Visual Activity as Indicator for the Analysis of Road Safety

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SYNOPSIS

In this paper the results are illustrated of a further phase of a research to evaluate the correlation between visual activity and distance covered on a road.
The quantification of a synthetic parameter representative of visual work, as Visual Load Index (VLI), already illustrated in previous publications, has been reshaped with other variables relevant to driving behavior such as speed, longitudinal acceleration, use of brake and accelerator pedals and road geometry.
Their connection with well-known parameters could lead to recognize some correlations with quantities within the Italian Road Standard, so that the methodology now proposed could be used in the normal design stage, without the aid of a particular equipment. These correlations will be studied in a further step, after the calibration of the visual behavior model.
To record the driver's visual activity, a vehicle was equipped with some video cameras and sensors managed by software ad hoc to extract and sort out the most interesting results. The images of the film have been processed through algorithms based on Image Processing techniques to recognize and classify some of the driver's postures.
The aim was to evaluate if visual activity can cause an overload of information which in turn, might influence the driving behaviour.

The experiments, carried out on a rural road, have shown that:

- The videotape hasn't highlighted a particular attention toward the road vertical signs, in many cases not very visible, also if present within the driver's field of view. Instead, the driver acquires the information about the road geometry, almost exclusively through marginal edges. These elements form the reference to eventually adjust the trajectory, as deducted also by Land.
- The driver recognizes a horizontal bend in the preceding straight stretch, at a distance that is a function of the speed and geometry coordination.
- In presence of obstacles, the driver must renounce at the feed-forward mechanism and interpret the bend according to driving experience, adjusting the trajectory only when inside the bend.
- There is a sharp decrease of the speed when the VLI reaches values of certain entity, while for lower values it is absolutely less important.

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INTRODUCTION

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Their connection with well-known parameters could lead to recognize some correlations with quantities within the Italian Road Standard, so that the methodology now proposed could be used in the normal design stage, without the aid of a particular equipment. These correlations will be studied in a further step, after the calibration of the visual behavior model.
To record the driver's visual activity, a vehicle was equipped with some video cameras and sensors managed by software ad hoc to extract and sort out the most interesting results. The images of the film have been processed through algorithms based on Image Processing techniques to recognize and classify some of the driver's postures.
The aim was to evaluate if visual activity can cause an overload of information which in turn, might influence the driving behavior.
The experiments, carried out on a rural road, have shown that excessive visual load, caused mainly by vehicle interaction and geometric singularity, produced a speed decrease. The variation of the radius, instead, did not significantly influence the driver's style.

POSITION OF THE PROBLEM

The increase in number of vehicles and their performance, the importance of road transport, the condition of the pavements, critical because of limited budgets as also a great number of accidents, uninfluenced to political measures, have encouraged scientific research towards the study of the human factor. This component, within the road system, represents a weak ring in the determination of dependable parameters because of the uncertainty deriving from age, pathologies, skill, experience, risk inclination, level of attention, etc.
On the other hand, the elimination of an unknown quantity, such as the human factor, could lead to an important mistake in the computation of the final results.
In this scientific area, the most recent researches have shown that it is difficult to foresee the approach for the future. There have been two leading movements in this field. The first one is represented by Authors such as Fambro et al. (1998), Wood et al. (1998), Lamm (1999), Wooldrige et al. (2000), etc., that generally based human behaviour on one variable which symbolizes the phenomena observed.
This has permitted the simplification and generalization of the theoretical base of the problem and to obtain quickly the quantities of interest, after the experiments on the road.
The other school, of which Hollnagel (1998) is one of the principal exponents, instead, is based on an approach strongly influenced by psycho-physiology and aims to represent the driving behaviour through sometimes too complex models. The target is to build a general scheme that also forms the bases to draw up some design standards. In this second case, the task is harder and, at least, not immediately solvable.
With regard to this school of thought, Bosurgi et al. (1999, 2000a, 2000b) and Pellegrino (1999) have recently proposed and applied a cognitive model not based on sequential logic, as usual risk analysis, but on an inference engine in function of some of the known cognitive variables. The great completeness of the scheme, certainly very realistic and workable with different scenarios and users' classes, needs a detailed data base so that the final results are as reliable as possible. Some examples are visual sharpness, levels of attention, skill, driving experience or particular scenarios that could influence the dynamic characteristics of the route, such as rainy events, night driving or various traffic conditions.
In order to overcame the difficulty in discovering a large amount of information, the present research has focused on those quantities more pertinent to understand the phenomena regarding driving behaviour. The widening of the themes dealing with vision has been considered priority since, through visual perception, the driver receives all the most important data necessary to interpret the external environment.
Donges (1978), among the first researchers more interested in these problems, outlined the most successful model in this field. According to him, the driver receives from road two different signs that can be thus

interpreted:

- An anticipatory feed-forward signal derived from the angular discrepancy between the direction of motion and the edges of the road.
- A feedback signal from the lane edge closest to the vehicle that provides fine-tuning to keep the vehicle in lane.

Therefore, the first mechanism is useful to estimate upcoming road curvature, while the second permits some small adjustments to be made required to control the position of the car inside the cross section of the road.

Between the first signal and the steering response, there is a time delay of about 1 second. It is important to underline that these signals are complementary to each other. In fact, if the feed-forward mechanism succeeds in measuring and matching curvature accurately, then in theory the feedback would be unnecessary.

On the contrary, if a correct interpretation of the bend is obstructed for any reason (because of coordination defects, vehicle interaction, etc.), then the feedback becomes decisive for the safety.

With regard to this, Land (1998a, 1998b, 2001) carried out some experiments, also in simulated conditions and ascertained that the road geometry must be completely visible to have the best driving performance. If it is only the far part of the road perceivable, drivers match curvature well, but their lane keeping performance is poor. On the contrary, when only the near part is visible, lane keeping is better, but steering becomes unstable.

Finally Land asserts, that the road edges in the field of view are the only necessary and sufficient visual cues for steering and understanding road geometry. The driver gazes at the tangent point of the bend because of its immobility with respect to other points within the field of view.

Therefore, it is possible to declare that there are some “normal” conditions in which the driver’s gaze is directed towards the internal edge of the curve or towards the centre of the road in case of a straight stretch.

For these reasons, the investigation of visual behaviour is important not only to define the input of the inference model already proposed by the Authors but, above all, to recognize the eventual link existent between the driver’s visual mechanisms and the traditional road standards.

The basic step of the present research has already been completed by Bosurgi et al. (2003a, 2003b, 2004) with the proposal of a parameter, called Visual Load Index (VLI), that provides a quantification of the driver’s visual activity on the road.

In this paper, the improvement of the Image Analysis techniques and an enhanced instrumented vehicle, has permitted the underlining of the principal mechanisms of driving.

METHODOLOGY

The present international standards include some audits that point out any possible anomaly in the consistency, linked to relationship speed-geometry. Many Authors consider speed as a direct consequence of road alignment and safety, in turn, depending on the speed, could be connected to conformity with the geometry standards. All these could be true if the principal hypotheses are respected but these, unfortunately, are very binding and hard to represent the real traffic scenarios.

The idea that man is influenced by other kinds of input, such as vehicle interaction, light conditions, geometry singularity, road signals, as well as road alignment, is the basis of the present research.

The target has been the interpretation of visual behaviour in order to recognize the threshold that causes information overload and the effect of this on the vehicle dynamic. In this way, it is possible to recognize the really dangerous conditions and the best operations eventually to be done.

To perform this task, some videotape recordings of road context and ocular movements have been made also with the aid of some sensors that have returned a data base regarding distance covered, speed, longitudinal acceleration, use of the accelerator and brake pedals. A portable GPS, moreover, has been used and has given back the user’s position on the road.

Output data, after the road test, have been further processed, estimating ocular movements through Image Analysis techniques and correlating the visual work to the road geometry, some traffic conditions and vehicles interaction.

The Instruments

The test was performed with a car containing a system made up of three analogic micro cameras, all synchronized via ad hoc hardware (Figure 1). A converter of analogic to digital signals allowed images to be recorded directly onto a portable computer installed on board and handled by an operator seated next to the driver. Besides, another main board to monitor the speed and the driver’s activity on the pedals was installed.

The three cameras were positioned as follows: one pointing forwards, another towards the driver’s eyes and the third pointed backwards. Cameras with different characteristics (focal length, maximum lens aperture,

light sensitivity, minimum focal length) were used depending on the type of function to be monitored.
A number of initial problems encountered were overcome. These were mainly linked to vibrations of the moving vehicle, sudden variations in lighting conditions, the synchronization of recording sources and having to deal with files of considerable size.

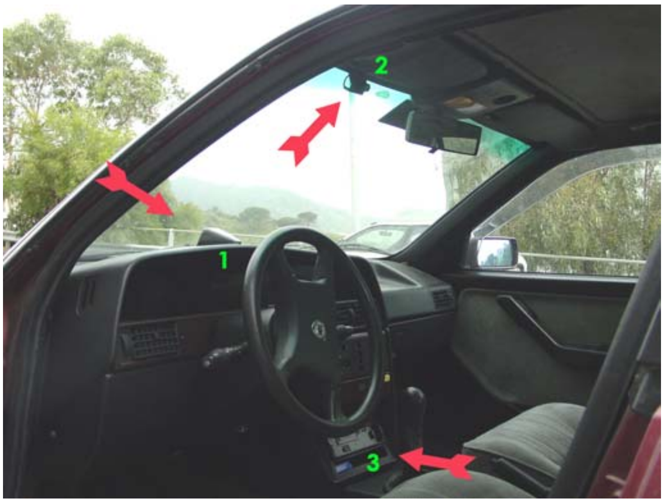

Figure 1: Instruments inside the vehicle: two of the three video cameras (1, 2) and the converter of the digital signal (3)

A special software to manage these instruments was setup, since the originality of the assembly did not consent the use of the packages usually available on sale (Figure 2). This software, based on the Aphelion (2001) language, allows:

- compression of the images in real time;
- possibility to run all the commands without the mouse, hard to use inside the car;
- the possibility to use of slow-motion, in order to underline all the small details into frames;
- visualization of the information about speed, acceleration and distance covered in the fourth quadrant of the monitor;
- automatic creation of a data file compatible with the most common computers.

Figure 2: Graphic interface of the three video cameras and the telemetry in real time.

Images Processing

The recordings have enabled us to recognize certain postures of the driver (who was unaware of the aim of the trial) associated with specific manoeuvres such as: overtaking or being overtaken, passing junctions with or without traffic lights or going past access roads from private land, handling bends or slopes, going through tunnels (Figure 3).
Also in this case, it has been necessary to setup a software ad hoc of which the principal phases have been illustrated in the flow chart of the figure 4.
To obtain further information about theoretical bases, all the necessary references have been included in the bibliography, such as Iannizzotto (2001) and Gonzales et al. (2001).

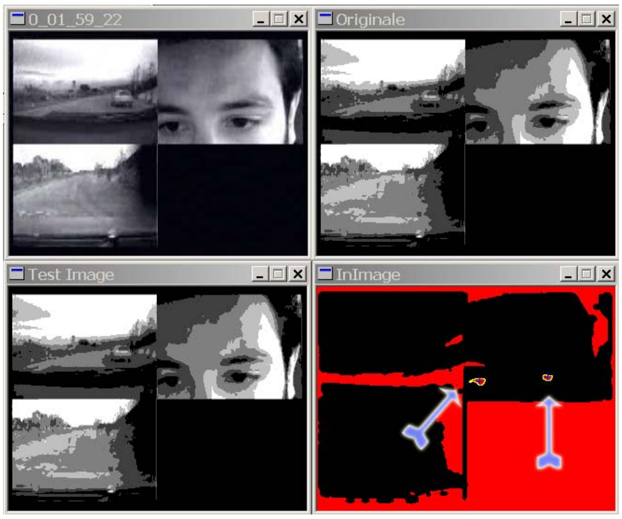

Figure 3: Some elaborations of the images and identification of the eyes position, shown by the arrows

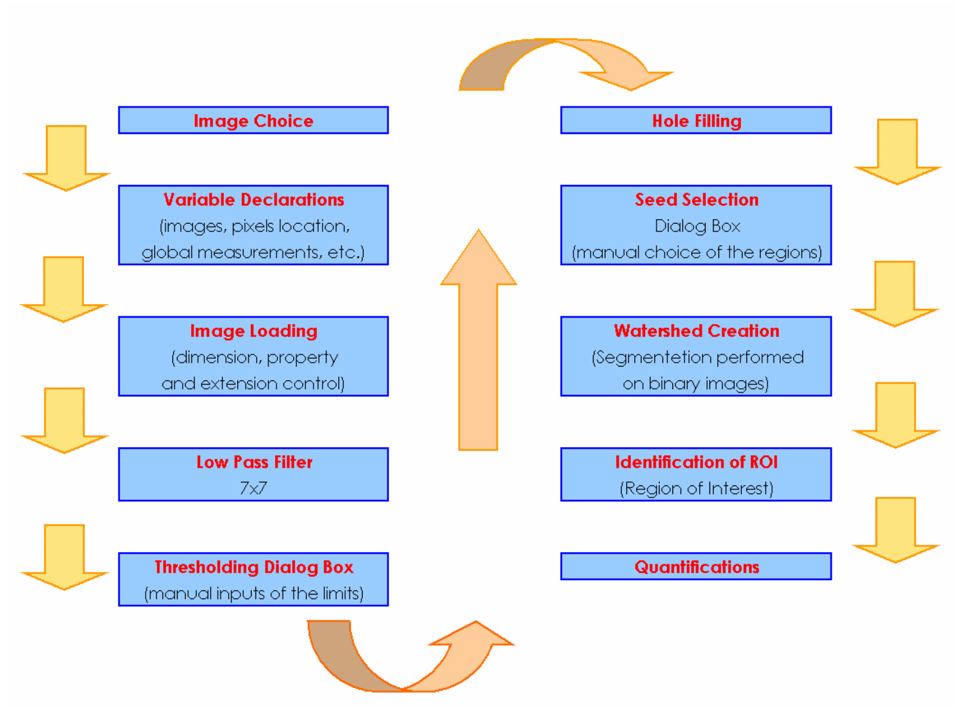

Figure 4: Flow chart of the Image Analysis software

Road analyzed

The trial were carried out on a rural road, covering a distance of about 7.7 km with uniform track in terms of its cross section and construction, with only a driver. This being necessary in order to prepare and calibrate the more correct methodologies before organizing a statistic representative specimen.

The morphological-architectural features were as follows:

- The cross section comprises two separate carriageways built at equal height, except for the final stretch of 300 m, where they are on different levels.
- The inland section nearest the hills carrying vehicles from north to south has three 3 m lanes, while the other, running south-north, has only two 3 m lanes.
- There are two footpaths of 1.40 m each positioned alongside the edge of the carriageways, the one on the coastward side is fitted with a safety rail.
- The central island is planted over and varies in width, between 2.5 m and 4.00 m, however there are no crash barriers.

The inland carriageway is the most dangerous, in that the size of the road platform, its division from traffic coming from the opposite direction and the morphology of the route all consent drivers to maintain extremely high speeds. The trials were carried out on this carriageway nearest to the hills.

Results

The video tape has highlighted some of the driver's attitudes during particular manoeuvres, such as overtaking, intersections with traffic lights or not, horizontal or vertical bends, tunnels and the conclusions are consistent with previous researches.

In detail, if the speed is low enough, the user periodically searches for supplementary information through the rear mirrors and the instruments on board. Obviously, the capacity to manage this information from several sources, depends also on the driving skill and it is, therefore, a characteristic of the statistical class of the driver.

In the case of "normal" condition, as previously specified, that have been altered by the presence of other vehicles or intersection or tunnels, the driver must process other data so complex as to exceed his capacity for analysis, so that the speed is consequently decreased in order to leave more time for decision making.

At this point, it is opportune to illustrate the way the visual load is measured, in order to understand the meaning of the results achieved. As already expressed, with regard to "normal" condition, the driver can move his eyes to evaluate an object outside the field of view. Nevertheless, if this movement is brief and, above all, isolated, there are no changes in the speed trend. On the contrary, if the movements are very frequent, the visual activity grows and the speed decreases considerably.

Therefore, the Visual Load Index (VLI) has been quantified in terms of eye movements with respect to "normal" condition. For example, turning a left bend the driver, generally, gazes at the left edge. The checking of the mirror (or of a road sign), forms a positive value of the VLI, that must be referred to the spatial coordinate of the road. In figures 6-9, the VLI has been reproduced through a segment always of the same length.

The identification of the coordinates of the eye position, has permitted the establishment of some ranges in order to recognize automatically the driver's posture and, therefore, to single out the driving action. In the following figures, the centroids of the regions locating the outline of the eyes have been drawn and with a good approximation, these could be considered the centre of the pupils. It is possible to note that the five postures can be easily distinguished from each other (Figure 4). Moreover, the straight line that connects these two points, represents the inclination of the head and, therefore, the pose assumed by the driver.

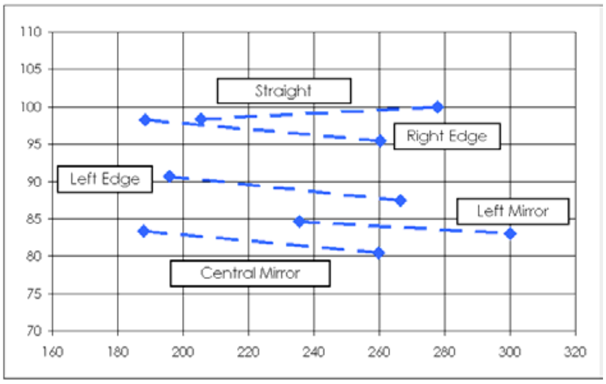

Figure 4: Centroids of the eyes in different poses

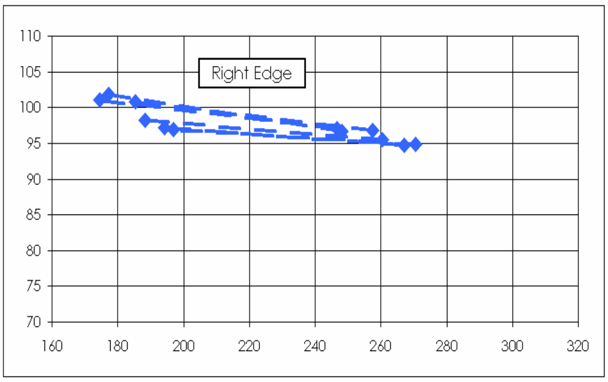

Figure 5: Centroids of the eyes in different time. Looking at right side

The assembly of some frames representing the same pose (looking at the right side in a right bend), at different times, demonstrates the exactness of the procedure (Figure 5). The coordinates of the eyes are all close to an average value and, therefore, this methodology consents the extraction of the interesting parameters with ease and a good level of reliability.

Nevertheless, it is necessary to specify in a more definite way the slight variance in the data of figure 5. Of course, short eye movements could depend on the radius of the bend and the vehicle position with respect

to the cross section. All these could be true, and in part it is so, if the pupils remains steady enough during the run of the curve. But this doesn't happen because of the feed-forward and feedback mechanisms described by Donges and Land. Especially for bends with small radius and difficult preventive interpretation, the driver looked at the internal edge, moving the eyes continuously. These phenomena suggest other relationships among the radius, the plane coordination, the speed and the traffic that are not recognizable with traditional approaches.
Instead, deviation from the "normal" condition happens when the driver searches for additional information through mirrors or instruments on board. These actions become more intense during overtaking or interaction with other users. If the time interval was very short, the driver didn't modify his behaviour but, in a opposite situation, the speed decreased considerably.
Analysis of the telemetry suggests, moreover, some considerations that must be properly verified. Here, some graphics have been briefly reported in which the speed, the percentage use of the brake and accelerator pedals and the Visual Load Index (VLI) are represented.
The figures below illustrates the most important situations:

- In figure 6, speed decrease is not correlated with the road geometry but, rather, with a visual activity caused by some overtakings. There is, in particular, a speed variation from 100 km/h to 72 km/h in the transit between two bends with the same radius (500 m), while there is an increase of V (78 km/h) in the next curve with R= 240 m;

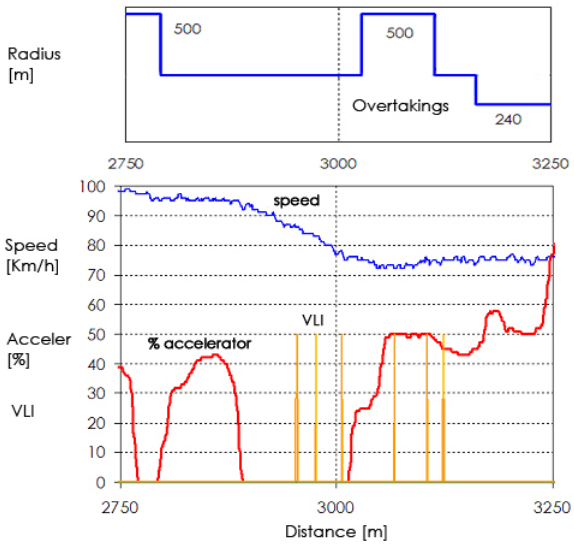

Figure 6: The decrease of V is only due to visual activity and not to decrease of R

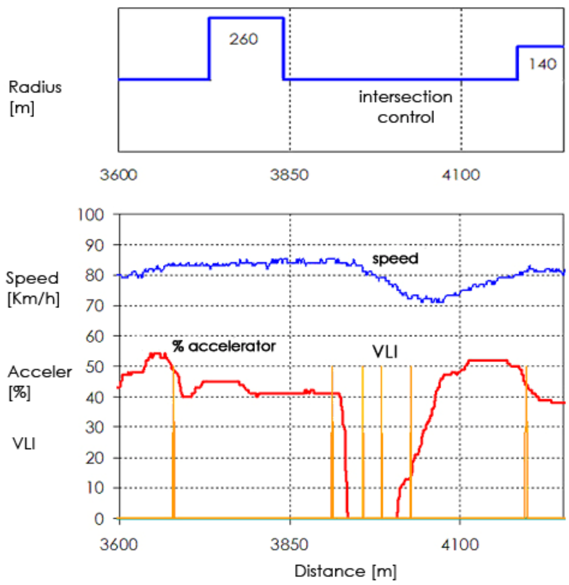

Figure 7: Also in this case the decrease of V is due to VLI

- Figure 7 too illustrates a speed decrease from 85 km/h to 70 km/h and this event is perfectly conjugated with an intense visual activity due to the driver's control near an intersection. The next bend, with

R= 140 m, produces an increase of the speed up to 81 km/h.

- Figure 8, instead, describes a traditionally recognizable situation, where the road alignment is the only influence. In this case, the driver decreases the speed from 80 km/h to 58 km/h by virtue of hard variation of the radii (R= 250, 110 and 80) of three consecutive bends. Therefore, in presence of bends with small radius, close together, there is an effective effect on the speed.

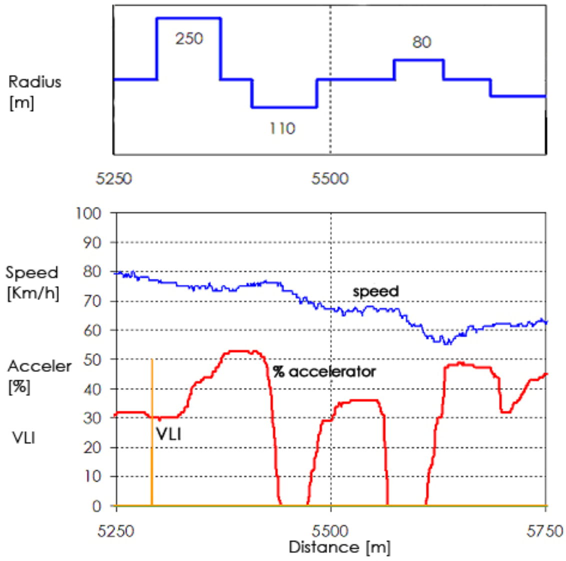

Figure 8: In this case the speed decreases in function of R

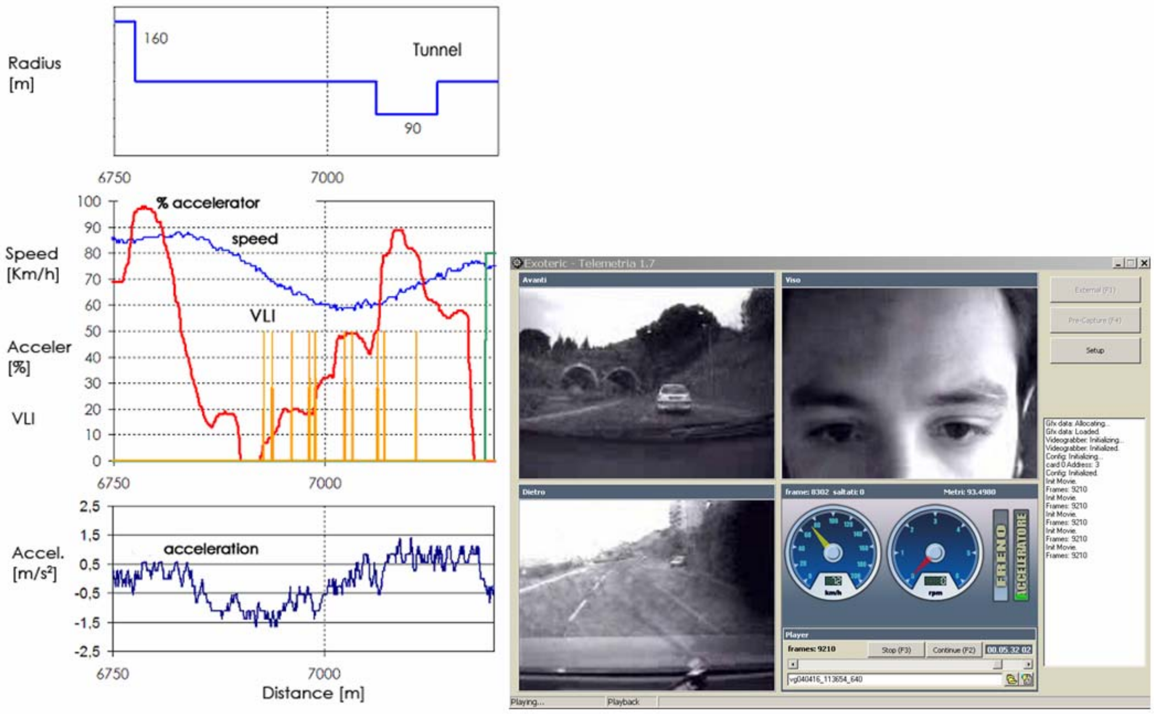

Figure 9: Intense visual activity near a tunnel. The accelerator pedal is not pressed.

- Figure 9 represents a particular situation, where there is a road inconsistency due to not coordinate vertical and horizontal bends, a tunnel and a vehicle to overtake. There is a sharp decrease of the speed (from 90 km/h to 60 km/h) in a short space and in correspondence with a very elevated visual activity. In this figure, the acceleration that varies from –1.6 m/sec^2 to a 1.5 m/sec^2 has been also reported.

These not very high values, suggest that there have been no emergency manoeuvres, but only a normal driving behaviour.

The video tape and, in particular, the single frames, show an obvious visual activity, aimed at finding data as to road geometry and the car that must be overtaken in precarious light conditions. The speed decrease is therefore a logical attempt not to overload one's management of the information system.

CONCLUSIONS

After these experimentations, some considerations can be deduced:

- The videotape hasn't highlighted a particular attention towards the road vertical signs, in many cases not very visible, also if present within the driver's field of view. Instead, the driver acquires the information about the road geometry, almost exclusively through marginal edges. These elements form the reference to eventually adjust the trajectory, as deducted also by Land.
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- There is a sharp decrease of the speed when the VLI reaches values of a certain entity, while for small values it is absolutely less important.

These considerations suggest the future directions of the present research:

- Experimentations with the aggregation of consistency statistic samples.
- Individuation of the critical threshold of the VLI when it negatively influences the driving behaviour.
- Analytical relationships between road geometry, traffic, speed and VLI, in order to foresee the visual activity in the design phase and without complex instruments.

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