In Field Data Collection for Driving Behaviour Analysis using the DIVAS Instrumented Car

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SYNOPSIS

An understanding of driving dynamics is fundamental in order to fully understand motorway operations and the combined effects of driver, vehicle and road in order to identify and evaluate measures to enhance highway geometric design with respect to safety.

Data on the driving dynamics of a vehicle is the basis for studying road user behaviour and for evaluating the interaction between the pavement and the vehicle and its effects on the driver. Moreover, it is well known that the task of driving imposes a mental work-load on the driver. This work-load varies greatly in task difficulty and task frequency. The level of this work-load seems to be greatly affected by driver expectations and capabilities. This paper describes a methodology that has been developed on the basis of an International Research Project financed by the Italian University Ministry and by the University of Catania. The aim of this project is to improve road safety with respect to human needs. In accordance with this aim, the Operating Unit of the University of Catania designed and set up a prototype of an instrumented vehicle.

The field data were collected using the Driver Instrumented Vehicle Acquisition System (DIVAS), travelling in normal traffic conditions. The car was equipped with a GPS receiver, vehicle speed and acceleration sensors, a video camera for recording the driver's view and event spotting (Dynamic Data) and a system for recording the driver's psycho-physiological responses (Human Data). All these data are acquired during the test with the corresponding GPS position of the car along the road. An evaluation system to quantify dynamic and human data during the drive is provided. Dynamic data refer to those depending on driver behaviour and road-vehicle interaction. They were identified as: Vehicle Speed, Vertical and Lateral Acceleration, car Trajectory, the driver's Visual Field and Spot Event. As Human Data, some psycho-physiological parameters were used which proved to be suitable for showing changes in driver behavioural aspects and, thus, in driver performance: Electrocardiogram (ECG), Electrooculogram (EOG), Electrodermal activity (EDA) and Electromyography (EMG).

The experiment, conducted on a two lane rural road, with different alignment characteristics and pavement conditions (Static Data), showed the capability of the system in acquiring information that can characterize driving behaviour with respect to the road features.

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INTRODUCTION

A knowledge of the interaction that takes place between the road environment and the road user is fundamental for the development of useful improvements in highway geometric design. Thus, the efforts of research should be focused on an understanding of the combined effects of driver, vehicle and road in order to correlate human behaviour with roadway geometric characteristics, placing a special emphasis on safety.

It is well known that the driving task imposes a mental work-load on the driver (Wildervanck, Muldner, Michon, 1978). This work-load varies greatly in task difficulty and in task frequency. The level of this work-load seems to be greatly affected by driver expectations and capabilities. Roads with design inconsistencies would be expected to violate driver expectancies and impose a higher work-load on the driver and critical driving dynamics. For this reason it will be useful to have a safety evaluation process as regards work-load and driving dynamics, in order to predict road scenarios that maximise driver performance capability. However, most of the guidelines in many countries in the world do not take the role of human behaviour appropriately into account. The achievement of suitable safety conditions could be obtained using a procedure that allows driver behaviour and mental work-load to be evaluated as related to road design.

With this aim a methodology for the improvement of road safety with respect to human needs was developed on the basis of a research project co-financed by the Italian University Ministry (COFIN 2001). With this research target in mind, the Operating Unit of the University of Catania designed and set up a prototype of an instrumented vehicle, named the Driver Instrumented Vehicle Acquisition System (DIVAS), which while travelling in normal traffic conditions is able to acquire and collect field data related to human behaviour.

DATA SELECTION

Aiming at a complete definition of the main elements of the road system that can influence human factors, information characterizing driving behaviour and dynamics was selected. More specifically, three sets of data were defined (Cafiso, La Cava, Heger, Lamm, 2003):

- Human Data (HD), representing the driver's behavioural aspects
- Dynamic Data (DD), referring to driving dynamics
- Static Data (SD), related to road geometry and other significant highway features.

Human Data

Various psycho-physiological parameters, which proved to be suitable for demonstrating changes in the driver's behavioural aspects and therefore in driver performance, were used as human data. Thus, HD can be directly related to internal processes such as emotions, attention, motivation and cognitive loads.

In accordance with the literature (Heger, 1995), the following signals were recorded: Electrocardiogram (ECG), Electrooculogram (EOG), Electrodermal activity (EDA) and Electromyography (EMG). These are standard signals that are commonly used in psycho-physiological measurement. As will be explained in the following paragraphs some indicators are extracted from these signals.

Dynamic Data

Dynamic data are those depending on driving behaviour, driving dynamics and road-vehicle interaction. They were identified as being: Vehicle Speed, Vertical and Lateral Acceleration, Car Trajectory, driver's Visual Field, Spot Event Occurrence. These data are significant of driving modes and of the dynamic effects directly related to driving comfort and road-vehicle interaction.

Static Data

Static Data represent the infra-structural features of the test course that do not change during the test, but which are significant with respect to driver behaviour. These features were identified as being: alignment, roadside environment, cross section and available sight distance. Moreover, in order to characterize completely human behaviour with respect to road characteristics, it is also necessary to analyse the influence of pavement characteristics in terms of surface distress, unevenness, and skid resistance [Cafiso, Di Graziano 2000, 2004].

The stretches on which surveys are to be carried out must be selected in order to have significant characteristics for driver behaviour. Moreover, road stretches have to be long enough to allow the driver to adapt to HD recording system and also to the vehicle to be driven. In order to characterize the level of influence of SD on driver behaviour in terms of road safety, each of the previously specified static parameters must be characterized along the road:

Alignment: the elements of horizontal alignment investigated were the length and bending radius of circular curves and the length of tangents. The vertical alignment was characterized in terms of gradient and length of grades.

Sight Distance: the available sight distance at each point of the road was evaluated considering both alignment constraints and lateral obstacles.

Road signs: the presence of specific road signs (such as speed limits, dangerous curves, chevron signs) were positioned along the road.

Section type and lane width: section type (number of lanes, single or double carriageway), lane and shoulder width have to be identified. In the example, all the road stretches investigated were selected from the same road type (two-lane rural roads) with lane widths of 3.00 meters and paved shoulders of 1.00 meter.

Presence of intersections: to avoid the influence of intersections, a section length of 150 meters before and after any intersection was not considered.

Surface characteristics: the influence of pavement characteristics was analyzed in terms of unevenness and skid resistance.

To acquire the information related to the static data a survey was carried out using the Mobile Laboratory of the Department of Civil and Environmental Engineering (DICA) purposely designed to satisfy a real necessity created by the considerable lack of information as regards highway design data (Cafiso, Di Graziano, La Cava, Calabrò, 2003). Measurements of geometric alignment were carried out using two Global Positioning System (GPS) instruments used in dynamic differential mode. The points surveyed with the GPS were fitted using a 2-D cubic spline regression, whose parameters were used to recognize the fundamental horizontal geometric elements (curves and tangents). At the same moment as the GPS acquisition of point co-ordinates, a digital image of the road vision picture was acquired for the identification and location of the relevant road features along the road and the evaluation of the sight distance. Pavement characteristics were surveyed using the SCRIM and IRIS2000 devices, respectively carrying out CAT measurements every 10 m and longitudinal profiles.

DESIGN AND SET UP OF THE DIVAS

The instrumented car is equipped with high accuracy instruments (GPS double frequencies, optical odometer, inertial gyroscope, triaxial accelerometer, web camera), all synchronized, using a multifunction Daq Card controlled by a specific software for data acquisition and geo-referencing.

In this way the post-processing information analysis, carried out using the acquired data, allows driver behaviour along the road to be measured. To reach this target, the listed equipment (Table 1) was chosen to achieve an optimum accuracy and compatibility with the necessary data bases.

A hardware and software system was designed and home built for dynamic and human data acquisition, synchronization and positioning.

The DIVAS (figure 1) is a standard medium class car (Fiat Brava 1800) equipped with the following instruments:

Table 1: Technical Characteristics of the instruments placed on DIVAS

Instruments	Technical characteristics
Power supply	Inverter CC 24 → C220V Charge power CC 24-12 V
GPS	Double frequencies precision kinematical modality: ±2cm+1ppm
Triaxial accelerometer	Sensitivity: 1000 mV/g Frequency: 0-150 Hz Precision: 30 µg
Optical odometer with inertial gyroscope	Sensitivity: 56.2 mV/°/s transversal angle 25 mV/km/h longitudinal speed 460 pulses/m displacement
Data acquisition DAQ card	4 digital inputs - 2 analogical and 24 digital outputs Data transmission to PCMCIA; 12-bit, 100 kS/s
Web camera	Resolution: 640 x 480
Computer system	2 Pc laptop P4 1.8 GHz 256 MB Ram
Varioport	7 input pre-amplified analogical ports - 2 ports for trigger input 1 COM interface for laptop

Figure 1: DIVAS

Synchronised data acquisition

The great number of instruments constituting the DIVAS have made the planning of a synchronised acquisition system necessary and the subsequent elaboration of the analogical and digital information coming from the various devices. In point of fact all data acquired must have a common time reference (ID).
The acquisition of analogical and digital signals is carried out by means of a multifunction DAQCard with 4 differential channels.
The elaboration system used to acquire and elaborate information is made up of two laptops having suitable interfaces (IEEE1394, RS-232. PCMCIA) to link them to the various devices. Figure 3 shows the instrumentation connection scheme.

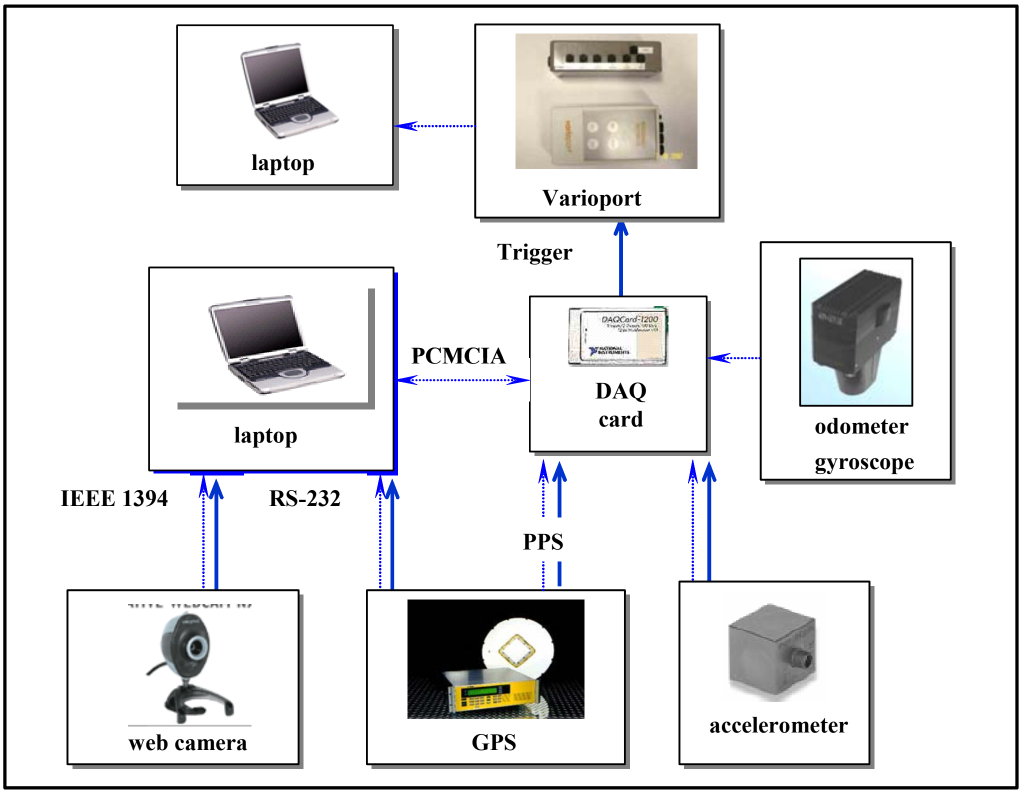

Figure 3: Instrumentation connection scheme

The multifunction card was programmed to acquire differential data from 4 analogical channels at an interval of 50 ms (20 Hz) between the various acquisition bursts. An acquisition burst relates to the sampling and the digitizing of the four analogical channels at a fixed speed equal to 10000 Hz. The moment that acquisition begins is synchronized with an interrupt signal (PPS) coming from the GPS receiver satellite at 1 s intervals (figure 4).

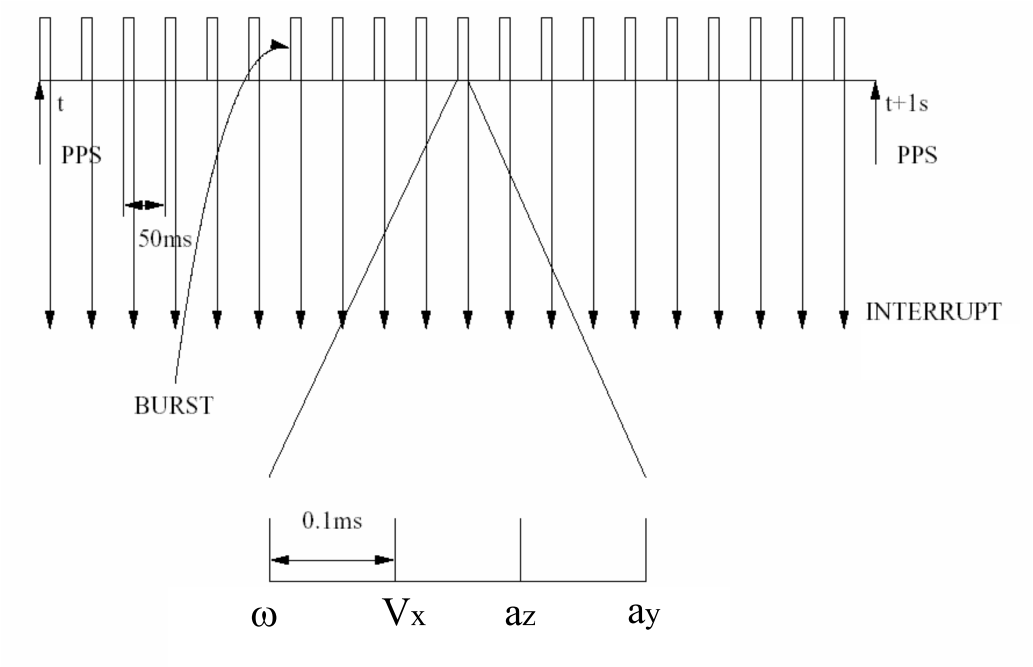

Figure 4: Acquisition and synchronization system scheme

In this way, 20 information from each channel are memorized every second, of which the first (time t) and the last (time t+1 sec) are geo-referenced.

The four analogical channels were programmed to acquire the yaw angle ω, the longitudinal speed V_x and the accelerations along two axes of the reference system (vertical a_z and transverse a_y). Moreover, the acquisition is synchronized with the web camera and the Varioport® system.

The Varioport® is a system that allows human data to be recorded. It is purposely designed to be worn without creating any driver restriction. It records electrical potential measurements associated with muscle contraction (ECG, EMG, EOG) and electrical property measurements of the skin associated with sweat gland activity (EDA). Furthermore, the ECG measures the electrical potentials generated by a heartbeat; usually known as the PQRST complex, where:

- the O wave is the initial excitation of the atrial muscle
- the QRS complex is the contraction of the L & R ventricles
- the R wave is the point of maximum ventricular activity
- the T wave is the re-polarisation of the muscle
- the systole is from P-S and the diastole from T-P

The cardiac cycle in an ECG is ~ 830 ms/72 bpm and generates a very large signal of over 2 mV. The EMG measures electrical potentials associated with muscle contraction with values measured in μV and ranging from 1 to 1000 μV. Facial (orbicularis oris and frontales) and neck muscle reactions were measured.

The EOG measures eye movements by means of the change in the voltage potential between the eye muscles, with an EOG amplitude varying from 0.4 to 1 mV.

The EDA is measured in μS (microSiemens) which reflect how well the skin conducts electricity; a greater sweat gland activity produces an increase in μS.

The multifunction Daq Card, programmed for a synchronized acquisition of all the data, is controlled by a specific software, created using the Microsoft Foundation Class technology, which permits various instrumentation to be managed simultaneously by means of different graphic windows, so as to acquire data coming from the individual devices as well as sending messages corresponding to the synchronized events.

All the signals coming from the instrumentation are de-codified in post-elaboration and returned in a suitable file (SIL.xls) in excel format. The graphic elaborations of some of the Dynamic Data acquired throughout 1 test kilometre follow (figures 5, 6).

Figure 5: Speed profile and an example of spot event acquisition

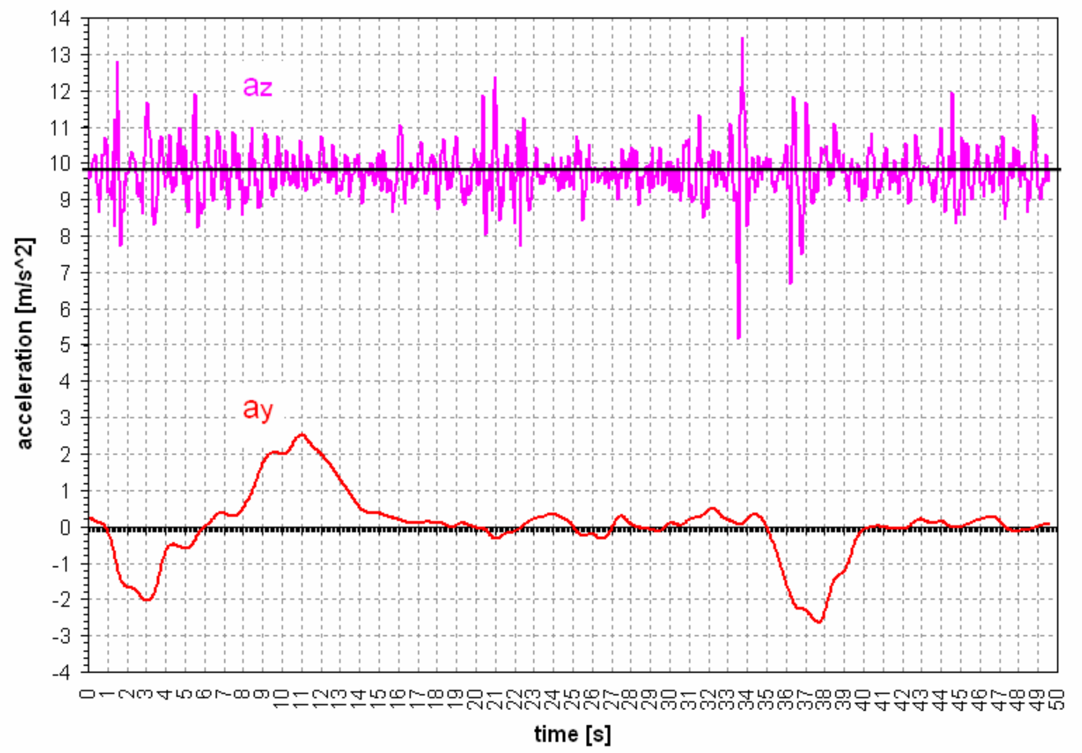

Figure 6: Vertical and transversal acceleration acquisition

Raw data recorded by the Varioport® are decoded by the Variograph® software. The same software allows the data collected to be visualized and exported (figure 7).

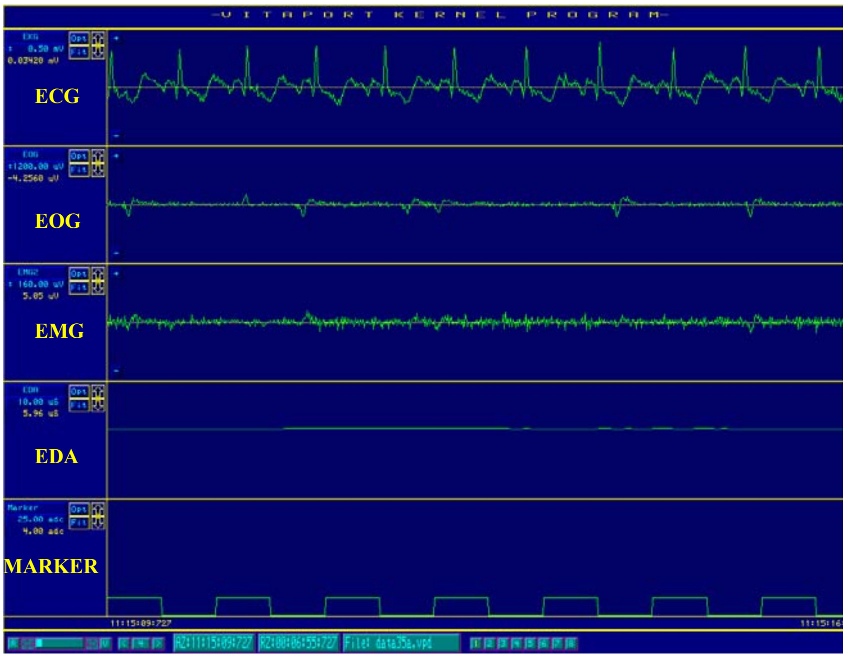

Figure 7: Visualization of typical Variograph® output

SPATIAL REFERENCE

As previously described, the on-board system acquires dynamic data at a frequency of 20 Hz, therefore all the information is referenced to a time step of 0.05 seconds. A higher frequency (512 Hz) is required for the human data. Furthermore, by means of the GPS receiver (remote) placed on top of the DIVAS, the vehicle location is acquired every second both recording the data in the SIL file and marking with a trigger signal the time acquisition on the Varioport file. To enhance the GPS precision, the survey is conducted in differential mode using a second GPS receiver (master) placed in a fixed position. By way of the differential correction a position error of only few centimetres can be obtained. If there are portions of the test course without, or with a bad GPS signal, then the position of the vehicle can be obtained by the data coming from the odometer and gyroscope system also installed in the DIVAS.
To refer the HD and DD to the geometric data, it is necessary to locate all the information along the road (test course). For this reason also the Static Data are referred by means of the GPS to the same geographic system (WGS 84). Therefore, a procedure (figure 8) was defined to transfer DD from a time series to a metric series: an example is shown in figure 9.

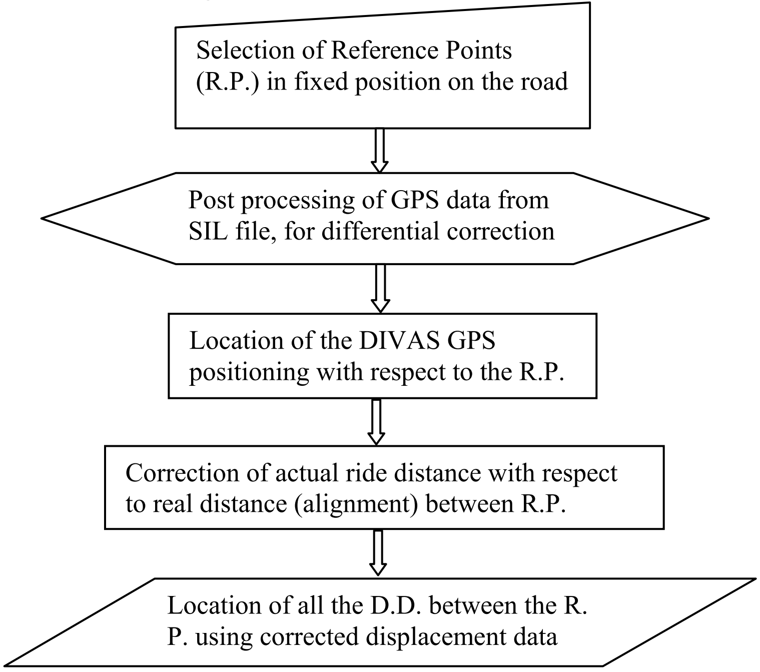

Figure 8: Flow chart to transfer DD from time to metric series

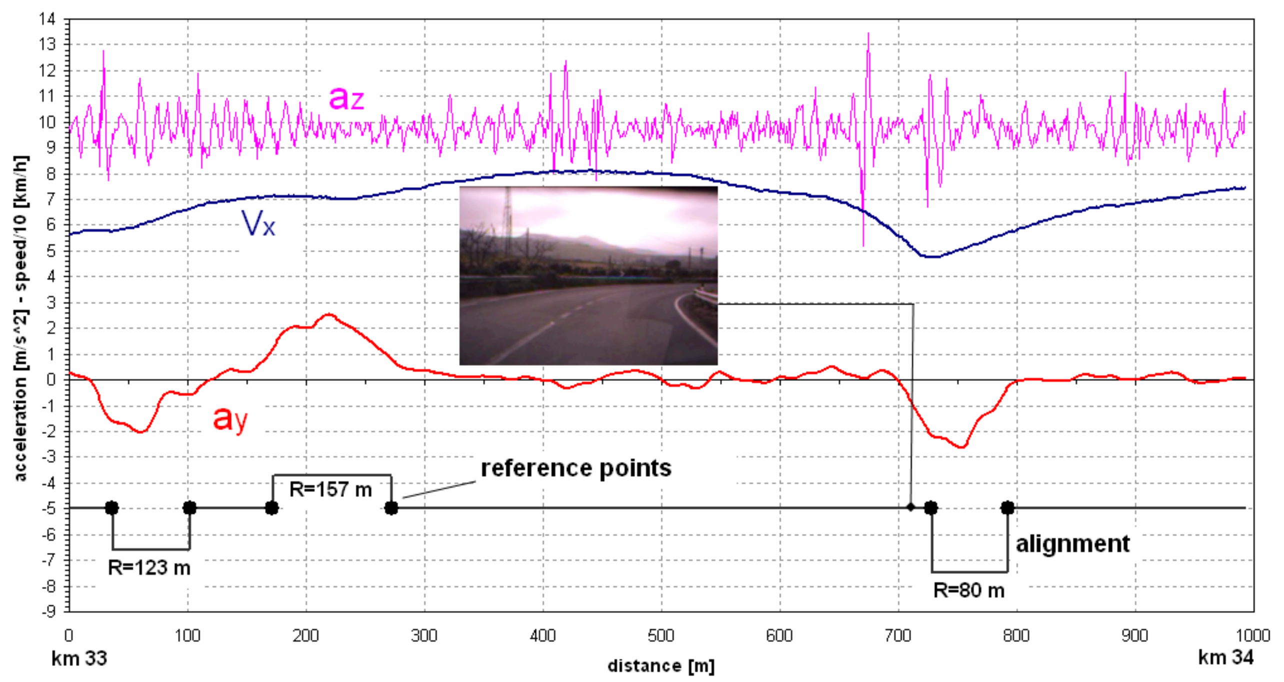

Figure 9: Example of DD and SD spatial synchronization

Because the human parameters to be evaluated are time dependent the same procedure is carried out not on the acquired data (e.g electrocardiogram) but on the elaborated data (e.g. heart rate) using the time synchronization between the SIL and Varioport® data obtained with the trigger signal.

PARAMETERS FOR DRIVER BEHAVIOUR EVALUATION

Among the data collected (figures 5, 6, 7) it is really only the speed profile that can be directly used for the evaluation of driver behaviour. Figure 9 shows a decrease in speed approaching the curve that is very evident in relation to the sharp isolated curve. The other DD and HD must be transformed to obtain evaluation parameters directly correlated to human behaviour, work-load and ride comfort.

More specifically, even if the average vertical acceleration (a_z) acting on the driver's body could be used as a parameter for measuring driving comfort, in reality it is only felt if it is sufficiently elevated and persists for a relatively long period. Instead, drivers are more sensitive to a change in the time of this vertical acceleration, namely jerk (figure 10). Therefore, applying Fechner's psychophysical law, it could be possible to correlate the standard deviation of the jerk (Js) with the NCHRP Ride Number (RN) (Liu, Herman, 1999).

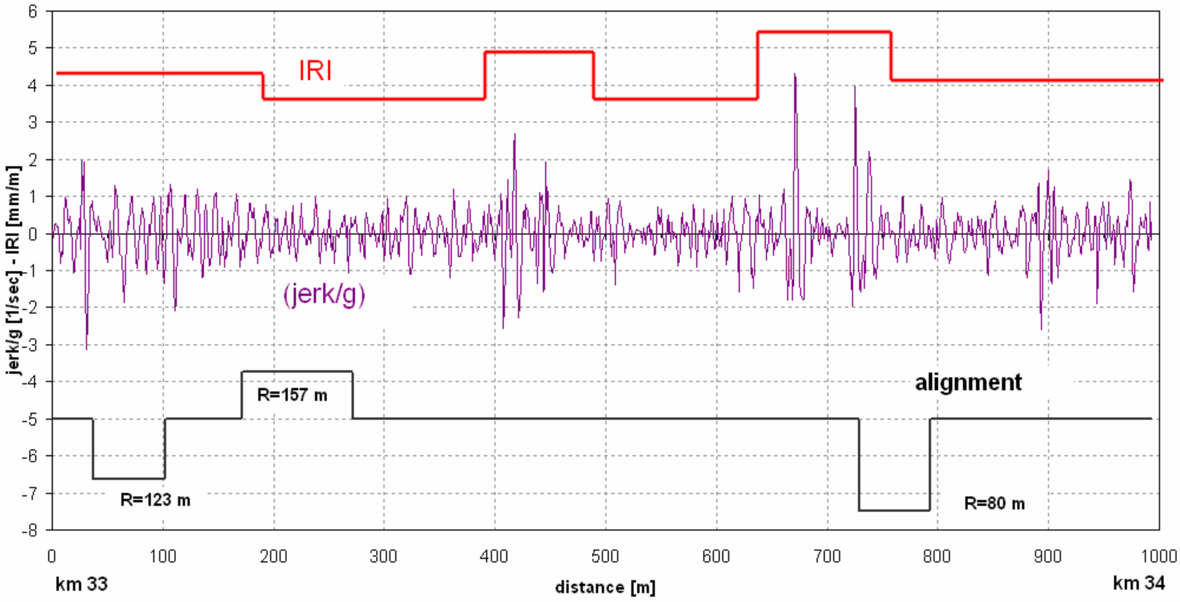

Figure 10: Example of jerk referred to static data

Moreover, the influence of surface characteristics expressed in terms of CAT (adherence available) could be related to the demanded skid resistance defined as the ratio between the transversal (a_y) and the gravitational accelerations (g). Moreover, the measurements of ay and v can be combined to obtain information about the vehicle trajectory. More specifically, the ratio a_y/v_y^2 represents the instant curvature (1/R) of the vehicle trajectory and can therefore be used to evaluate the actual trajectory as compared to the horizontal alignment. An example of data transformation is shown in figure 11.

To consider the influence on comfort of the centrifugal force (a_y) on a circular curve, the variation on time of the transversal acceleration, expressed as the rate of gain of radial acceleration C, could be analyzed.

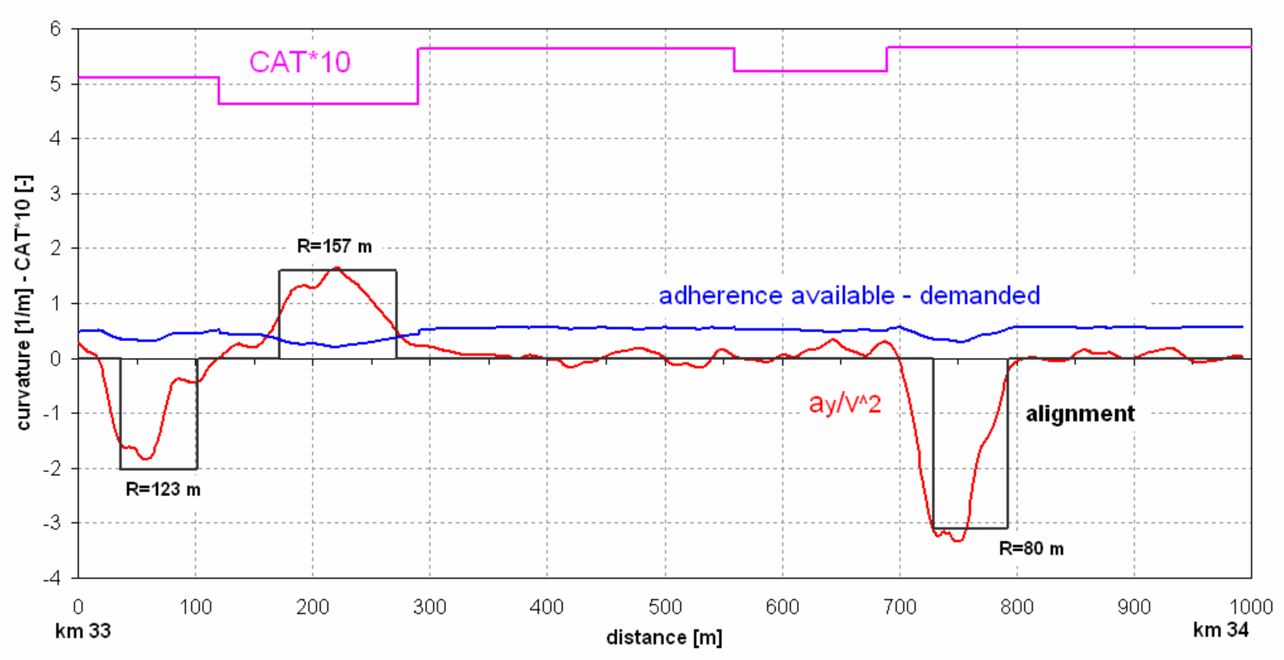

Figure 11: Example of a_y elaboration referred to static data

Referring to Human Data the ECG signals can be used to measure Heart Rate (HR = number of R spikes/minute) and Heart Period (HP = duration between R spikes). An example of the use of the ECG in psychophysiology is to measure how the body reacts to a loud burst of noise; this noise generates a startle reflex and can be indexed by an increase in heart rate (Fueredy, Heslegrave, Scher 1992).

The EMG can measure facial reactions to pleasant and unpleasant stimuli. Pleasant stimuli increase activity in the “smile” muscles (zygomatic) while unpleasant activity increases movement in the “frontales” muscle (corrugator).

The EOG can be used to measure Blink Rate (BR) and Duration (BD). The blink rate is highly correlated to visual stimuli which require attention. In such cases a decrease in the Blink Rate can be observed.

The EDA measures changes in response to emotional and cognitive activity; it can also index arousal. It is possible to look at measurements such as amplitude, rise time and response latency.

In particular the EDA-Amplitude is the most frequently used parameter of electrodermal activity, for example to measure an orientation reaction. The EDA-Area is a measurement of the amount of mental effort needed with respect to a particular event. The EDA-Level is a tonic parameter, which means that this parameter usually reflects the work-load over a longer time period. Figure 12 presents an example of the elaboration of HD as compared to SD. The analysis of the parameters deriving from HD such as heart rate and blink rate shows a variation in the psycho-physiological reactions of the driver corresponding to a change in the workload. An increase of workload levels could be associated to design inconsistency due to defects in road alignment.

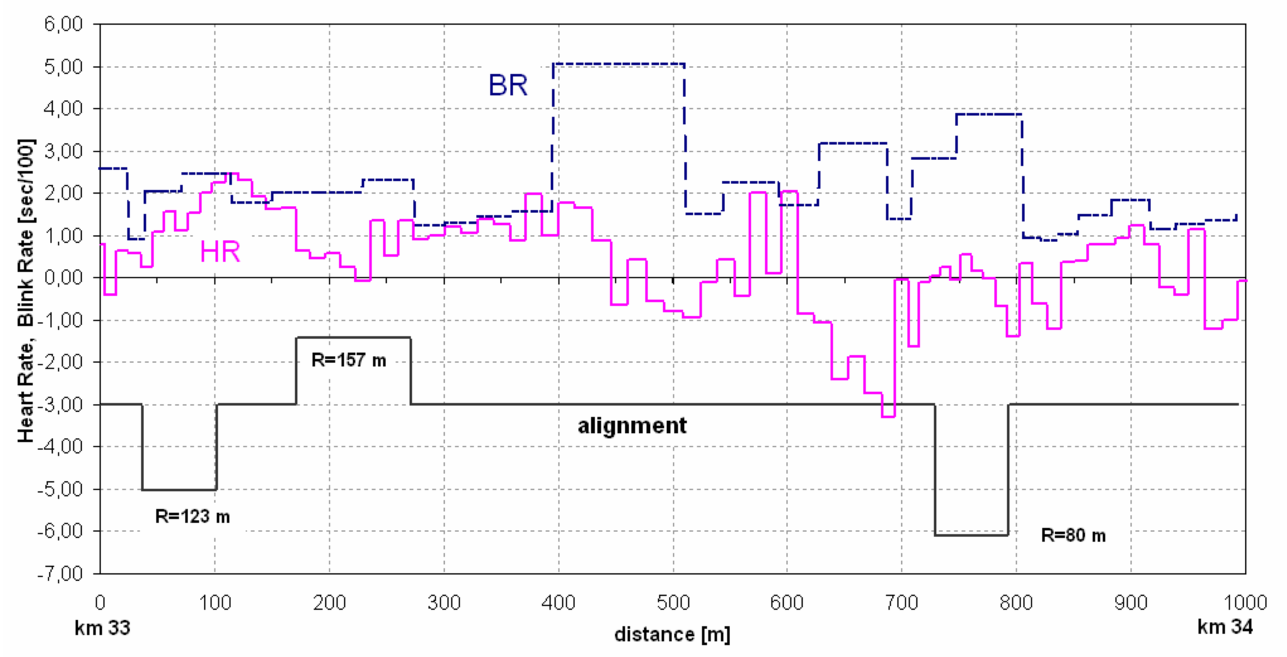

Figure 12: Heart Rate and Blink Rate referred to Static Data

CONCLUSIONS

To improve highway design standards for road safety with respect to human factors, an instrumented vehicle (DIVAS) and an evaluation system to quantify driver behaviour and mental work-load were designed and carried out.

DIVAS is able to collect field data while travelling on roads in normal traffic conditions. The car is equipped with a system designed to collect both the "dynamic data" which depend on driving behaviour and road-vehicle interaction and the "human data" representative of the psycho-physiological parameters that can be related to the workload created by the driving task. In the experimental project the road is characterized by means of "static data" referring to the infrastructure features that have a significant effect on driving behaviour and traffic safety.

The development of the DIVAS system is one of the results of a research project, sponsored by the Italian MIUR and conducted by the operating unit of the DICA with international co-operation.

The test shown in this paper confirms the capability of the system to acquire information that can characterize driver behaviour and mental work-load with respect to the road features.

At the present moment research is still in progress with an experiment conducted on selected test courses on two lane rural roads in Sicily using a representative sample of test drivers.

Although, the experiment is still in progress, the first results show a considerable influence of the horizontal alignment and sight distance on Dynamic Data. Also, the evaluation of Human Data gives original information about the mental workload of the driver and its correlation with the road features

It is foreseen that data elaboration will provide useful information regarding the interaction that exists between the road environment and road user behaviour in order to develop appropriate design alternatives for improving road safety.

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REFERENCES

Cafiso S., Di Graziano A. (2000), *Influence of macrotexture, skid resistance and surface unevenness on driving safety.* PIARC, IV International Symposium on Pavement Surface Characteristics of Roads and Airfields. Nantes, France

Cafiso S., Di Graziano A., La Cava G., Calabrò S. (2003), *Progettazione e sperimentazione di un sistema per il rilievo ad alto rendimento della viabilità in esercizio*, XIII Convegno SIIV, Padova, Italy

Cafiso S., La Cava G., Heger R., Lamm R. (2003), *Integrating Human Factor Evaluation in the Design Process of Roads – A Way To Improve Safety Standards For Rural Roads.* XXII WORLD ROAD CONGRESS AIPCR , Durban, South Africa.

Cafiso S., Di Graziano A. (2004), Road Surface Distress And Driving Performance – Transportation Research Board 83rd Annual Meeting, Washington D.C., U.S.A.

Fueredy J.J., Heslegrave R. J., Scher H. (1992), *T-Wave Amplitude Utility Revisited: Some Physiological and Psychological Considerations*. Biological Psychology, vol. 33, pp. 214-248

Heger R., (1995), *Driving Behavior and Driver Mental Workload as Criteria for Highway Geometric Design Quality*. International Symposium on Highway Geometric Design Practices, Boston Massachussets, U.S.A.,

Liu C., Herman R., *Road Profile, Vehicle Dynamics, and Ride Quality Rating*. Journal of Transportation Engineering, vol 125, N. 2, 1999.

Wildervanck C., Muldner G., Michon J. A.(1978), *Mapping Mental Workload in Car Driving.* Ergonomics, Vol. 21m, pp. 225-229.