In-Vehicle Virtual Traffic Lights

a Graphical User Interface

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Abstract—**Traffic control through an adequate location of devices can improve traffic flow and reduce collisions. Today's technology is capable of virtually conveying to the driver information that is traditionally displayed through traffic signs on the road. Relying on this technology we propose a novel approach to regulate traffic through the ubiquitous optimized management of individual intersections replacing the physical devices by Virtual Traffic Lights. We virtually prompt the driver with information related to traffic control and evaluate the user interface system with respect to safety and user acceptance to identify possible negative effects on the primary driving task. Results are promising since the driving performance using Virtual Traffic Lights did not significantly differ from the performance using conventional devices.**

Keywords: Virtual Traffic Lights; Traffic Control; User Interfaces

I. INTRODUCTION

Today, Intelligent Transportation Systems (ITS) technologies are capable of duplicating the information displayed on static traffic signs [1]. In-Vehicle displays can provide the driver with more complete information than a single visual glance. Since driver's awareness of the surrounding environment results mainly through visual means, the driving information is recognized by the driver, potential problem situations are then identified and actions are subsequently executed to avoid accidents [2]. This paper addresses the challenge of conveying virtual traffic information to the driver of a vehicle in a manner which does not compromise driving safety i.e. in an intuitive and unobtrusive manner. We propose a particular setup, which is evaluated in a simulated environment: namely display the driver with an In-Vehicle visual presentation of the information that is conveyed regularly by traffic control devices located on the road. The idea is to replace the physical devices by Virtual Traffic Lights (VTLs) that are displayed inside the vehicle and supported by V2V communication [3]. Traffic control through an adequate placement of traffic lights can reduce delay for road side traffic and moderate thus the occurrence of collisions [4]. This novel approach to regulate traffic intends to improve traffic flow through the ubiquitous optimized management of individual intersections enabling thus the creation of a traffic light depending on the need. We explore the driver's reactions when confronted with a novel Human Machine Interface (HMI) to display Virtual Traffic Lights. We evaluate the system to identify possible negative effects of the VTLs on the primary driving task. The remainder of this paper is organized as follows. In the next section we revise related work in the areas of road design and Human Machine Interfaces in a vehicular context. Section III gives an overview about traffic control devices. Section IV presents a detailed description of the methodology used to collect relevant data to evaluate the Human Machine Interface for the VTLs and section V reports on the evaluation of the system, using a driving simulation environment. Finally, Section VI concludes the paper.

II. RELATED WORK

The number of traffic signs detection and recognition systems based in computer vision has increased in the last years [5]. Emerging technologies make it possible to duplicate on displays within the vehicle, the same information displayed on traffic signs [6]. Some adaptive traffic light systems based on wireless communication between vehicles and controller nodes at intersections have already been proposed in [7, 8]. Relying on the replacement of the physical traffic lights by the ubiquitous optimized management of individual intersections we propose a novel approach to present the driver with the information that is conventionally presented through physical traffic lights.

It has been shown in several works that the interaction with In-Vehicle systems might increase the driver's workload. In this case the driver usually reacts making the primary driving task as easy as possible and adapting his driving behavior to a safe state, e.g. driving slower [9], [10]. Recent research about the design of road elements has been compiled based on established practices in [11]. Some of these elements of design depend on the driving speed and are for instance the intersection sight distance or length of the roadway ahead that allows the driver to be aware of a potential conflictive situation as is the case of an intersection. According to [12] to be effective, traffic control devices should adhere to design, placement, operation, maintenance and uniformity aspects. The features of device's standard designs should be modified only if there is an evidence of need since it has been shown that attempts to change the current standard representation of traffic lights have failed over time. For example, a vertical bar for go, a horizontal line for stop and a diagonal line for caution have not been socially accepted [13]. Therefore guidelines, which provide advice on how interfaces should be designed, have to be followed to ensure a good interaction with the VTL system. A variety of organizations have developed standards and regulations to design In-Vehicle user interfaces.

In this context, special attention has to be given to safety and usability focusing on users and tasks, design improvement to reach the desired result and final test. Getting detailed statistical data on the systems the users have previously used is the base for a simple, intuitive design [14], [15].

Additionally a performance improvement can be reached affecting the user behavior through a user-centered design and thus reducing user error [16]. Further design guidelines for safety in In-Vehicle information systems were compiled in [17]. For example visual information that requires an immediate response by the driver should be displayed in a prominent place [18]. The recommended location for a visual display should be close to the driver's line of sight, within 15 ° of the driver's vertical and horizontal viewing position respectively separated by a maximum of 30 ° [19]. Our system's implementation adheres to the current design principles for In-Vehicle information systems and presents the driver with an intuitive user interface for traffic control that replaces the traditional traffic lights.

III. TRAFFIC CONTROL DEVICES

Below we state the main characteristics of the design elements of conventional traffic lights in terms of the aspects mentioned in [12].

A. Physical Traffic Lights Characteristics

- Design: The design components size, shape, color, composition, lighting and contrast provide a clear and simple message that is easy to understand.
- Placement and Operation: An adequate visibility is ensured placing the devices within the field of view of the road users. An adequate signal placement depending on the traffic control need provides a good legibility that allows the road user a good response time.
- Maintenance and Uniformity: Functional maintenance determines proper functioning, legibility and visibility. Uniformity of devices implies message recognition and understanding. Consequently it involves a reaction time reduction and supports the manufacture, installation and maintenance efficiency.
- Color Code: The usual color code to display traffic lights uses green to signalize that a movement is permitted. Orange is used for temporary traffic control, red for stopping or prohibition and yellow means warning.
- Mounting: Traffic lights have to be positioned so that they are visible to drivers. They can be located on street corners, hung over the roadway, etc. outside the roadside border area.
- Signal Timing: Vehicles are detected at traffic lights and this information is used to determine priority and traffic light phase duration. The intersection control performance depends on detection system and signal control settings. The factors that determine these settings are the geometry of the intersection, the traffic volume and the vehicle speed.

B. Virtual Traffic Lights

The main challenge of virtually representing traffic lights is to reflect the characteristics of the conventional traffic lights and make the transition to a new visualization process as smooth as possible. A good interface design complies with specific design requirements. In a driving environment, special attention has to be given to safety and usability. As a consequence of it, the interface has to be simple and easy to use without interfering with the primary driving task. This means that the time to recognize the displayed information has to be as short as possible. Additionally the information conveyed by the Human Machine Interface has to reflect the outside real world traffic conditions: a good visibility needs to be ensured with a good luminance contrast of the displayed information, brightness and contrast. In addition the use of sun glasses or weather conditions (e.g. bright sun) need to be taken into account as well as the best possible location of the user interface.

Since the very first traffic light installation people had to go a long way to get used to the traffic lights and to obey them. The transition of physical traffic lights to Virtual Traffic Lights has to follow a slow process that gives the driver the chance to progressively adapt to the new concept. Below we state the main characteristics of the virtual representation of the traffic lights.

- Design: We used a Head Up Display (HUD) to project the virtual object on the vehicle's windshield. Since a small amount of information has to be conveyed, this representation way is ideal to display the few elements required in the specific situations. The images used in the projections correspond to a real road environment and displayed signs representing traffic lights ahead, arrows and traffic lights. Since we use unfamiliar symbols a text label showing the distance to the intersection completes the information provided to the driver according to the specifications in [17].
- Placement and Operation: Following the specifications in [17] we projected the Virtual Traffic Lights information 2.5 to 4 meters away from the driver's eyes in his lateral field of view. This avoids a road vision obstruction that can result from the projection in the central field of view.
- Maintenance and Uniformity: Due to the electronic nature of the system's implementation to display the VTLs, the maintenance is similar to the other electronic components in the vehicle. In addition, the installation of the sensors and the V2V communications enables a similar functioning of all the traffic lights virtually displayed.
- Color Code: Luminance contrast requirements were followed to ensure that there was no visual interference with the road traffic environment and that the projected images were visible in all weather conditions.

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- Symbols used: The VTLs should be functional in situations where an adequate stopping sight distance at the intersection is not available. This is the case that applies when physical infrastructures that are visible to the driver as a reference point are nonexistent. Therefore, the VTL approach displays a traffic light ahead warning sign (Fig. 3, A1, B1) so that the driver has information about an approaching intersection. Through the windshield projection of the traffic lights, the driver is able to see at every moment the traffic light's state. This characteristic makes our approach unique, since it prevents situations where the field of view of traffic lights mounted on the road can be obstructed by objects. The distance of placement of signal ahead signs are determined by the vehicle speed, the legibility distance, and the vehicle's maneuvers time [12]. In Portugal this distance varies between 300 and 150 meters [20]. According to this, a traffic light ahead sign was displayed on the windshield at a distance of 200 m before the intersection.

- Signal Timing: Our VTL system assures an effective response to changes in traffic conditions through a robust detection system. The traffic light phase awareness allows in addition warning the driver if a traffic violation occurs. Each vehicle maintains an internal database with information about intersections where a virtual traffic light can be created. When approaching such intersections, if a VTL message is detected, the current state of the VTLs is presented to the driver through the In-Vehicle display. Our detection system bases on beaconing and location tables features of VANET geographical routing protocols, such as Geocast [21]. When vehicles are approaching intersections and do not detect VTLs' messages, they consult their location tables and the road map topology to infer crossing conflicts that will give rise to the collaborative creation of a VTL. We assume lane-level accuracy on the location tables and a common digital road map that also has lane-level information of topology.

C. Driving Performance Metrics

In our work we determined the most relevant metrics to identify possible negative effects of our user interface for Virtual Traffic Lights in the driving performance. These metrics are applicable in the scenario where the traffic lights are more frequently used, namely, an urban scenario that demands interactions with other road users. Since the scenario influences the selection of one or another metric and our environment implies driving interruptions it does not allow for much flexibility when using performance metrics. Thus, the most commonly used metrics in driving performance studies are speed metrics that determine the speed reducing effects of traffic signs in road intersections. As a result speed variation and brake activity are the most applicable metrics in our scenario. The speed variation determines the variation of speed in a situation that requires the driver to adapt the vehicle's velocity to new road circumstances such as the existence of a traffic sign or intersection. The brake activity determines the driving performance in situations where the driver has to respond quickly to a road circumstance. The simulator conditions of our test allow us to define and represent an accurate event that will cause the desired braking reaction, namely to switch the traffic light to red. In our experiment we use identical onset events for different subjects. The metric is a straightforward metric of driving performance on a regulating or monitoring level [22].

IV. METHODOLOGY

To evaluate the driving performance we first defined the events that cause a variation in the speed applying them in the same way for each participant.

The experiment consisted on driving through a predefined path without secondary tasks in a medium to high traffic density without critical events. We logged the indicators that caused variation in the scenario such as a red traffic light, and the speed and distance to intersection. We calculated the brake activity through the deceleration change rate by measuring the speed and calculating the change in deceleration. Additionally we collected driving performance data and subjective ratings through a post task questionnaire. The collected data length was the same for all the participants and it allowed comparing every point overlapping similar speed data sections and determining differences in the speed variation.

A. Procedure and experimental setup

The participants were given a short explanation about the experiment procedure and purpose and were indicated to drive as usual respecting traffic laws. During a training session with no data logged, each participant drove one lap through the circuit stopping or driving according to the traffic lights. After this familiarization with the simulation tool, the participants were asked to drive through the predefined path that consisted of a total of 2874, 6 m. In the early stage test phase different user interface design approaches were compared. The participants in this phase drove once using a user interface and once using a different one. In the summative evaluation phase we used two scenarios, one without physical traffic lights to test the VTLs approach and one with regular traffic lights. To make sure that the physical traffic lights in our scenario complied with standard regulations, they were located so that they were visible to the driver from a distance of 80 meters at a speed of 50 km/h and a distance of 35 meters at a speed of 20 km/h. according to the intersection sight distance tables computed values from the exhibit 9-67 in [11].

The speed limits in our urban scenario were 50 km/h. Accordingly, the stopping sight distances were 65 meters. The participants in this evaluation tested both approaches. Finally the participants were asked to fill in an online post task questionnaire coupled with a database, asking for demographic information and subjective rates.

Circuit: Fig. 1 shows the circuit used for the simulation and a partial view of the 3D scenario without vehicles and the path to follow in the experiments.

The vehicles included in the scenario were cars and trucks of different sizes. The velocities of the cars in our urban scenario varied from 20 to 70 km/h. A speedometer showed the speed of the car's participant. The scenario consisted of one road in the shape of an eight with a range of two to three lanes and had one intersection (A). The lanes were distributed as follows: a) At the north part of the intersection, two lanes heading south (one to go straight and turn right and one to turn left) and one heading north. b) At the south part of the intersection, two lanes heading north (one to go straight and turn right and one to turn left) and one heading south. c) At the east part of the intersection, two lanes heading west (one to go straight and turn right and one to turn left) and one heading west. d) At the west part of the intersection, two lanes heading east (one to go straight and turn right and one to turn left) and one heading west. The scenarios road signs and markings were designed according to the rules from the Portuguese Road Infrastructure Institute INIR. In particular we considered the norms for road marks according to the dimensional characteristics and criteria of use and placement and the norms for vertical signaling and its characteristics and placement criteria [23]. To compare the driving performance with the VTL an additional scenario with physical traffic lights was used. We located them 2.5 meters high counted from the ground to the lower limit and 5 meters high when placed over the road.

Equipment: The simulation platform we used for our tests consisted of a real vehicle cabin with projector visualization. It integrated a VANET simulator and an In-Vehicle driving simulator for a realistic driving feeling and provided a driver centric perspective of VANET-enabled applications [24]. Realistic graphics that represented roads, signs, traffic lights, and traffic completed the graphical interface. The simulation platform permitted to test the utility of Dedicated Short-Range Communications-based systems such as the Virtual Traffic Lights and the communication capabilities between the simulated vehicles. In addition the simulator was able to render potential damage, and offered the possibility to change the cars and the scenario. Fig. 2 illustrates the general experimental setup.

B. *Early Stage Tests*

To improve the human–centered design of the VTLs user interface, we performed a formative evaluation early in the design process. In this phase we compared different design solutions in the simulator framework. We then re-designed the first virtual prototype based on the evaluation's results of subjective rates. Sample: Six persons (3 male, 3 female, average age class 27-35) where asked to participate in tests to compare two system designs. The designed user interface to display Virtual Traffic Lights consisted of graphical components that were projected on the windshield of the vehicle through a head up display (Fig. 3):

A) 1) A graphical sign indicating traffic light ahead that is displayed with its correspondent distance label (200 meters) before arriving to the intersection. Alternatively the driver was shown a different sign indicating intersection ahead (Fig 4). 2) A sign consisting of green or red colored arrows that reflects the same behavior than a conventional traffic light indicating the driving priority of the driver and vehicles in the vicinity. The image is displayed in a range from 150 until 0 meters before the intersection and its size depends on the distance to the intersection. B) 1) Sign indicating traffic light ahead with distance label as before and sign indicating intersection ahead. 2) Sign consisting of green or red colored arrows that indicates the driving priority of the driver and vehicles in the vicinity from a range between 150 until 50 meters before the intersection. The image size increases or diminishes depending on the distance to the intersection. This image intends to provide the driver with awareness about the driving priority in the environment. 3) A sign representing a conventional traffic light that displays green or red and is displayed in a range from 50 until 0 meters before the intersection adapting its size to it. Fig. 5 shows the projection from inside the simulator.

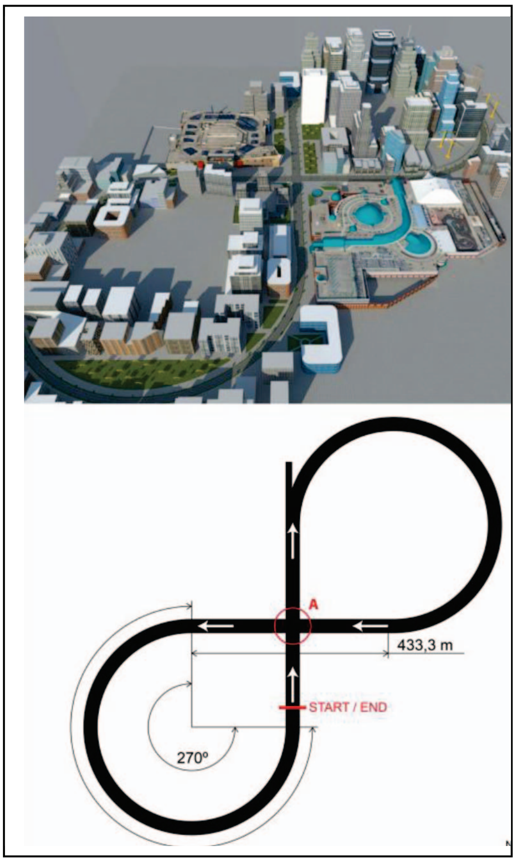

Figure 1. Driving scenario used for the evaluation of the HMI for virtually representing traffic lights in the car: the figure at the top shows a 3D view of the whole scenario; the figure at the bottom gives an overview of the circuit used to perform the tests.

Figure 2. General experimental setup to perform the evaluation of the VTLs.

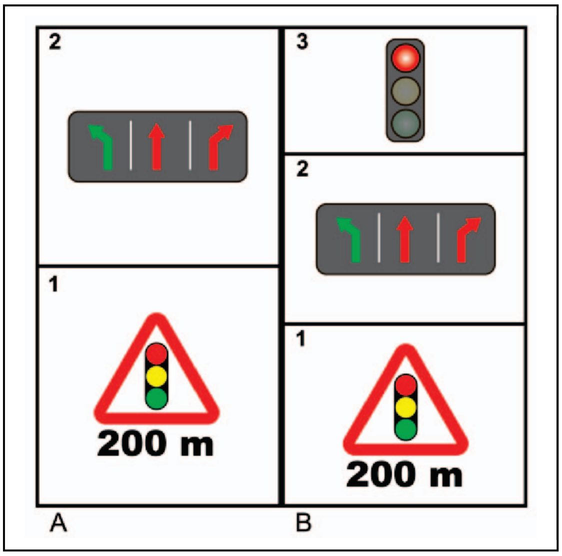

Figure 3. Images projected on the driver's windshield corresponding to two different user interfaces design solutions. A) The image represents the interface through the traffic light ahead sign and driving priority through green or red colored arrows. B) The image indicates the traffic light ahead, driving priority and driving permission through a traffic light image.

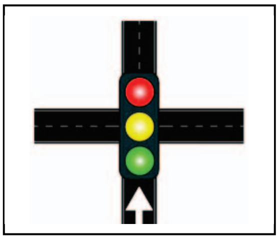

Figure 4. Image representing an intersection ahead.

C. Summative Evaluation of the HMI for the VTLs

To identify interaction problems and user friendliness we performed an evaluation of the HMI design according to the specified system requirements from Section I. We evaluated the final prototype as a whole with respect to safety and user acceptance and quantified the safety-reducing effects on the driving performance through the speed variation relative to the posted or projected traffic lights. The same time window was used in the comparison of the VTLs' solution with the one based on physical traffic lights. To measure the driving performance, we logged the speed data points to get the speed variation and brake performance. Additionally we recorded the traffic light state. The data was automatic evaluated after a filtering process and under a previous manual control.

Figure 5. In-Vehicle view of the VTL image projected on the windshield.

Every participant in the experiments performed the tests twice, once with the VTL and once with the physical traffic lights, thus the groups were related to each other and our samples were dependent. To find out whether the use of one or other system had an effect on the brake activity of the driver, we applied the T-Test for dependent samples and compared the actual difference in means between the VTL and the traditional traffic lights groups on the deceleration rate. To ensure a representative sample for the experiment we selected 10 participants (5 male, 5 female, average age 35) with a driver experience between 6 and 10 years. Every person ran two laps through the circuit with the VTLs and two with the physical traffic lights logging a total of data related to eight traffic lights for each person.

V. PRELIMINARY EVALUATION RESULTS

The data resulting from the early stage tests helped to improve the human-centered design of the VTLs user interface since 100% of the participants agreed that the first design used to indicate intersection ahead was not intuitive enough (Fig. 4).

Based on this feedback we redesigned the interface and prompted the participants with the images A1 and B1 from Fig. 3. Further tests with these both approaches indicated that B reflected the idea of a traffic light in a more intuitive way. This was confirmed by the percentage of participants (83%) that considered the design in B to be simpler and easier to understand than the design in A. Nevertheless none of the designs were considered dangerous or unsafe by anyone. 90% of the participants classified the information presented by the user interface for Virtual Traffic Lights as clear and intuitive and they did not find the system distracting or unsafe. However they admitted that having been previously familiarized with the system helped them to better identify the information provided. 55% of the participants considered the Virtual Traffic Lights at least as safe as the conventional set of traffic lights.

As for the brake activity the deceleration change rates differed slightly when using the Virtual Traffic Lights (0.0914) and when using the physical traffic lights (0.0626). However this difference in regard to the brake activity was not significant ($t(9)=1.615$, $p=0.141$).

Regarding the speed variation metrics, no differences could be determined in the performance with one or the other system. As expected a high data variation regarding the speed could be observed depending on the participant. For example, Fig. 6 shows the decrease in the speed in a red traffic light situation for two participants with the virtual traffic light system and the conventional traffic light representation at a distance from the intersection less than 25 meters.

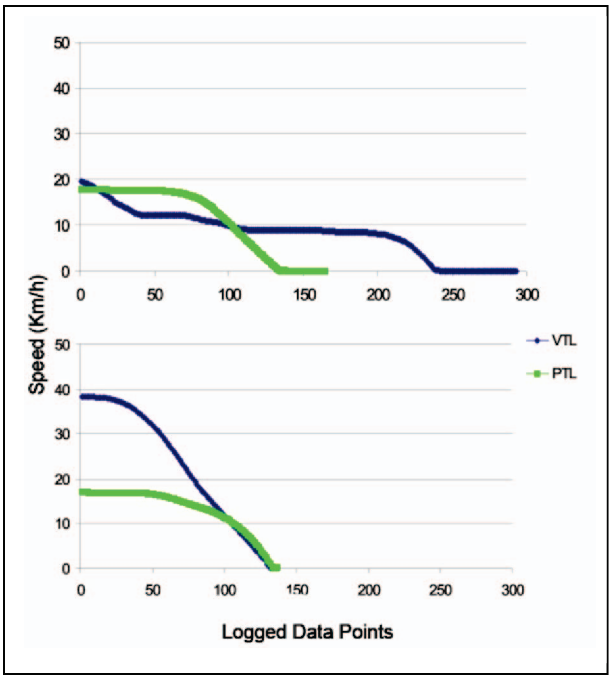

Figure 6. Speed variation depending on the traffic control device. The graphic illustrates the data corresponding to two drivers.

VI. CONCLUSION AND FUTURE WORK

We presented in this paper a novel Human Machine Interface to virtually prompt the driver with information related to traffic control. Even if the acceptance of a new traffic light concept and representation is challenging, the participants in our tests recognized and followed the instructions given by the symbols used in our interface. The driving performance within the virtual scenario did not significantly differed from the driving performance locating physical traffic lights on it. However, since a slight higher tendency in the deceleration change rate could be detected when using the VTL, further tests with more probands are required. Additional data would allow performing tests where a high number of participants is required, i.e. testing for equivalence, e.g. trying to prove that the two systems, with VTL and PTL are essentially equivalent, and that any difference is of no practical consequence. Additional steps related to the optimization of this system need to be conducted to ensure the required degree of safety that regular traffic control devices convey. Our results indicated that the chosen metrics to measure the driving performance with the final prototype as a whole with respect to safety and user acceptance were appropriate to provide data that could be interpreted in further testing phases and were consistent with the driving scenario and experimental design.

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