METHODOLOGY OF EVALUATING SAFETY IN AUTOMOTIVE USING INTELLIGENT SENSOR ARCHITECTURE AND NEURAL NETWORKS

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Abstract:

This paper deals with the methodology of creating a new intelligent system to improve the driver's safety and comfort in an automobile transportation. A description of the necessary hardware and architecture is made in details. Then the mathematical body of the system is described as well as its application on the acquired data. The application of the model on the data is made in two phases, first off-line and afterwards on real time acquired data. All the elaboration of the data results in one safety index for the current driver and situation. The data is always stored in the system's memory in order for the system to self- improve with time.

1. General introduction

Many projects in European Union programs are devoted to the increase of safety in automotive, in order to reduce deaths and accidents down to 50% in the next few years [1]. PSYCAR project, funded by EU in a Regional plan, starting from Lombardy Italian Region and Austrian Region, is one of these projects and the methodology used as well as some preliminary results are reported.
A preliminary driving simulation system has been developed [2]. On this system, the driver, environment and car are sensorized. All the data is stored in the computer's memory and, after the end of the simulation sequence, is elaborated to develop the basis of the real-time safety evaluating software.
Vigilance tests are used during the simulation, to determine the driver's attention and vigilance level. The results of the tests are also stored and afterwards associated to the driver's, environment's and car's sensorized parameters. Statistics and mathematics support the assignment of a weight to every parameter detected by sensors and assembly the results in different packages of perceptive sensorization according to the car, the path, the driver, the environment and all the possible influences which computer can detect and electronic board can manage. The final result is the association of the current scenario, to one safety index varying from 1 to 100.

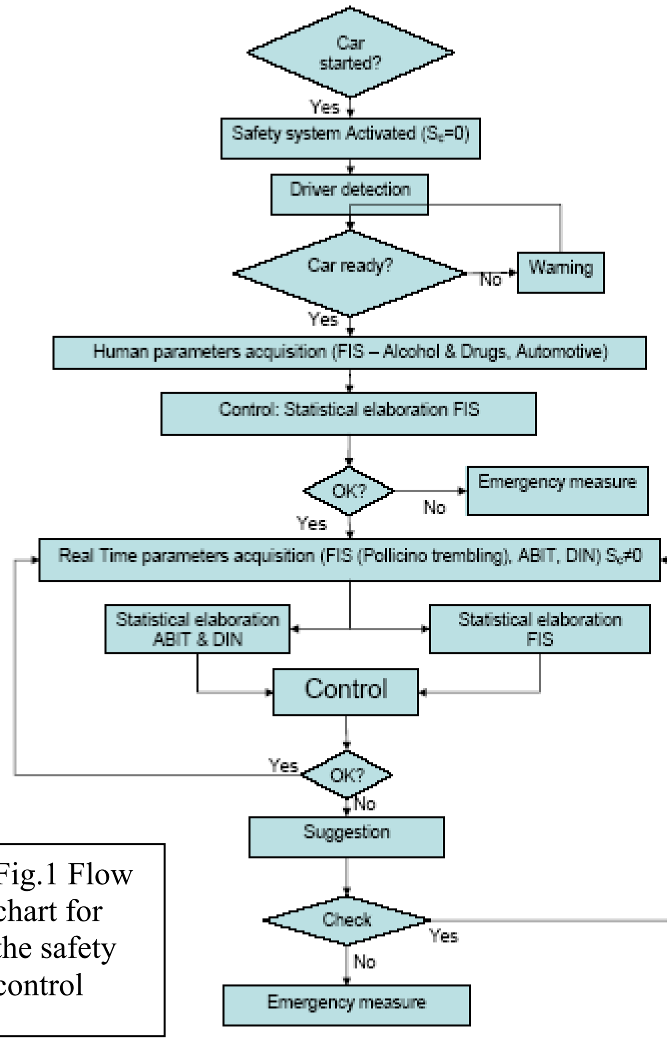

Fig.1 Flow chart for the safety control

The same perception is afterwards used for real-time evaluation of the safety.
Miniaturisation is also one of the main topics, which with wireless transmission and satellites like Galileo and others can offer communication all over the world, to catch data and leave results in control stations.
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. Intelligent sensor placement is fundamental for the system's applicability. The driver feels his/her situation in a smooth and personal way, in order to be deepened in his perception with the consciousness of the car plus driver plus environment conditions.
The change of the presence of new sensors and nanosensors, with a new design and a new diagnostics, will give a higher reliability to the car and to the driver.
RAMS like "Reliability Availability Maintainability Safety" will be the main aspects which mechatronic and computer and processor use can promote.
In particular, an intelligent distribution of the sensors inside the car in order to sensorize the car's interior and the driver's physiological parameters will provide the system all the necessary sensory data. This data, combined with the car's mechanical sensorized parameters will result, through a new, innovative statistical and mathematical model, based on classic multivariate analysis, fuzzy logic and neural networks, to a safety index easily interpreted by the driver. Indexes can be collected in mathematical way in a statistics shape and can be sent to a centre of collection and suggestions, in a teleassistance shape [3].

2. Selection of the physical, environmental and mechanical 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 [4,5].

The car dynamical parameters are already measured in every car on the market. Velocity, acceleration, distance, time, engine rotations and drift are parameters that experience has proven that are important in order to determine a critical situation. In addition to that, sensor positioning for these parameters is quite obvious and already tested over many years. All these parameters are monitored and stored in the system described.

Environmental parameters selection is also important and experience on this field has proven that temperature inside and outside the car, humidity, noise and oxygen concentration are parameters capable of determining a potentially unwanted situation.

However, 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 frequency, hand trembling, galvanic skin resistance, heart rate variability, body temperature, alcohol in blood concentration and cerebral waves are physiological parameters that can possibly detect a person's neurophysiologic state [6].

At the first part of the procedure described in this paper, all the above parameters are measured. The innovation of the methodology lies on the fact that none of these parameters is interpreted alone, but the combination of all the sensory signals is that determines the driver's current safety index.

Statistical methods of multivariate analysis determine the correlation of all the parameters with the driver's vigilance and attention level, helping also to discard unnecessary sensory signals that do not correlate with the safety of the person.

3. 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 and only acquisition board. In this way, the board, having all the signals available, is in the position to define the current scenario and then make a calculation of the driver's safety index for this scenario.

For this to be achieved, several aspects should first be considered [7, 8, 9].

In order to avoid wrong signal interpretation and to maintain homogeneity, all sensory output signals are transformed in the same type of electrical quantity. This quantity is usually voltage and in addition to that, the same output voltage range is used for all sensors, which is part of the signal conditioning procedure [10].

To achieve this requirement, signal amplification is necessary. The signals from the environment sensors are quite strong and vary typically from 0 to 5 Volts, so that they do not need any amplification before their digitalisation.

Signals from the car's dynamical parameters are also strong signals needing only a voltage divider in some cases.

However, the signals from the physiological parameters sensors are of a very low amplitude, so amplification is needed in order to achieve the 0 to 5 Volt variation.

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 criteria, stating that the sampling frequency should be at least 2 times higher than the maximum frequency appearing in the signal to be sampled, 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. Data provided from the sensor's manufacturer as well as simple calculations determine this fact.
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 saving of the data 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.

4. Off-line statistical data elaboration

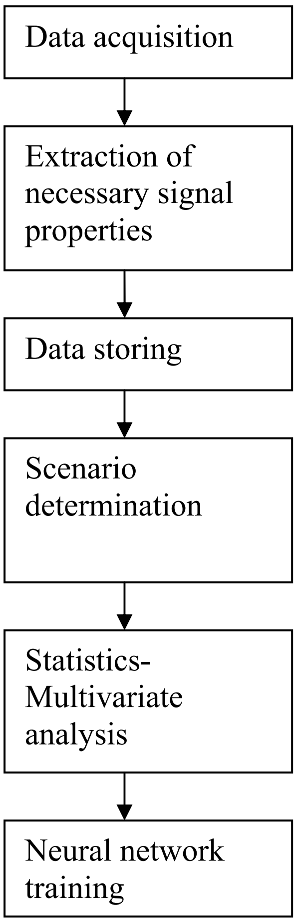

Fig.2 Off-line procedure

Main goal of the PSYCAR project is to define the right parameters for driver's psycho-physical status monitoring inside the "Car System". Besides that, the correlation between these parameters, all the other sensorized 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 safety index.
All the data acquired on the simulation system is stored in the computer memory.
Since not every signal is valuable at its pure form, this data is elaborated in order to obtain only the necessary properties out of each signal.
This part of the procedure ensures that the statistics correlate the signal's properties to the driver's attention and not the signal itself, which, in the case of physiological parameter signals, can have great differences from person to person.
Then, the current scenario is determined by some of the parameters' values.
The data obtained by the statistics is used to train a neural network, which is the heart of the on-line data elaboration and safety evaluation.
This system and methodology is original for the safety in automotive.

5. Real-time data elaboration and neural network

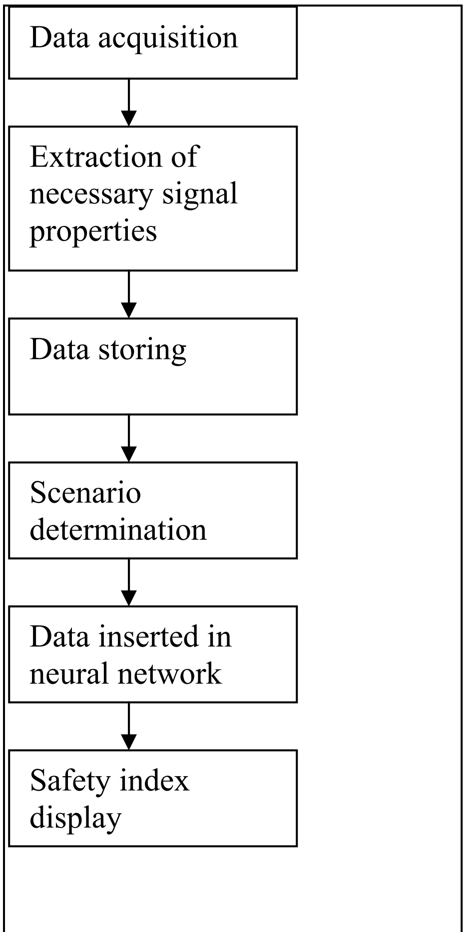

Fig.3 Real time procedure

The purpose of the system is a real time evaluation of the driver's safety. 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 neural network for every scenario is created and trained.

Neural networks are the most efficient tools available today for function approximation and with their ability to adapt and learn continuously are chosen to be the heart of the system.

In order to provide the neural network with the necessary parameters, defined off-line, to calculate the safety index, data from the past few seconds is first elaborated.

This data elaboration extracts from the signal only its necessary properties.

Besides from the safety index calculation, the system also saves all the data.

This data is important for the proper adaptation of the neural network to the current driver, since this data will be part of the neural network's training set for the current driver.

In this way, the system ameliorates and grows every time the car is used.

6. The statistical and mathematical body

The sensory signal j is represented by σj which is interpreted in its physical range [σj] indicated as rj. If σj is inside rj, a regular belonging is guaranteed. If σj is outside rj , a possible problem in the sensor has occurred and the system indicates the failure, but continues to run, without taking under consideration the faulty sensor's value.

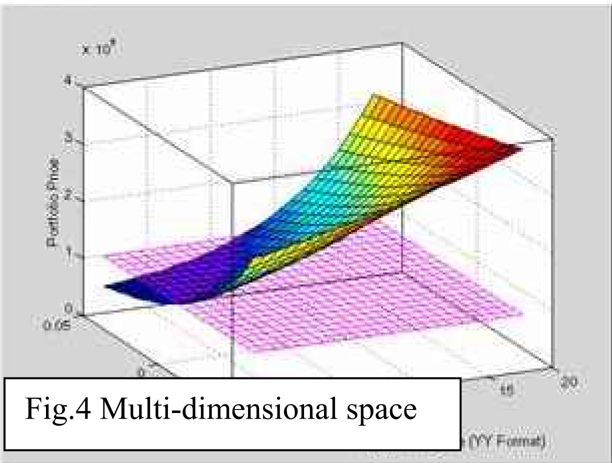

Fig.4 Multi-dimensional space

The faulty sensor's value is approximated by previous experience, using statistics.

Different scenarios are examined. Every scenario is pre-determined and data is collected off-line for every scenario separately.

For every scenario, a multi-dimensional space is created using the off-line multivariate statistics [11]. In the figure, a three dimensional space is presented, spaces with more dimensions work in the same way. In this space every combination of sensor values, corresponds to a safety index that varies from 1 to 100.
The vector containing all the sensory data $[\sigma j1\ \sigma j2\ \sigma j3 \dots\ \sigma jn]$ is used as an input set to train a feed forward neural network, using a back propagation algorithm. Its corresponding output vector is just a 1x1 vector containing the safety index value.
Back propagation is used to calculate the Jacobian jX of performance with respect to the weight and bias variables X. Each variable is adjusted according to Levenberg-Marquardt,

$$jj = jX * jX$$
$$je = jX * E$$
$$dX = -(jj+I*mu) / je$$

where E is all errors and I is the identity matrix. Mu is the adaptive value that changes according to the performance value. The training stops only when the performance is minimised, meaning that the target error goal has been met.
When training is completed, any set of parameters can be inserted into the current scenario's network to get a corresponding safety index. The choice of the current scenario is made by examining the current data.
The neural network is re-trained every time the driving session ends. Data acquired during the session is evaluated and statistics are used to determine a possible new input vector for a corresponding safety index.

7. Preliminary simulator system

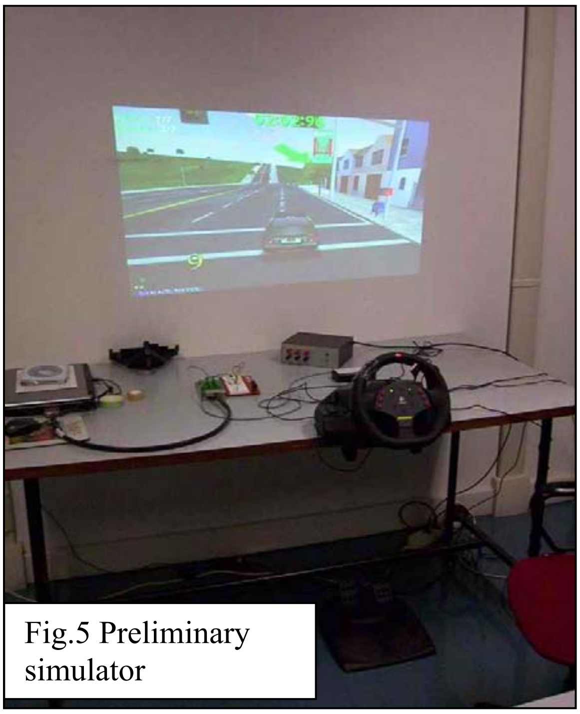

Fig.5 Preliminary simulator

A preliminary 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 the impression of actually 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 addition to these sensors, six Electro-encephalo-gram (EEG) signals are monitored. The apparatus to measure these signals is necessarily put on the driver's head but it will not be put on the actual system when it will go out of the laboratory.

The EEG signals are used in order to have an index of the driver's vigilance [12,13,14,15].
Also, using a two- channel optical incremental encoder the system can retrieve the steering wheel's position and velocity.
On the steering wheel are also placed a series of small pressure sensors. These sensors, besides measuring the driver's force on the wheel, are also used to measure his/her reaction time, during the vigilance tests.
Temperature and humidity sensors for the cabin are also placed in the simulation room as well as a temperature sensor for the environment outside the car system.
Apart from the driving simulation and sensorization system, two video cameras have been placed in the simulation room, in order to monitor the driver's face, reactions and body position, as well as the errors he/she is making.
In order to collect all the sensory data, a preliminary board with the sensors has been created and a LABVIEW program (VI) has been made for this purpose.

7.1 Protocol for the simulation system

The simulations are made on two different driver conditions. At the first part, the driver has slept during the last night, while in the second he 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.
The duration of the experiment is two hours and a half per person, and has three repetitions for the two different conditions. 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, the date, time and environmental conditions are noted and the car is always positioned at the same point.
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 initialised. During the procedure and in pre-defined times that the subject does not know, the driver must press hard on the pressure sensor. The response time is stored with all the other sensory data. This response time along with the data from the EEG signals [16,17] and the number of errors the subject has made will determine his/her safety index.

7.2 Description of the simulation system's hardware and software. Sensors, signal acquisition, conditioning and scaling, data storing

In order to collect all the necessary signals, a breadboard has been created [18]. On the board are placed two sensors; a temperature sensor (Analog Devices TMP01) where the temperature outside the car is simulated and measured and a temperature/ humidity sensor (Honeywell HIH3602C) to measure these factors inside the simulation room.

Fig.6 Sensors on the steering wheel

A system to filter and amplify all the physiological sensors has been developed by the ELEMAYA company and is used in the simulation system.
The A/D converter is a National Instruments DAQ-card 6062E with a capability of sampling up to a scan rate of 500kSaples/sec.
The pressure sensor is created after order by the STM Company.
The optical encoder used is incorporated at the steering wheel, made by Logitec and has two channels.
As described earlier in this paper, signals must be expressed in voltage and must have a range of 0 to 5 Volts. All of the sensors in the application comply with these regulations except from the Honeywell temperature sensor, whose output is a resistance that changes with the temperature variations (RTD).A simple electrical circuit is made to transform resistance into voltage before its digitization.

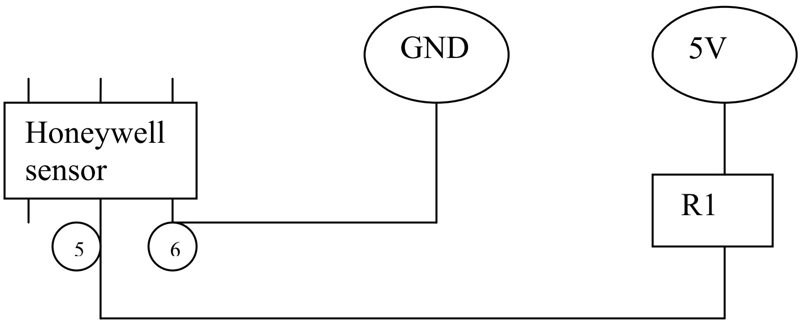

Fig.7 Circuit used to measure voltage instead of resistance

In this way, the voltage across the sensor pins 5-6 (RTD pins) is measured instead of measuring the RTD resistance.
The output of the optical encoder is already digital and so no signal conditioning is needed. Nevertheless, a D-type flip-flop (Texas Instruments CD74ACT74E) is used to determine the rotation direction. The first channel of the encoder (channel A) is connected to the clock input of the flip-flop, while the second channel (channel B) is connected to its D input. The output (Q) of the flip-flop is the direction of the rotation of the wheel, given on the binary system (0 or 1).
All the cables in the circuits are twisted together, as more as possible, in order to reduce noise.
The digitization of the signals is made at a sampling frequency of 30Hz, following the Nyquist criteria [19].

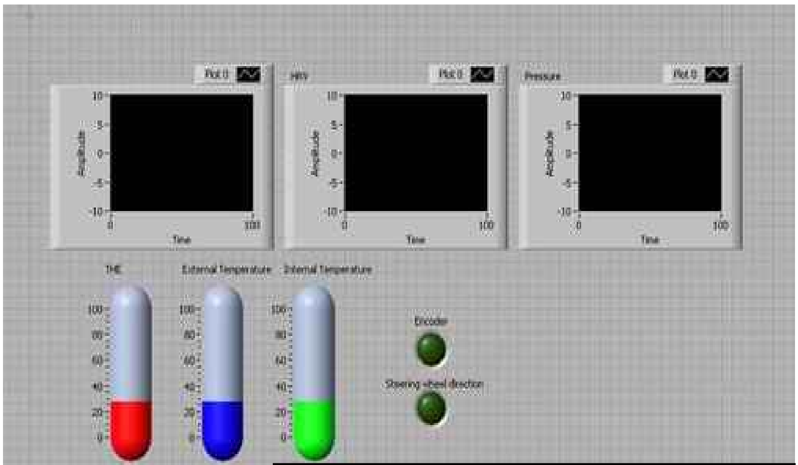

Fig.8 LABVIEW VI, 8 channels

All the signals are acquired and digitized. In order to handle the signals a LABVIEW VI has been created [20, 21].
This VI acquires all the sensory data and checks them to ensure all sensors are properly working. Using the data provided by the sensor's manufacturer, regarding the sensor's output voltage range, a check is made to see if the voltage available to the application at the moment, is inside that range. This is done using a compare ("if") function in LABVIEW.
The voltages produced by the sensors are not yet translated into the physical quantity they represent (signal scaling). This is done using LABVIEW function blocks. For every signal, at least one function block is needed, and using the mathematical function provided by the sensor's manufacturer, the voltage number is translated into its physical quantity.
Data storing is made using LABVIEW measurement files (.lvm). These files are simple text files that can be used by other applications for statistical or other reasons. In order to store as less data as possible, temperature measurements are stored every one second. This is made by averaging the last 30 temperature measurements and then saving the number. A software mean filter is used for this purpose.
All the other data is stored in one array, where every array column corresponds to one sensor and every array line corresponds to one sampling session (1/30 sec.).
At the end of one simulation session, two different files contain all the acquired data.

Devices and sensors used on the simulator

Device's manufacturer/type	Parameter to measure
Logitec Momo steering wheel with pedals	Driving simulation
Honeywell HIH3602C	Humidity/Temperature Inside the car
Analog Devices TMP01	Temperature Outside the car
Elemaya Visual Energy Tester	GSR/ HRV/ THE/ EEG
Logitec encoder	Steering wheel position/speed
Video camera Mustek DV9000	Driver's body posture/ Facial expression
Video camera	Driver's driving errors
ST Microelectronics	Pressure on the steering wheel

7.3 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 performance and vigilance decrease. For the moment, only one scenario, the sleep-attack scenario is examined.

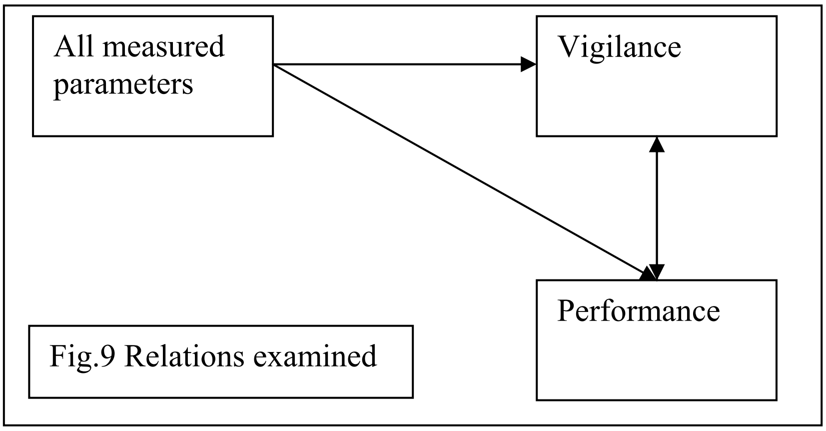

Fig.9 Relations examined

The index of the driver's performance is measured by counting the errors he is making during the driving session. Observing the acquired video stream, a number of errors can be counted and related to every lap the driver makes on the virtual circuit.
Furthermore, the driver's vigilance decrease is measured by studying the EEG signals as well as observing his facial characteristics and driving position on the video stream acquired.
The stored data is statistically analyzed using the JMP program.
The observed phenomenon is not linear and so a standard linear analysis is not adequate.
Multivariate analysis is used, using the JMP program, in order to identify categories of input that are related to a certain output index. The figure (Fig.6) shows the relations that are examined and that the system is trying to identify.
At the end of the analysis the correlations are available between the groups of parameters and their corresponding output safety index. Using these values as inputs and output respectively, a neural network can be trained for the application.

7.4 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. Among with the data, the driver's ID is also stored. In this way, the system becomes personalized and will be afterwards trained based on the driver's personal characteristics. The driver's ID is obtained by his key or by a password.

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 neural network that has been trained off line uses as input the current values and provides the desired safety index.

These current values are not just the signal values at the time being, but the important parameters of every signal (i.e. number of GSR peaks and not the GSR value itself) calculated over the last seconds

The simulator system program uses a MATLAB script to call the neural network and calculate the safety index, while the retrieval of the important parameters for every signal is made using MATLAB scripts and LABVIEW software filters.

8. Future steps- New sensors, testing platform

Fig.10 Test made in real

The work of Linz University, which is the partner in the project Psycar of European Union for the development of mechatronic systems, is devoted to introduce new sensors which should be able to be integrated into the Psycar system. Examples: - accelerometer for the lateral forces; - sensors for acceleration and braking of the vehicle; - sensor on the steering wheel for the trembling, etc.

All these sensors will provide even more data to be examined and correlated with the driver's safety.

The mathematical model of driver and the car: should be simple, from the parameters the condition of the drivers should easily be estimated and the correlation between the sensors and the parameters should be easy.

In order to check the mathematical model it is necessary to create a realistic Pc simulation. With a steering wheel, break and acceleration pedals mounted on the pneumatic platform a realistic driving feeling should be produced.

In addition to that, a simulation software is being developed in order not to use a PC game but a program from which data such as exact car location, car speed etc. can be available.

Using this simulator system, to test the system described by this paper, the results will be much more close to the driving reality. Maybe new ways of examination will result.

9. Meanings of Psycar Project: conclusion

Applications of results to high class cars and to mass automotive may be quickly applied, because new technologies and new methodologies of research and application today easily offer the capability to cover with the maximum safety the drivers all over the world [22].

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* ftp://robo55.mecc.polimi.it id psycar pw psycar folder PSYCAR

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