained by the statistics, such as correlation indexes and mean values for every signal, is used to create a fuzzy logic controller.

Fuzzy sets and rules are created based on these statistical results. The overall off-line procedure is shown in Fig. 1. The general purpose of the system is a real time

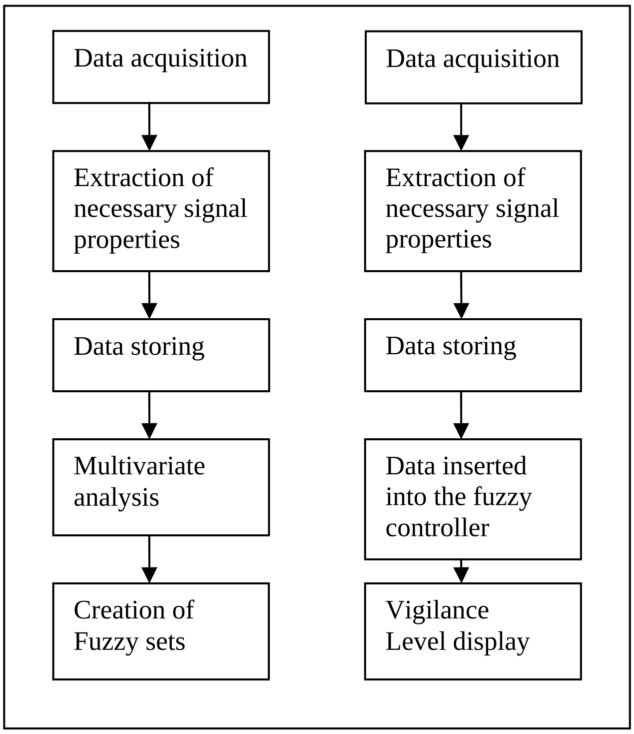

Fig. 1. Off-line (left) and real-time (right) procedures

evaluation of the driver's vigilance. Since only a very small amount of time is required for an in-car situation to become dangerous, the system is evaluating the driver's state continuously.

Based on the data from the off-line statistical analysis, a fuzzy logic controller is created. Fuzzy logic is the most efficient and appropriate tool available today for evaluating non- deterministic situations. Because of this fact, a fuzzy logic controller is chosen to be the heart of this system.

In order to provide the fuzzy logic controller with the necessary input parameters, defined off-line, data from the past ten seconds is first elaborated and the parameters extracted by this elaboration are passed to the controller. As the inputs to the fuzzy controller include also some parameters that are calculated over the last ten seconds, this small elaboration is needed.

Besides from the vigilance level index calculation, the system also saves all the data. This data will later be used to train a neural network, that will help the system adapt to each driver separately and to ameliorate with time. The real time procedure's block diagram is shown in figure 1 (Fig. 1).

VI. The statistical and mathematical body

The heart of the system is a fuzzy logic controller. The inputs to this controller are the GSR, heart beats per minute (BTS), THE and respiratory frequencies phase angle (RFPA) values (measured in two body spots, one on the thorax and one on the abdomen). The output of the system is a vigilance level index.

In order to define the membership functions for every input and for the output, the results from the multivariate analysis are used, taking also under consideration several medical aspects. For every input signal except from the respiratory frequencies phase angle, five membership functions named 'very low', 'low', 'medium', 'high' and 'very high' are defined and correspond to a physical parameter's state. For the last input, the respiratory frequencies phase angle, the membership functions are only three ('low', 'medium', 'high') and correspond to the phase angle measured. For the output index, the membership functions are also three.

For the creation of the fuzzy logic rules, the multivariate analysis results are still the basis. In addition to these results, some rules are written based on the medical experience; for these rules a lower weight value has been assigned.

VII. Simulator system

A. General description

A simulator system has been developed at the Robotics Lab of the Politecnico di Milano. The system consists of a computer games' steering wheel with pedals and a computer game that is projected in front of the driver giving him/her the impression of actual driving.

On the steering wheel, GSR (Galvanic Skin Response), HRV (Heart Rate Variability) and THE (peripheral body temperature) sensors are placed in order to measure these driver's parameters. In this way, the driver does not have to do anything special that would not normally do when driving.

In order to measure all the polysomnography signals, including the respiratory frequencies, a portable medical apparatus is used. The apparatus is necessarily connected to the driver's head and body but it will not be placed on the actual system when it will go out of the laboratory. The only signal acquired with this apparatus that will eventually be used in the final version of the system, is the respiratory frequencies sensors which will be placed on the driver's safety belt.

The software that simulates the circuits is made especially for this application by the Linz university's PSYCAR research team. The software also calculates and stores the driver's reaction time. This procedure is better described in the next section.

Apart from the driving simulation and sensorization system, two video cameras have been placed in the simulation room, in order to monitor directly the driver's

face reactions and body position, as well as the errors he/she is making. The videos from the video cameras are used in order to have all the simulation procedure registered and available at any time.
In order to collect all the sensory data a MATLAB function has been written.

B. 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.
In addition to that, two different circuits are simulated, a straight line circuit and a curved one, and also two different car speeds, slow and fast, are used for the simulations.. These are used to produce different requirements for the driver's attention level. The duration of the experiment is thirty minutes per person, and has eight repetitions, one for every combination of the circuit type, the driver's conditions and the car's speed. 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 simulation is initiated. 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 brake. In this way, his/her reaction time is measured and stored among the other parameters acquired. This response time along with the data from the polysomnography signals [14, 15] determine his/her attention level.

C. Description of the simulation system's hardware and software

In order to collect the GSR, THE and HRV signals, 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 is used a photoplethesmographic sensor, while for the THE is used a thermocouple. All these signals are filtered and amplified by the same ELEMAYA system. The A/D converter is a National Instruments DAQ-card 6062E with a capability of 500kSamples/sec. All the cables in the circuits are twisted together, as much as possible, in order to reduce noise. The signals are digitized at a sampling frequency of 200Hz, following the Nyquist criteria [16].
In order to handle the signals a MATLAB function has been created. This function acquires all the sensory data and checks them to ensure all sensors are properly working, using the data provided by the sensor's manufacturer. Each sensor's output is translated into the physical quantity it represents (signal scaling), using another MATLAB function.
Data storing is made using 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.).
Apart from the pure signal, a filtered version of every signal is saved. For determining the correct cut-off frequency for every signal, medical advises have been followed and Fourier analysis has been made. 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.
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 13 and have been mentioned earlier in paragraph II. The software for this polysomnographical acquisition is the Medcare's Somnological Studio. The software can store 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.

D. Statistics on the acquired data

The purpose of the statistical analysis is to find a relation between all the measured parameters and the driver's attention and vigilance decrease. The index of the driver's attention is measured by studying the EEG signals as well as observing his/ her facial characteristics and driving position on the video stream acquired. In addition to these, another very important parameter that determines his/her attention is the reaction time to the appearing obstacles.
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 circuit, car speed and driver condition combination. In addition, correlation and cross-correlation matrixes 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.
Studying the results of all the above statistical multivariate analysis methods, the creation of the fuzzy logic membership functions is possible as well as the fuzzy rules set.

E. Real- time safety index calculation using the simulator

The data acquired on the real-time mode of operation, is still saved in the same way as earlier. 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 difference that occurs in the real time is that the safety index must be provided instantly and in a continuous way updated. To keep up with this requirement, the fuzzy logic controller uses as input the current values and provides the desired safety index. These current values are not just the signal voltage values, but the important parameters of every signal calculated over the last ten seconds. For example, a small elaboration is made at the HRV signal providing as input for the fuzzy controller the driver's current heart rate and not just the voltage value provided by the HRV sensor.
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.

VIII. First results

The simulator system proposed and discussed in this paper is used in a daily basis in order to acquire enough data to adequately support the statistical analysis. Some first observations though, can already be made and actually some first results have been acquired.
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 [17]. Examined from another point of view, the lower the GSR value, the more vigilant the driver.
In addition to this, another important phenomenon observed is the fact that both the heart rate frequency and the peripheral body temperature where relatively lower when the subjects were sleepless.

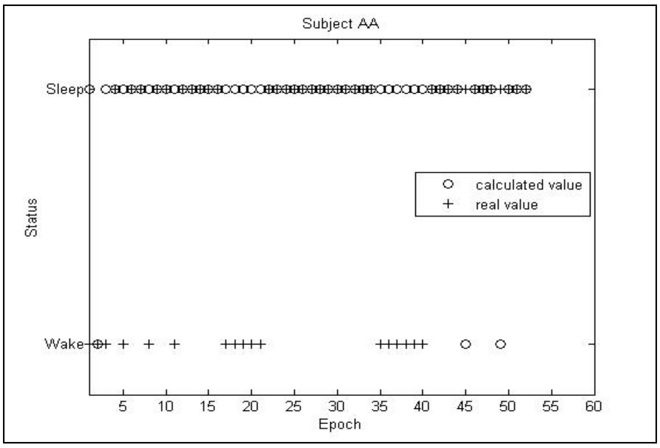

Fig. 2. Confrontation between calculated and real sleepiness level for 52 epochs with two sleepiness levels. The '+' symbols present the real sleepiness level while the 'o' ones present the calculated value for every epoch. For every epoch, when the '+' and the 'o' symbols coincide the result is considered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

Finally, perhaps the most interesting result is the fact that the phase angle between the two measured respiration frequencies is smaller when the person is sleepy and almost zero when he/she has actually fallen asleep. The more vigilant the driver, the wider the angle. Interesting HRV variations have also been found analyzing the minute before a sleep attack.
In order to have a success index for the control system realized, the system's output was confronted with the medical team's sleep reports. For every 30 seconds (one epoch) the doctors defined a sleepiness level, based on medical data and created these sleep reports. Since these medical sleep reports include only two or three different sleepiness levels (awake, sleepy, very sleepy), the fuzzy logic controller's output was divided into two or three levels. When using three different sleepiness levels the controller's success reached a 60,78% score, while when using two sleepiness levels (awake, sleepy) this score

raises to 79,61%. The result from this confrontation is presented in figure 2 (Fig. 2).

IX. Future steps

New sensors will be added in order to provide car's dynamical and mechanical data to be examined and correlated with the driver's safety.
In addition to that, a driving simulation platform has been developed by the Linz university. Using this simulator system, the results will be closer to the driving reality. The final step would definitely include tests made using a real car.
Finally, 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.

X. Conclusion

The methodology discussed and proposed by this paper is innovative for the field of safety in automobiles and is ameliorating day by day. The already developed simulation system along with the well defined protocol also presented earlier in this paper, are being used in a daily basis to acquire more data for the statistical analysis and the fuzzy controller set-up.
As this data is being analyzed, the need to modify certain characteristics of the system and the need for new sensors appear. Some sensors may also be eliminated. Nevertheless, the experience acquired by these simulation procedures will be used to set up the protocol and the final system for the simulation using the Linz university's platform. A pre-industrial prototype will also be created after the valuation of the results acquired and the final sensors choice. The final tests on the real car will prove the applicability of the safety system discussed and its capability to provide maximum safety for drivers all over the world [18].

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