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Potential of Immersive Virtual Reality Models in Studies of Drivers' Behaviour and Interventions to Improve Road Safety

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Abstract

The article reports the results of an interdepartmental research project of the Dept. of Construction and Transport and the Dept. of General Psychology of the University of Padova on the use of immersive virtual reality models in the analysis of drivers' behaviour and the evaluation of interventions to improve road safety.

Keywords --- **Drivers' Behaviour, Immersive Virtual Reality, Road Safety**

1. Introduction.

Other conditions being equal, road safety is highly dependent on drivers' behaviour and their perception of risk [1][2]. Driving behaviour is closely connected to the personal motivations of the driver, as well as the series of inputs he receives continually from the external environment while driving [3].

Within the ambits of ongoing studies on the driving behaviour of road users in real conditions, the Road Research Unit of the Department of Construction and Transport set up an interdepartmental research project with the Human Technologies Laboratory of the Department of General Psychology of the University of Padova, in order to extend the research to human driving behaviour in a virtual reality. The main reason for interest in the project was the wish to reproduce a 'real' context being studied by the Road Research Unit in a virtual environment, to be submitted to tests in an immersive environment on a statistically representative sample of volunteers aged between 24 and 33 years old.

The potentials of studies in a virtual reality [4][5] - in terms of empathy on the part of the volunteers and accuracy in terms of the original 'real' environments [6] - make them well suited to application in new areas of research such as that of the road sector, allowing topics to be studied related to driving behaviour that traditional driving simulators are unable to fully satisfy.

2. Methodological approach.

The two main objectives of the research project were to verify the validity of virtual reality in the field of road engineering, and to test the efficacy of some interventions aimed at improving road safety applied to a recent real case-study of the Road Research Unit of the Dept. of Construction and Transport of the University of Padova.

The variable used to describe driver behaviour in the different test environments – in its turn an index of the efficacy of the solutions proposed in each situation (independent variables) – was the speed of transit along assigned control sections of the stretch of road, which had previously been used for the characterization of the real environment.

The research activities were organized so as to flank the reconstruction of the real study context in a virtual environment with further instrumental measurements on site, in order to be able to better calibrate the characteristics of the immersive environment to be used with the volunteer subjects. The initial phase of the project involved the reproduction of the virtual model and measurement of the drivers' speeds in the real study context, traditionally used in the road sector to describe drivers' behaviour on the road. In the second phase, after calibration of the virtual model on the basis of the real data acquired during the previous phase, five different driving environments were tested in the virtual environment, in order to verify the efficacy of the different environmental modifications introduced in the test scenarios.

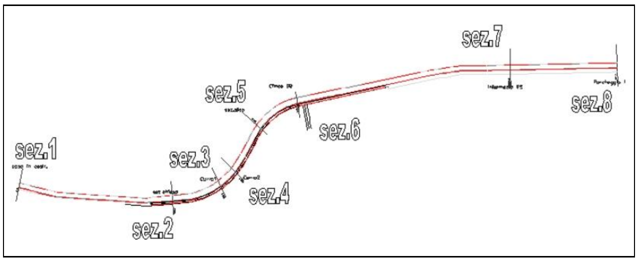

Figure 21 Planimetry of the 'real' stretch of road

The studied stretch of road is composed of two long straight sections to the east (the right in Figure 1) and west (left), between which an S-shaped planimetric variant was recently introduced, with geometric-functional characteristics assimilable to those of type E “urban district” roads according to the Italian regulations in force on the subject of the planning and building of roads. The curvature radiuses of the design variant measure 96 m and 81 m, respectively, proceeding from left to right in the geometric characterization of the axis.

The most interesting element from the point of view of behaviour evaluation is the presence of a new road intersection in section 6 (Figure. 1), which introduces an error in the perception of the route arriving from the east (right). This is further aggravated by the position of the street lighting, which does not allow an efficient interpretation of the physiognomy of the route in night-time driving conditions. An evaluation of the efficacy of the vertical road signs is also of great interest, as these are placed at points which are not very visible while driving. The distances of visibility are also very poor on the curvilinear stretch, and such that the mutual visibility between vehicles entering the bends from either direction is not assured. These elements were found to be critical during the experimental campaign conducted on the real road, the results of which made it possible to identify a set of design improvements, at both structural (planimetry of the road) and functional level (horizontal/vertical road signs), to be verified in the virtual environment.

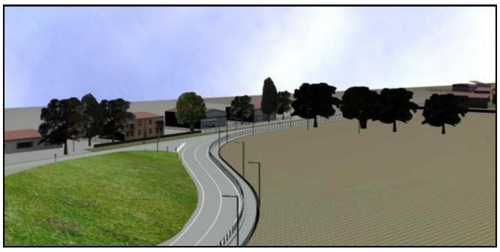

Figure 2 Aerial view of the virtual model.

For the reconstruction of the real environment in a virtual reality, the first basic objective was a cartographical reproduction of the study context. A series of surveys was used to define the exact position of buildings, fences, road verges, ditches and other elements in the territory. When the two-dimensional representation was complete, it was necessary to reconstruct the volumes of the buildings, roadway, the bicycle lane along the south side of the stretch of road, courtyards, fields, ditches, trees, dividing arches, lampposts and vertical road signs. For graphical reasons, only the façades of each building visible from the road are represented, as single regions, and the trees are reproduced as flat elements. In the same way, to reduce the number of sides of the dividing arches and lampposts the volumes were calculated by extrusion of hexagonal flat surfaces and not of circles, considering the proposed number of sides sufficiently accurate. Textures were then assigned to the various objects, either by using photographs taken in the real environment or by assigning suitable colours to the areas of greenery and background (a semicircle covering the environment with a texture representing the sky).

A model car was reproduced within the virtual environment, limited just to the dashboard, upper part of the steering-wheel and front bonnet, in order to reproduce real driving conditions as closely as possible. The car model chosen was a mid-range Mercedes. The decision to use a car existing on the market instead of a simple “ideal” model was made to render the driving test even more realistic.

After having calibrated the virtual model’s characteristics on the basis of those recorded in the ‘physical’ reality of the studied stretch of road, by exploiting the potentials of the virtual environment, five different driving scenarios were defined and reproduced, differing from one another by a single characteristic (independent variable). The characteristics of the different driving environments – with the description of the variables modified with respect to the base environment (the real one) – are summarized in Table. 1:

Letter	Modified variables	Note
A	-	
B	Vertical signs	
C	Horizontal signs	
D	Horizontal and vertical signs	Combination of B and C
E	Planimetric project	

Table 1 Characteristics of the driving environments.

The five test environments were labelled from A to E, the first one (A) corresponding entirely to the characteristics of the real environment, to the last (E), constructed to include a substantial modification to the planimetric geometry of the route, through attenuating the bends.

The modifications introduced to the vertical road signs (driving scenario B) correspond to the application of the signs shown in Figure 3, positioned respectively from left to right at a distance of 150 m, 100 m and 50 m prior to entering the S-shaped bend, in both directions of transit. The signs belong to the ‘perceptive’ signs category, the efficacy of which is well documented in the literature [7] [8].

Figure 3 Types of vertical signs inserted in driving environment B.

The third environment introduces modifications to the horizontal road markings in terms of their retroreflection (night-time visibility), by the insertion of an optical marker every 10 m along the lines delimiting the roadway and lanes. Previous studies have demonstrated that the introduction of these markers can have an effect on drivers’ attitude to speed in

curvilinear stretches, as well as improving the perception of the planimetric geometry of the road axis [9] [10].
For the driving tests in the different environments, a sample of 15 volunteers was selected with an average age of 26.3 years (D.S. = 4.6), who had held a driving licence for at least five years. The sample was composed of 9 males and 6 females, two of whom wore spectacles (1 male and 1 female). All the volunteers were given a full briefing on the test, stressing the necessity to relax and act as naturally as possible. The subjects then underwent a training session, with similar characteristics to the test environment, with the aim of acquiring the necessary confidence with the test equipment. All the volunteers were asked to drive in all the environments (in casual order) and in both directions of travel.
The subjects wore a helmet – complete with headphones to receive the driving sound effects – to reproduce the test conditions in the immersive environment with stereoscopic vision. The testers were each provided with a steering-wheel and brake and accelerator pedals, the sensitivity of which was calibrated to reproduce the real driving environment as closely as possible. After having mastered the equipment in a training environment, the subjects were invited to drive along the test route in both directions in the different environments. During the test, the model registered the speed, acceleration, breaking and instantaneous spatial coordinates of each volunteer, to be used in the successive kinematic study of the driving behaviour in relation to the different inputs.

3. Results.

The flexibility provided by the elaborations in a virtual environment allowed a great deal of information to be acquired relating to the drivers' behaviour in the different driving scenarios, from data on the instantaneous speeds, determination of the chosen driving trajectories, to determination of the acceleration and braking patterns.
Traditionally, the behaviour of the road user is described in the engineering literature through the trend of the operative speed (speed profile) on a given stretch of road, the *operative speed* being intended as the 85° percentile of the distribution of the speeds recorded on a given measured section, i.e., the speed exceeded by only 15% of the vehicles in transit. In agreement with this, a characteristic speed profile was determined calculated in all the scenarios, starting from the cumulative distribution of all the volunteers in the sample and selecting from this the value corresponding to the 85° percentile on all the control sections. Operative speeds are generally calculated exclusively on 'isolated' vehicles, i.e., at least 4 seconds apart, in order to ensure the maximum autonomy of the driver in the choice of driving behaviour [12]. In this specific case, the speed recorded for each of the volunteers in each of the environments was considered as operative, in that it derived only from the interaction of the driver with the driving environment.
The level of efficacy of the different safety interventions in the test environments B to E was evaluated by a comparison between the operative speeds in the base scenario (A) and those measured in the other environments, with specific attention paid to the sections considered critical for the above-described reasons (e.g., section 6).

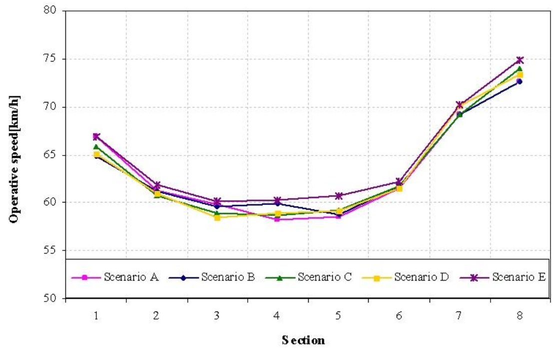

Figure 4 Speed profile in the different driving environments in direction of travel A (left-right)

The results of the tests conducted in daytime lighting conditions in the direction of travel A (left-right) demonstrate substantially homogeneous behaviour in the different scenarios. The only difference worth mentioning is in scenario E (with geometric modifications), in which there was a more stable and less jerky (moderate accelerations) approach to driving along the curvilinear stretch, despite the marginally higher speeds in absolute value to those recorded in the other test environments.
In daytime conditions the modifications to the vertical road signs and those to the horizontal road markings appear to have no effect (Figure. 4).
In the opposite direction, there was a marked dissimilarity in the approach to the circular bend, corresponding to section no. 6 (new intersection): more specifically, the introduction of the vertical warning signs and the placing of optical markers along the horizontal road markings led to a greater adjustment of the speed selected approaching the bend, followed by more stable driving behaviour along the entire length of the S-bend.

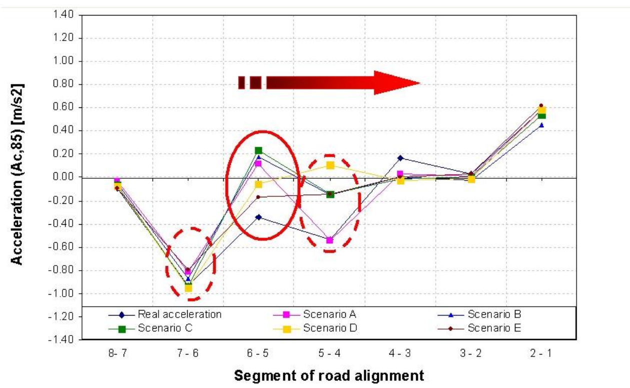

Figure 5 Profile of the accelerations in the different driving environments in direction of travel B (right-left)

The geometric modification of the route provides an undeniable improvement in terms of its legibility, as demonstrated by the graph in Figure 5, which reports the partial accelerations/decelerations between successive control sections, referred as before to the 85° percentile of the distribution of recorded accelerations.

4. Future developments.

Activities are underway concentrating on the verification of the different environments under night-time conditions, when the interventions on the vertical and horizontal road signs are expected to have maximum effect.

Conclusions

The initial results (the results from the night-time experiments are still to come) have demonstrated that virtual reality models can also be of notable interest for engineering purposes. In this specific case, by allowing detailed information to be acquired on the behaviour of road users (accelerations, braking, instantaneous speed and trajectories) that cannot be measured in reality, but also as a valid instrument for the prior evaluation of interventions aimed at improving road safety, such as modifications to road signs, geometry or the driving environment in a more general sense.

The volunteers' sensation of physical presence in the virtual environment – emphasized by the test methods in an immersive environment with stereoscopic vision –contributed significantly to their identification with the different driving environments, providing reassurance on the validity of the results obtained.

The current limitation to applications in the road sector consists of the over-simplification of the dynamic characteristics of the vehicle model, in terms of inertia and destabilizing forces while driving (especially on a bend), which unavoidably alter the information on driving behaviour with respect to the corresponding real environment.

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