A SIMULATION ENVIRONMENT TO EVALUATE DRIVER PERFORMANCES WHILE INTERACTING WITH TELEMATICS SYSTEMS

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Abstract: The evaluation of user interfaces for vehicular telematics systems is a challenging task, since it is necessary to understand the effects of interaction on driving performances. To this aim, in 2005 we developed and presented a framework specifically conceived for the indoor evaluation of these systems. In this paper we present some significant improvements of that proposal. In particular, we describe a graphical analysis tool able to provide a clear and deep insight about driver behaviors using the high amount of data generated by the simulator. Moreover, we report on the evaluation analysis that has been performed to assess the effectiveness of the framework for measuring driving performances.

1 INTRODUCTION

Researches on User Needs report that people want to be connected any time and any place, even in their cars (Comunicar, 2002; Microsoft, 2005). To answer this requirement, information and communication technologies have been fitted into automobiles, giving rise to *Vehicular Telematics Systems* (VTSs), which represent the in-vehicle convergence of mobile communications and information processing, allowing drivers and passengers to stay in contact with the world outside their car. VTSs allow drivers to exploit a plethora of features, such as multiple audio sources (MP3, DAB, and DVD), web browsing, e-mails, phone calls, voice control, and so on. Moreover, most advanced VTSs (e.g.: BMW *iDrive*, Fiat *Connect+* or GM *onStar*) are starting to provide *services*, i.e. advanced functionalities involving interaction with a support centre. Typical examples are remote vehicle diagnosis, dynamic route calculation (taking into account road, vehicle, traffic and weather conditions), tele-aid, hotel reservations, etc…

However, the diffusion of VTSs is also causing concerns about road safety, since these systems can heavily increase driver's mental distraction (Burns, 2001; Tijerina, 2001), which is widely recognized as the most prevalent cause of crash (Toms, 2001). Thus, since road safety is paramount, it is a short term priority to limit driver distraction inducted by VTSs, by enhancing the usability of these systems.

Human-Computer Interaction in the automotive domain can be considered a new and open research area (Marcus, 2004). Specific tools and approaches are required, mostly to assess the visual/cognitive workload inducted by these systems and to understand the effects of VTS interaction on driver-vehicle performances.

Currently, several universities, companies and research centers, have equipped laboratories with sophisticated driving simulators, able to simulate a high variety of physical phenomenon, ranging from the kinematics effects inducted by different suspension geometries, to very complex traffic scenarios (for instance, the NADS (NADS, 2005)). Some of them are used also for indoor evaluations of VTSs, but these laboratories usually cost hundreds of thousands of dollars and are very demanding to set-up (Green, 2003), being prohibitive for small institutions specifically focused on HCI research.

Thus, there is a strong needing for simpler VTS evaluation systems, able in the meantime to assure high-quality reports. To address this issue, in (Costagliola, 2005) we proposed a framework specifically conceived for the indoor evaluation of VTSs User Interfaces (UIs). The goal of this framework was to support researchers in an easy collection of valuable data on driver's behaviors (and thus on mental workload), being in the

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meantime cost-effective, by requiring standard hardware and simple set-ups.

In this paper we describe some improvements of the framework and report on its evaluation. One of the most distinguishing features offered by the proposed framework was the possibility to assess the navigation assistance provided by VTS, by automatically generating virtual test tracks starting from a VTS cartographical database. At the best of our knowledge, currently no other simulation facilities offer this specific but important feature, compelling to evaluate on the field the VTS navigation assistance module. In the following we will describe how we have improved the realism of generated tracks starting from a VTS cartography. Indeed, the current version of the system is able to reproduce much more realistic scenarios, taking into account road types, contextual information, etc… As a result, the realism and the sense of immersion in the virtual scenario experienced by the subjects, that represents a crucial feature for a simulation environment, has been improved.

Secondly, to handle the huge amount of experimental data collected per session, we developed an apposite application, named *Telemetry Analyzer Tool* (TAT). The aim of this tool is to support the data analyst in understanding the relationships occurring between VTS interactions and driving performances, by providing a clear, graphical representation of the subject behaviours, such as input on controls, followed trajectory, etc…, related to the timeline of the test. This is a highly demanded feature (Barr et al., 2003), leading to the generation of high-quality, repeatable analysis and reports.

Moreover, we have carried out an evaluation analysis meant to verify the effectiveness of the proposed approach for measuring on-road driving performances. To do that, we have employed a set of sixteen subjects. The conducted tests report that after about 20-25 minutes of training, subjects behave on the simulator in a way similar they drove a real car, thus supporting the validity of the simulator.

The remainder of the paper is structured as follows. In section 2 we introduce the main aspects to consider when dealing with driver distraction, as well as the approaches used to evaluate it. In section 3 we briefly recall the main characteristics of the evaluation framework, then we will focus on how we integrated the driving simulator and the vehicular navigation module. In section 4 we describe the data analysis features we developed, while in section 5 we report on the assessment of the framework. Finally, a discussion on final remarks and future work will conclude the paper.

2 VTS USER INTERFACE EVALUATION ISSUES

Usability evaluation of traditional desktop applications can be considered an established topic within HCI. It is based on a shared understanding of basic concepts and extensive guidelines (e.g. (Nielsen, 1993)).

However, these established concepts, methodologies, and approaches in HCI are being challenged by the increasing diffusion of *ubiquitous* computing, i.e. applications executed on wearable, handheld, and mobile computing devices. This move beyond stationary use is requiring new approaches to evaluate mobile UIs. Indeed, the main difference is that mobile systems are typically used in highly dynamic contexts, where the user is normally busy in other primary tasks, such as walking, driving, etc… (Lumsden, 2003).

This holds especially for the evaluation of VTS UIs. Indeed, static evaluations of these interfaces, performed with a subject totally focused on the system, do not provide significant information about the effectiveness of the UI. Instead, it is necessary to set up a meaningful test-bed, where subjects are mainly focused on the primary driving task and concurrently interact with the VTS. Researchers can evaluate driver distraction through the analysis of some indirect indicators on vehicle dynamics.

To accomplish these tests, two approaches can be adopted:

1. the interaction with a VTS is analyzed while the user is driving a real car (eventually on a track closed to the traffic), or
2. the driving is simulated in a laboratory, through some real-time computer-generated virtual scenarios.

Each of the two approaches presents advantages and drawbacks. The former is more realistic, because the subject drives a “real” car. However, it requires the availability of a car equipped with specific instrumentation able both to capture information such as travel speed and lane position and to video record the road scene and driver eye glance (e.g. (Tijerina, 1998)), and possibly of a closed track. Moreover, usability evaluations on the field are not easy. Three fundamental difficulties are reported in the literature. Firstly, it can be very complicated to establish realistic cases capturing key situations in the dynamic context above described (Nielsen, 1998). Secondly, it is far from trivial to apply established evaluation techniques, such as observation and think-aloud when an evaluation is conducted in a field setting (Pascoe, 2000). Thirdly, field evaluations complicate data collection and limits researchers controls, since subjects are acting in an environment with a number of unknown variables potentially affecting the set-up (Johnson 1998). In particular, the last issue heavily applies to naturalistic tests in the vehicular domain, since data are usually collected by some video cameras, and many studies report how time-consuming and labor intensive is gathering data from these videos (Barr et al., 2004), providing in the meantime low-quality reports.

On the contrary, driving a virtual car, simulated by computer graphics in a laboratory, significantly reduces the above difficulties, since tests are accomplished in a safe and controlled environment, where the risk of personal injury and property damage is eliminated. Moreover, it is more comfortable for researchers, which can get a higher amount of high quality data and carry out more controlled and repeatable tests, by presenting to different subjects the same scenarios. The main difficulty is to provide an adequate degree of realism in the virtual scenario, since car dynamics and activities in the subject's physical surroundings can be difficult to recreate realistically (Pirhonen et al., 2002). Thus, in order to ensure significant results of the tests, it is necessary to develop simulation environments which exhibit a high level of realism.

3 THE PROPOSED TEST-BED

The test-bed we proposed in (Costagliola, 2005) was aimed at presenting a realistic simulated driving environment to conduct indoor evaluations of VTS UIs, by providing subjects with credible feedbacks for their actions (e.g.: steering wheel shake when leaving the lane and going off-road), and sense of presence in the virtual environment, being in the meantime cost-effective both in terms of hardware and personnel resources. The test-bed is intended as an integrated framework, composed of three main facilities: a driving simulator running on a graphical workstation, a VTS, and some tools to analyze subject's behaviours, stored in a telemetry database.

In order to provide driving features, we customized an open-source car simulation engine, the *Racer* system (Van Gaal, 2000). We choose this engine thanks to its many advantages: it provides satisfactory dynamics of the virtual vehicle by using 6 Degree-Of-Freedom models and motion formulae from Society of Automotive Engineers, it is very flexible, since almost all simulation parameters are customizable through text files, there is enough documentation, it supports force-feedback devices, it provides high-quality OpenGL rendering, the tracks and the scenes are quite easy to create both by scratch or through many free user-friendly editors, and last but not least, it is free for non-commercial use.

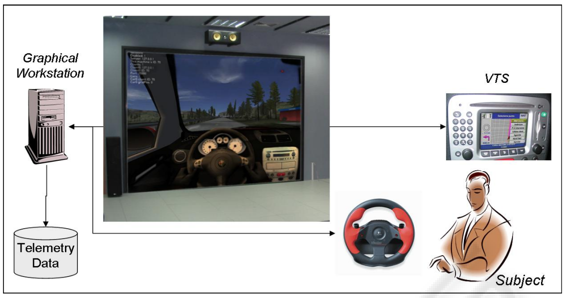

Figure 1: The test-bed Architecture.

Special care has been devoted to enhance the sense of presence of the subject in the virtual environment. Subjects sit on a car seat, interacting through a force-feedbacks steering wheel, able to return realistic haptic feedbacks to driving input, and two foot pedals. The simulated scenario is projected onto a wide-screen covering a significant subject's angle of view (>135°), while a 5.1 surround system provides a realistic spatial audio, as suggested by (Green, 2003).

To get data able to inform on driver distraction, the simulator was customized to offer some further features, such as the possibility to generate asynchronous external events to test driver's response times. For instance, to add meaningfulness to the simulation, other simulated cars were added on the track with their own (repeatable) behaviors. To recreate these situations, we exploited the *Racer* features related to the Artificial Intelligence (AI), allowing for a basilar simulation of traffic conditions, programming different vehicles to follow specific routes and behaviors on the track.

The simulation engine has been enriched and complemented by some tools we have developed specifically to address vehicular issues. The former tool, allowing for an integration of the VTS navigator module in the simulated environment, is described in the following.

3.1 Integration of the Navigator in the Simulated Environment

The first distinguishing feature offered by our framework is the integration between the simulation engine and the VTS navigator module. Currently, at best of our knowledge, evaluations of the navigation assistance subsystems can be performed exclusively on the field, since virtual tracks employed in simulations usually are not a counterpart of a real geographic area. Even if dealing with digital reconstructions of existing roads, driving simulators do not provide features for converting in real-time the spatial coordinates of the virtual car into real GPS ones. Hence the navigator has not knowledge about the virtual car position, resulting of no use in indoor evaluations.

To address this issue, we developed two subsystems: one responsible to generate a Racer track stating from a real cartography, and one able to translate the coordinates of the virtual car driven by the subjects, into a stream of bytes emulating a real GPS serial sensor sent to the VTS. As a result, the road virtually driven by the user on the simulator is shared as a map on the VTS. This permits to exploit, indoor, many standard navigation features, such as Map Display and Route Guidance. This integration is a powerful instrument, enabling to perform many significant tests. For instance, it allows researchers to evaluate different modalities (vocal, iconic, etc…) for providing routing assistance to the user, or the most appropriate vocabulary to support the way-finding, as well as to assess the cognitive work inducted by these different approaches.

In the following we will describe how we have developed this feature.

3.1.1 Sharing the Cartography

The Racer engine adopts a proprietary graphical format to represent tracks, named DOF1 and based on the SGI IFF file format. DOF1 exploits OpenGL XYZ coordinate system and contains all the information about the scene graph of the model. In particular, it holds data about the geometry objects composing the track, i.e. information about the vertices and the normals, together with other data, such as the texture used to render the surfaces.

It is worth pointing out that currently there exist two standard global cartographical databases adopted in the automotive domain: the Navteq and the TeleAtlas one. We focused on the former, thanks to the availability of a powerful SDK, useful to manage navigation system applications and to interact with the Navteq open format SDAL (SDAL, 1999) used for the map database.

In order to obtain a shared cartography, we developed a tool able to generate an appropriate DOF1 track file starting from an arbitrary sized rectangular area of a SDAL map. In particular, this translator generates the geometry primitives starting from the parcels that are the basic units of I/O used in the SDAL format. Figure 2 (left) shows a rectangular area of a SDAL map, while Figure 2 (right) illustrates the corresponding generated DOF1 track.

Another challenging issue was about road width, since SDAL does not contain such information. Instead, for each segment representing a section of a road, there is an associated attribute, the *Rank*, indicating its rating, based on characteristics such as speed limit, road type (e.g., interstate, highway) and access limitations. For instance, rank 0 represents the lowest one (local streets), while rank 4 represents the highest level (national arterial road network). Basing on this information we defined 10 kinds of road templates (two for each rank, to consider one or two-way roads), each one with its own geometries and textures to represent different number of lanes, presence of guard-rails, etc…

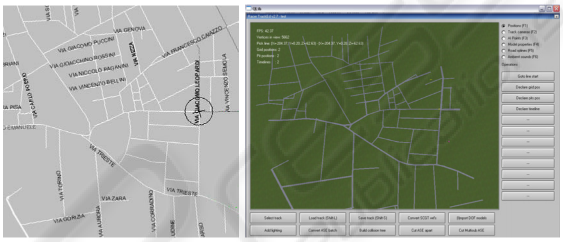

Figure 2: A real SDAL map (left), and the corresponding generated DOF1 one (right).

3.1.2 Updating the Localization

To address the second issue concerning with updating in real-time the position of the car on the map we have let the simulator to export information about the car movements and the navigator to accept this information as if it comes from GPS sensor. In particular, it was required to get information about coordinates, speed, and heading of the car. *Racer* engine is able to output this information, for various purposes (multiplayer, logs, etc…). Thus, we implemented a daemon able to catch this information and, after some elaboration, to send the necessary data on a serial port, emulating a real GPS sensor. In this way, every VTS (or even PDA) able to be connected to a GPS serial sensor can be linked to the simulation environment, providing real-time route guidance information.

4 DATA ANALYSIS

In order to assess a VTS UI, it is important to quantify the "safety degree" of the considered VTS. Nevertheless, safety cannot be directly measured (probably except in retrospect) (Tijerina, 2001). In the literature, several indirect measures of safety have been proposed based on the evaluation of the driver distraction inducted by the system (e.g. (Camp, 2000)). Let us recall that, when dealing with vehicles, two main kinds of distraction should be considered, namely the visual one and the cognitive one. Each of them leads to different problems: degraded vehicle control (resulting in problems in lane-keeping, speed maintenance, etc…), and degraded object/event detection (*looked-but-did-not-see*) (Brown, 1994), which is a more insidious to evaluate, since vehicle control remains largely unaffected but detection and reactions of unexpected object and event is degraded (Tijerina, 2001). Several indicators have been proposed to measure driver distraction during a test session. Among these, the most important are *speed maintaining*, *input smoothness*, *lane-keeping* (see Figure 3), *car following performance*, and *driver reaction times to asynchronous events* (Tijerina, 2001).

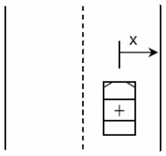

Figure 3: Distance to be measured for Lane-Keeping.

It is worth noting that the result of a VTS usability assessment is a set of *telemetry* data, i.e. a lot of numerical information, such as user input and vehicle dynamics, describing how the car and the driver behaved during the experiment. It is important to properly analyze this valuable amount of data in order to get information on subjects' distraction and highlight potential degraded vehicle controls or degraded object/event detection. Moreover, these telemetry data can allow researchers to infer how subjects' visual/cognitive workload is influenced when external factors are changed. For instance, it is possible to understand the consequences of exploiting different sensorial channels or different layouts for VTS graphical user interfaces, by comparing the gathered test datasets on the same subjects. In order to properly analyze these data, it is necessary provide analysts with suitable tools supporting them during information interpretation. To this aim, the proposed framework has been enhanced with a specific data analysis environment, detailed in the following.

4.1 The Telemetry Analyzer Tool

The Racer provides a built-in logging feature, which was customized to gather all the needed telemetry data. In particular, during a test running, each 250 milliseconds we sample the following parameters:

- Time
- User Input
    - Steering input
    - Force Feedback output
    - Throttle input
    - Brake input
- Vehicle Dynamics
    - yaw, pitch and roll
    - vx, vy and vz
    - ax, ay and az
    - x, y and z
    - Overall distance
- VTS I/O (if possible)
    - Key pressed on the VTS prototype
    - Asynchronous events generated by VTS

All these data are stored in a log ASCII file. Separate files are used to store other significant information, such as details on asynchronous events generated both by the simulator, (i.e.: AI controlled cars actions), and/or by the tester (i.e.: actions required to be achieved by the subject).The amount of data collected per session in this way can be really impressive. For instance, a 20 minute registration (a typical duration for a VTS test session) generates a data matrix with about 4800 rows and tens of thousand of cells. As a result, it is almost impossible to effectively analyze this huge but fundamental amount of data without a suited supporting tool. Neither standard analytics software products, such as *R*, *Statistica* or *Excel* can successfully address this issue, since it is very difficult for a researcher to understand the most significant distraction indicator, the lane-keeping (shown in Figure 3), without a graphical representation of the subject's followed trajectory overlapped to the testing track.

Thus, there is a strong needing for a supporting tool, able to graphically visualize the fundamental parameters describing subjects' behaviours. To answer this issue, we developed an integrated application, named *Telemetry Analyzer Tool*, whose main objective was to visually render the driver-vehicle performances during the whole test session. In particular, the tool graphically presents both the temporal/spatial relationships among data (that usually are difficult to understand in a textual way), both the main subjects' actions together with other numerical information, such as speed, time, and overall distance.

In the following the main features of the tool and its user interface are detailed.

4.1.1 Main Features of the Developed Tool

The tool offers three main features. Firstly, it visually present all subject's input, time by time. To control the timeline of the logged data, the tool provides some widgets, recalling an interface of a Video Recorder, allowing a researcher to gain a deep insight on subject's behaviours, through the whole test session.

Secondly, it provides a visual representation of the trajectory followed by the subject, overlapping the map of the track. To evidence driving errors, whenever the trajectory followed by the vehicle's centre of gravity comes within less than 50 cm of the left/right edge of the lane, it is represented in red colour (or in a different shape) for the specific frame.

Thirdly, it provides some comprehensive report on the test session, such as the percentage of time spent too near or too far from the central line, etc…

The resulting user interface is shown in Figure 4.

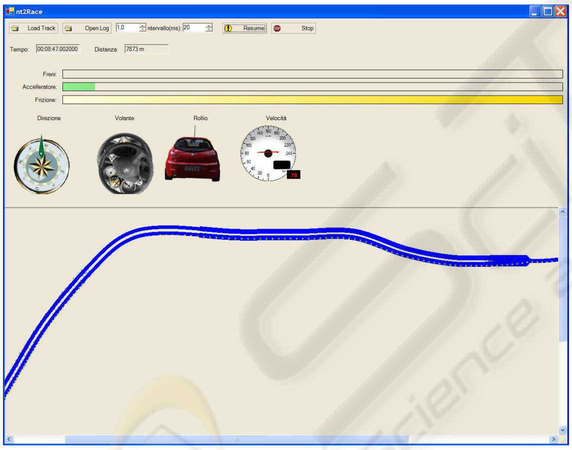

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Figure 4: The Telemetry Analyzer Tool GUI.

As depicted, it is possible to notice that the UI is divided in three horizontal zones:

- The uppermost contains the widgets suited to load track and log files and to manage the timeline through some controls recalling a VCR. Through these controls it is possible to select a specific frame t_i, a time-interval t_i-t_j, or to playback the entire test session t_0-t_n. It also possible to change the time scale, to accelerate or slow down the playback, as well as to move frame-by-frame.
- The central section is aimed at dynamically present visual information about user behaviours, for the current frame t_i. Once selected an instant of time t_i, or for each frame during the playback, it renders the status of all user input at t_i. In particular, driver input on brake and throttle are rendered through some histograms, while the steering wheel angle is presented both visually and numerically. This section provides also information about main parameters on vehicle dynamics, such as heading, speed, and roll, useful to evaluate overall input smoothness.
- Finally, a lower section shows a top view of the track, with the trajectory held by the subject in the current frame/interval. This section also encompasses widgets suited to control zoom, pan, and rotation of the track.

About numerical reports, the tool is able to invoke the Microsoft Excel DCOM control to generate graphs of the collected data, on a number of different parameters. Some examples of generated scatter plots are visible in Figures 4 and 5.

5 ASSESSING THE PROPOSED TEST-BED

As stated in section 2, the potential problem with an indoor simulator is the lack of realism. To this aim, we conducted a preliminary study to validate the effectiveness of the simulator in measuring real driving performances, by involving a group of sixteen external subjects. To gain insight on the realism of the framework, we applied methodologies proposed in other simulators' assessments (e.g. (Lee, 2002), ()). In the following we provide the details on the assessment.

5.1 The Subjects

Sixteen volunteers (11 males, 5 females) were involved in the study. Age of the subjects varied between 24 and 42 years (mean 31.6). All participants have a valid driving licence, a good corrected visual acuity, and years of driving experience ranged from three to 21 (mean of 10.4). Annual mileage was between 2,400 and 25,000 (mean of 8,250). We asked them also details on typical driven roads, mean number of hours spent in driving per week, and if they usually play at driving computer games. Four subjects stated that they spent over 1 hour each week playing computer games that involved driving (racing). Two subjects reported no previous experiences with driving games. The other participants reported to play computer games only occasionally.

5.2 Methodology

The experiment consisted of three driving sessions, gradually increasing in difficulty. Whenever a sufficient level of proficiency was rated, subject move the next step. After completing the driving tasks, subjects received a questionnaire, to express their impressions on the simulator.

During the first session of the experiment, we tested elementary driving skills, such as steering, acceleration and braking control. Subjects were instructed to drive on a simple and flat track, composed of many straights, and few, easy turns, maintaining a stable speed of 60 km/h, if possible. Just before a curve, they were asked to reduce speed, to enable a smoother turning.

The second session of the experiment was based on a more complex track, representing a hill road, with turns, tunnels, climbs and descents hills, harder turns, and other cars. Again, we asked subjects to maintain a steady speed of 80 Km/h, and to never pass 100 Km/h, a harder task due to the specific characteristics of the track.

In the third session, subjects were asked to perform some secondary tasks on a VTS, while concurrently continuing to perform the primary driving task. The track was easier than the previous one. Subjects had to respect the signals, to keep a mean speed of about 80 Km/h, if compatible with track properties and speed limits, and to never pass 100 Km/h.

Approximately each session took 20 minutes per subject. The selected test tracks were intended as closed circuits, and each subject was asked to drive for three laps, to better understand improvements in vehicle controls.

Obviously, during each session we logged all the parameters described in Section 4.

5.3 Results

We observed that the simulator has a smooth learning curve. Subjects familiarized very quickly with the simulator, reaching adequate performance after 15-20 minutes of training. In particular, after some initial hesitations due to the different steering response, subjects were able to profitably drive the vehicle, maintaining constant speed and being able to correctly keep the lane. Moreover, these behaviours were achieved through smooth input.

A graphical representation of such improvements is given in Figure 5 and Figure 6. Such figures plot the speed hold by Subjects 2 and 5, respectively, in the same section of the track, on the three different laps during session 2. We selected for the graph a segment where the road descents, turn right and then climbs. Thus it is very demanding to maintain constant speed, and in particular to not overpass the 100 km/h. Looking at graphs, it is possible to notice that in the first lap (the blue line), subjects were not able to smoothly maintain the speed. Indeed, the line presents steps, and, in case of S5, it varies from 30 to 95 Km/h. Lap 2 (the purple line) and 3 (yellow line) were smoother, indicating enhancements in driving performances.

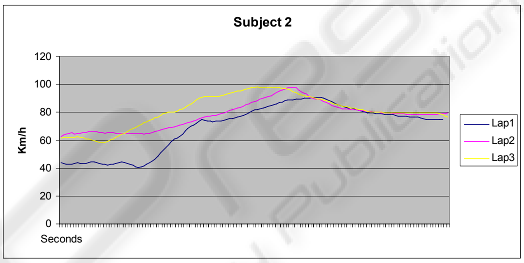

Figure 5: Subject 2 driving behaviour.

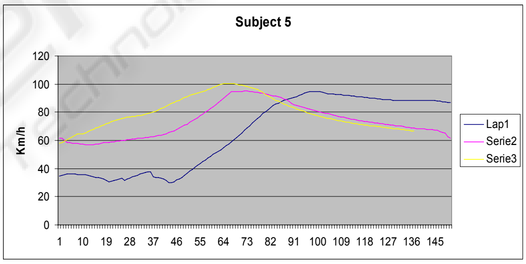

Figure 6: Subject 5 driving behaviour.

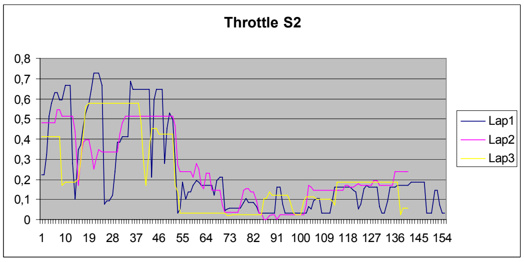

Figure 7: Subject 2 throttle behaviour.

Similarly, in Figure 7 it is possible to appreciate improvements in the throttle control, through the various laps. Once completed the driving sessions, subjects filled in a questionnaire, to express their impressions on the simulator. About results, in mean, subjects felt the simulator enough realistic

(6.57, in a ramp 0..10), even if more stressing and a little more difficult than real driving.

However, some concerns come from the steering wheel, which resulted too much direct in its action, being different from the real one. This is due to the economical input device, which is more game-oriented. Indeed, its excursion is limited to about 200° from full left deflection to full right deflection. In real car this value is comprised from 360° and 720°. We are currently searching for more realistic steering wheels. Telemetry data analysis and survey result are omitted for sake of brevity, but are available upon request.

6 CONCLUSIONS AND FUTURE WORK

Safety on the roads is one of the main goals for everyone involved in the automotive field. The advent of VTSs can distract user from the main task of driving the car, with potentially fatal effects. Nevertheless, it has been estimated that these systems will become commonplace in the last few years. Thus, it is a short term priority to investigate solutions to enhance usability of VTSs and then limit driver distraction. Nevertheless, the evaluation of UIs for automotive systems is a challenging and expensive task, requiring specific methodologies and tools. To address this issue, we realized a framework specifically conceived for the indoor evaluation of VTSs usability. In this paper we reported on some improvements we developed, aimed at enhancing the effectiveness of that test-bed. In particular, we developed some instruments to offer the possibility to assess also the navigation assistance provided by VTS in the indoor facilities, thanks to the automatic generation of realistic simulator tracks starting from a VTS cartography.

Moreover, to support researchers in an easy collection of valuable information on driver's behaviors (and thus on his/her mental workload), we developed a specifically suited application, aimed at providing a graphical representation of the main driving parameters and subject behaviors. Finally, we validated the framework in measuring on-road driving performances, by employing a set of sixteen subjects, with positive results.

About future work, we are working to add further realism to the generated scenario, in order to recreate the surrounding environment, since SDAL contains further information about the kind of area (country, national park, urban, etc…). For instance, for urban zones, we are working to generate scenarios with buildings, semaphores, etc…

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