HMI to exploit the potential of Distributed Computing in Sensor Systems

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***Abstract* — The complexity of in-vehicle interaction systems is constantly growing. However, thanks to the increased availability of sensing systems in the driving environment and communication infrastructure able to radically change the interaction modalities at driving, the existing situation is likely to progressively turn into a cooperative scenario, in which the vehicle and the driver share tasks at perceptual, decisional and control level. This paper describes an innovative human-machine interaction paradigm developed in the SAFE STRIP project to exploit the potential of C-ITS to implement new mobility paradigms, to turn the traditional vehicle perspective into a more efficient traffic perspective. In order to achieve this challenging objective, the overall HMI strategy has been re-designed, to foster the adoption of a new, more active role of the driver and the other road users. The preliminary prototypes developed in the SAFE STRIP project are also described in this paper.**

Keywords — Human-Machine Interface, Negotiation-based interaction, C-ITS, Connected vehicles, Cooperative interaction

I. INTRODUCTION

The in-vehicle interaction domain is radically changing in the last years. New relevant trends include the progressive automation, the electrification and the proliferation of complex and sophisticated infotainment systems. Among these trends, connectivity through smart infrastructures seems to be a promising tendency to increase the safety and the comfort, with a relevant impact on cost-reduction, including development and maintenance costs. This process is also known as C-ITS, i.e. Cooperative Intelligent Transport Systems.

As stated by Proskawetz [1] modern vehicles, equipped with driver assistance systems, "can feel (by sensors), see (by cameras) and – in future – speak (by communication systems)". This future, in which the communication between vehicles and humans improves to the point of becoming smooth and natural, now appears closer and closer. The new technology of cooperative Intelligent Transport Systems and Services (C-ITS) enables communication between vehicles and traffic infrastructure. It is based on the principle that cooperative parties (ITS stations, i.e. in vehicles, road side units) exchange information among each other in terms of standardized message sets. The receiving ITS station analyses the incoming data and makes use of them, resulting in a self-organization principle at local level.

Human-machine interfaces (HMI) for this kind of systems should ensure a safe operation of the vehicle, taking into account the human capabilities. When C-ITS services warn a driver of a dangerous situation, the information provided should be limited to the minimum necessary for understanding and taking adequate action in the available timeframe [2]. C-ITS messages should not distract the driver, especially when managing an emergency manouver. The timing of alerts is furthermore essential and should be adapted to the emergency situation. They should be provided early enough for the driver to be able to react properly. For emergency cases, the C-ITS message should provide the driver with only the information on his/her expected behavior. The interaction between human and machine should be designed in such a way that any licensed driver is able to effectively and safely use the C-ITS services. As a consequence of this, as stated by EU commission final report in September 2017 "HMI for safety-critical situations should be consistent across all vehicles, including pictograms' form, color and positions, auditory warning sounds, and haptic warnings". At this stage, however, standardization is not yet at a significant level.

II. RELATED WORKS

Traditionally, safety-critical in-vehicle information is based on warnings used to alert the driver, informing him/her to properly react to an unexpected event [3].

However, the use of warnings in a mobility context includes a certain number of ergonomic issues, e.g. workload and distraction [4], intelligibility of each warning to understand the correct action to be performed in a short time, combination of contemporary warnings (with different severities) provided by co-existing applications [5]. The warning-based interaction paradigm involves a real-time driver-vehicle communication, acting on the imminent request of reaction by the human user. This implies a focus on the effectiveness of communication and efficiency in terms of reaction times [6].

In recent years, new promising approaches are spreading to improve the interaction between drivers and vehicles. Among them, a relevant role has been assumed by the HMI displayed on nomadic devices: the availability of fast and reliable wireless communication systems (e.g. Bluetooth, 4G and preliminary examples of 5G networks) has allowed the development of interaction systems displaced on devices other than the traditional vehicle equipment. Several examples include the use of smartphones as additional screens for infotainment and driving-related contents [7].

Moreover, in a Cooperative Intelligent Transport System (C-ITS) framework, where the vehicles are connected to each other and/or with the infrastructure and share data (e.g. position and speed of all vehicles), the number of unexpected events is drastically reduced or even set to zero [8]. In a fully connected scenario, a warning-based HMI strategy should be replaced with a more sophisticated HMI strategy [9] able to exploit the potential of C-ITS.

III. SAFE STRIP PROJECT

In the context of C-ITS, SAFE STRIP aims at boosting cooperative system applications in the road environment through a revolutionary idea: to offer their functionality through low-cost micro/nano sensor communities embedded in road elements (in road pavement tapes/markers), thus not requiring costly sensors or infrastructural elements.

Data collected is processed to a high-level perception system, suited for ITS applications. Relevant applications (as described below) aim to:

- Embed static info (i.e. enhanced map data, speed limit, curvature, asphalt characteristics, etc.) to be transmitted to the vehicle, that are programmed after deployment and reprogrammed when the use of the road changes or during road works.
- Receive dynamic info (i.e. TMC messages), process and transmit them to the passing vehicles, to be offered to the driver/rider in a personalised manner.
- Measure dynamic environmental parameters (like temperature, humidity, water, ice, oil, smoke) and accurately estimate each vehicle's friction coefficient (through road sensors data fusion with vehicles' intelligent tyres' info).
- Sense passing vehicles, including non-equipped ones, measure the transit time, speed and lateral position in the lane, provide basic classification of the vehicle type and, thus, offer key road load & circulation data to the TMC.
- Sense pedestrian crossings, work zones, railway crossings and other critical areas and warn the driver/rider well ahead of them.
- Enable high accuracy and low-cost automatic parking/tolling/insurance policies.
- Define and manage lane-level virtual corridors for automated driving.

SAFE STRIP system has been implementing two complementary as well as alternative solutions, one to address equipped vehicles (namely, intelligent vehicles with on board sensors and C-ITS or automation applications) and one to address non-equipped vehicles (the great majority of current vehicle fleets, including also vehicles that are very difficult to equip with rich on-board sensorial platforms, like PTW's).

The solution for equipped vehicles relies on the direct communication of strip data to the vehicle. This has been enabled through the communication of the so-called On Road Unit (ORU) and the On-Vehicle Unit (OVU) by means of the IEEE802.11p enabled microcontroller (and communication module).

The ORU includes all hardware systems that are installed on the road/strip and are necessary for acquiring data from the sensors and for transmitting data to the passing vehicles. It consists of the following elements:

- The on-road sensors (e.g. humidity, ambient light detector, temperature, etc.), which are wired on a micro-controller capable of interfacing with the road sensors, e.g. through a GPIO hardware interface.
- The communication module that supports the IEEE 802.11p protocol. It has been deployed as a SoC (system-on-chip) solution, equipped with the appropriate communication module, or one connected to the previous micro-controller through a proper hardware interface (e.g. UART), enabling their direct communication. The micro-controller sends the data it receives from its interconnected sensors through the communication module to a paired SoC installed on the vehicle

The OVU is based on an automotive embedded computer and it is connected to 802.11p and LTE communication unit enabling data exchange with other vehicles or infrastructure.

This solution also presupposes the use of Road Side Bridges (RSBs) for the communication between the ORUs and the existing LTE cellular infrastructure.

The solution for non-equipped vehicles and PTW's relies on vehicular networking with the LTE-enabled On-Board-Units (OBUs) or smartphones, which exploits the already existing LTE cellular infrastructure to communicate over the wireless medium. RSBs are present in this solution as well, for the communication between the ORUs and the existing LTE cellular infrastructure.

The vast potential of SAFE STRIP will be demonstrated through applications for:

1. Cooperative safety functions for enhanced ADAS/ARAS equipped and non-equipped vehicles,
2. Road wear level and predictive road maintenance,
3. Road work zones and railway crossings warnings,
4. Merging/intersection support,

5. Personalised VMS'/VDS' and Traffic Centre Information,
6. Dynamic trajectory estimation and interface to automated vehicles
7. Supportive added value services (such as Virtual Toll Collection and Parking booking and charging).

These are among the most challenging applications, ranging from C-ITS to autonomous vehicle ones. They do not cover all potential SAFE STRIP enabled applications, but they prove that SAFE STRIP is flexible, cost-effective, C-ITS compatible and able to support most of the ITS present and future applications.

As a consequence, SAFE STRIP is particularly relevant to demonstrate the ability of an innovative HMI paradigm to exploit the potential the aforementioned ITS applications.

IV. Design of HMI for C-ITS

The design of a new HMI paradigm for C-ITS should take into considerations 3 relevant challenges.

A. Distributed architecture

First of all, the architecture of the HMI modules should reflect the distributed architecture of the overall system, based on standard publish-subscribe-based messaging protocol (e.g. a Message Queuing Telemetry Transport - MQTT) that is designed for connections with remote locations where a small code footprint is required or the network bandwidth is limited.

This architecture has an impact on the HMI, that should be split into 3 logic modules:

1. A cloud-based module for the implementation of the HMI strategy
2. A set of distributed device-based modules to display the HMI strategy on different devices (e.g. smartphones, wearable devices, etc.)
3. A prioritization module to select the information to be displayed on the HMI in case different applications co-exist in the same scenario.

All types of modules (i.e. HMI strategy and mobile applications) are expected to communicate continuously and to always be connected to the MQTT broker.

B. Negotiation-based upon warning-based strategy

The second characteristic of this innovative HMI is that it should not be based on warnings to alert the driver in case of unexpected events, but it should allow the drivers to easily negotiate the access to common resources (e.g. an intersection, a roundabout, etc.). This approach goes beyond the traditional in-vehicle warning-based strategy, but it entails the design of a new communication strategy. The success of these strategies relies less on extraordinary intelligence and more on sophisticated negotiation of changing context and subsequent behaviour [8].

The negotiation-based does not substitute the warning-based strategy, but it is built upon it to support the driver to take the right decision (and perform the right manoeuvre) instead of alerting him/her in case a collision is likely to occur.

C. Ubiquitous HMI

The third element to be taken into consideration for the design of this innovative HMI for C-ITS is the ability to be seamlessly displayed on heterogenous devices. In fact, since it is based on data collected from different remote sensors, the overall interaction strategy should be adapted to address the needs of different road users (e.g. pedestrians, cyclists, motorcyclists, drivers, etc..) that are expected to be provided with different devices to access it (e.g. instrument cluster, aftermarket displays, smartphone, smartwatch and wearable devices, etc..).

V. HMI in the SAFE STRIP project

Since it covers several challenging applications, ranging from C-ITS to autonomous vehicles, SAFE STRIP is particularly relevant to demonstrate the ability of an innovative HMI paradigm to exploit the potential of present and future ITS applications.

The approach described in section IV has been applied for the design of the HMI for all applications described in section III.

A. Distributed architecture

For all applications, the architecture represented in Fig. 1 has been considered, based on an MQTT broker for the communication among all modules.

All entities (RSB, co-driver, applications, DSS, HMI strategy and mobile app) are considered by the system as a software module. The software modules communicate with each other only via MQTT protocol.

In addition to the RSB and the applications (cloud side) already described in section III, the architecture includes a co-driver for the implementation of the intelligence of all safety-critical applications, e.g. the merging/intersection support.

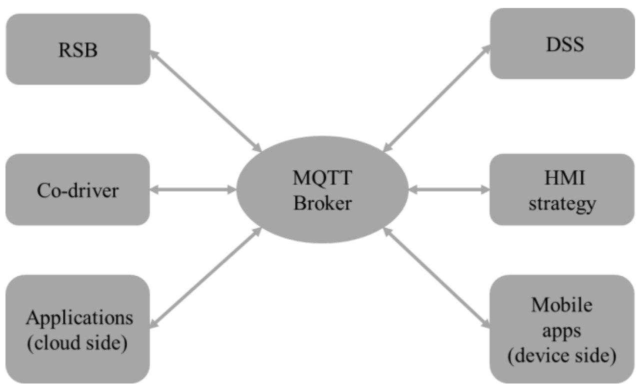


Fig. 1. Logical architecture for the end-user application (on mobile app)

By applying the guidelines described in section IV, 3 key elements have been considered for the implementation of the HMI:

1. A cloud-based module for the implementation of the HMI strategy
2. A mobile app for iOS and Android smartphones
3. A Decision Support System (DSS) to prioritize co-existing applications.

The following sequence describes the steps for each run:

1. RSB, co-driver and applications upload real-time data (based on infrastructure, vehicle and sensor data) to specific topics of the MQTT broker
2. The DSS, that has subscribed to those topics, prioritizes the application to be displayed and updates the corresponding topic of the MQTT broker
3. The HMI strategy module, that has subscribed to that topic, applies the strategy only for that application, and in turn updates the MQTT broker
4. The mobile app, that has subscribed to the topic updated by the HMI, shows the graphical layout corresponding to the received value.

B. Negotiation-based upon warning-based strategy

C-ITS has the potential to implement new mobility paradigms, to turn the traditional vehicle perspective into a more efficient traffic perspective. In order to achieve this challenging objective, the overall HMI strategy should be re-designed as well, to foster the adoption of a new role of the driver and the other road users. They are not passive and risk-prone elements of the traffic, but they should have an active role to facilitate the traffic flows.

As described in section IV, the HMI strategy designed in SAFE STRIP applies 2 different (and complementary) approaches:

- Warning-based approach: for critical information, i.e. pop-up warnings to inform the driver that a collision is likely to occur.
- Negotiation-based approach: for situations in which the vehicle and the driver/rider negotiate a resource.

In this new perspective, the HMI has a twofold role:

1) To facilitate the negotiation process to access a common resource (e.g. to enter an intersection, a roundabout, etc.)

2) To provide the right information to the driver to increase trust and acceptance, and (in the long term) overcome the unavoidable resistance of the market against the introduction of innovative systems.

Moreover, to deal with the existing promiscuous traffic scenarios (with equipped and non-equipped vehicles, as well manual and partially automated vehicles), the negotiation-based strategy in SAFE STRIP has been designed upon a traditional warning-based strategy, to allow for a seamless switch to the latter if a risk of collision is imminent due to an unexpected event, not detected and considered by the overall C-ITS.

Therefore, the HMI developed in SAFE STRIP includes a traditional warning-based strategy as well as an innovative negotiation-based strategy to timely support the drivers by recommending the right action to access a common resource.

For example, the system negotiates with the other vehicles (according to their speed, position, etc.) and the infrastructure (according to environment constraints, such as limited road visibility and traffic) the first available time slot and the HMI suggests the most appropriate moment to start the manoeuvre.

To avoid increasing the cognitive workload of the driver, the graphical layout has been designed to provide only the information that is necessary to support the driver:

1. Brief explanation of the situation the driver is requested to deal with (from now on also called "WHY")
2. Representation of the most appropriate action to be undertaken (from now on, also called "WHAT").

The negotiation-based strategy creates a dialogue between the driver and the vehicle, to increase the Situation Awareness and foster the adoption of the correct behaviour suggested by the system.

C. Ubiquitous HMI

The HMI module of SAFE STRIP aims at exploiting the sensing and communication system connected to the infrastructure to advice the users, enhancing safety and efficiency. Since the intelligence is decentralized (i.e. it is outside the vehicle) the Human-Machine Interaction strategies can be potentially applied to all the vehicles in the traffic scenario. Moreover, by distributing the sensors and the intelligence of the system, and elaborating the strategy on the cloud, the HMI can be also deployed on any nomadic devices (instrument cluster on the vehicle, smartphone, wearable devices, etc..). As a consequence, the potential of the HMI relies less on the computational capacity of the devices and more on their low-latency connection.

In SAFE STRIP a distinction has been done, according to the availability of on-board communication and visualization systems, between equipped and non-equipped vehicles: for equipped vehicles the HMI is integrated into existing embedded displays, while for non-equipped vehicles and PTW's, the HMI is displayed into a mobile app for iOS or Android smartphones.

Warning and recommendations are issued by the HMI strategy module according to the prioritization of the DSS (that relies on fusion of infrastructure, tyre and vehicle data, whenever available), and a personalization mechanism is applied (by the DSS) to tailor the information to the real needs of each road user and the target device he/she is using.

In this way, all vehicles can benefit from the SAFE STRIP system, i.e.:

- Equipped vehicles are able to integrate the SAFE STRIP info into their own perception system, to enhance their functions or coordinate their decisions with the infrastructure. In addition, they are able to share their own on-board perception (they can even share the driver's intentions as estimated by the intelligent system, which can greatly improve the cooperation of autonomous/semi-autonomous vehicles) and intended manoeuvre with the perception provided by SAFE STRIP, to spot possible missed objects or inaccurate descriptions and thus enhance the robustness of the system.

- Non-equipped vehicles (including PTW's) can implement basic driver assistance systems through SAFE STRIP interface. They only need aftermarket devices (e.g. smartphones) that connect to SAFE STRIP. This allows the non-equipped vehicles to benefit from several C-ITS functions without integrating any new system. The advantage is twofold: C-ITS applications can be deployed sooner (without waiting for a complete vehicle fleet's replacement) and address a much broader fraction of vehicles (including those that are difficult to equip, e.g. PTW).

VI. HMI PROTOTYPING

In SAFE STRIP project, an iterative design and validation path has been adopted. This activity has foreseen a "human-in-the-loop" approach, in order to involve the users from the very preliminary design phases. The involvement of the users happened both for design and validation phase: to validate the HMI, in fact, we developed simulation scenarios based on the communication of the elements in the driving environment. The overall system was simulated in order to have driving scenarios in which the applications could exploit the potential of the distributed sensing system.

At the moment, two experiments using driving simulators and one using a riding simulator have been performed with simulated scenarios based on the use cases that will be used in the project's pilots. This allowed to have the possibility of testing a "close-to-real" scenario from the very beginning, long before the transfer of the system on real roads.

The HMI design process started with the definition of an HMI strategy, aimed at defining the modality in which each information should be provided, in terms of sensory channel (e.g. visual, audio), device (i.e. existing screen for equipped vehicles, smartphone for non-equipped vehicles) and urgency. For this last point, an incremental audio and visual strategy based on colour intensity and audio frequency, has been implemented.

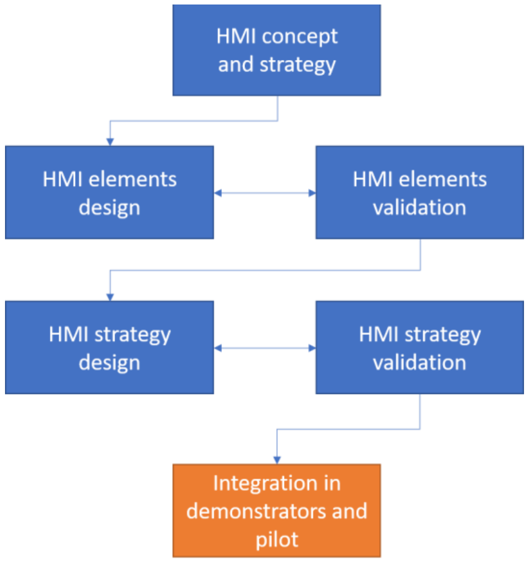


Fig. 1 HMI design process in SAFE STRIP

Moreover, a first version of the visualization on the smartphone has been prototyped; as stated before, it is based on two informative levels, i.e.

- what is the reason of the warning/information
- what the driver should do

This application will be included as part of the overall SAFE STRIP architecture: it will communicate with the MQTT broker, receiving data from the sensors and the application, in order to warn the driver according to the situation and its criticality.

Fig. 2. HMI mobile application early prototype

The most innovative interaction designed in this project is the information related to the co-driver developed in SAFE STRIP. It is a system able to suggest the most effective behaviour to ensure a safe and comfortable driving.

For the co-driver, we designed three different solutions to be tested in simulated context. The three representations are designed to express the message (i.e. to decelerate and reach a given speed) in different ways: in this sense, the aim of the test will also be to select, besides the most appropriate HMI element (in terms of likeliness and easiness of comprehension), the most effective solution to negotiate a behaviour.

The first prototype, an analogue representation (Fig. 4), visualizes the actual behaviour the driver should have in order to reach the optimal deceleration. In fact, it shows the feet and its movement on the pedal, in order to explain "when" and "how much" the driver should brake to reach the optimal speed.

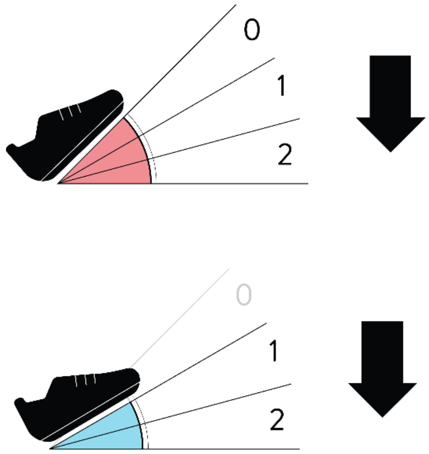
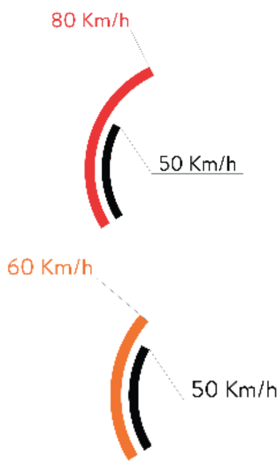


Fig. 2. Negotiation-based HMI approach 1

The second prototype compares in real-time the instant speed with the ideal speed to be maintained by the driver. This visualization strategy does not use an analogue metaphor, while it is based on the use of a well-known interaction mode, i.e. the speedometer, even if the car speed cannot be considered as a natural behavior for human drivers.



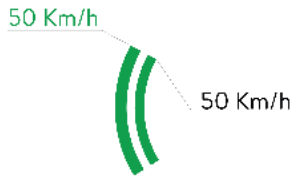


Fig. 3. Negotiation-based HMI approach 2

The third representation is a fused modality between the previous ones. It is based on the concept of exploiting an analog metaphor, through a dynamic element showing the expected speed decrease, and the explanation given by the current and target speed.

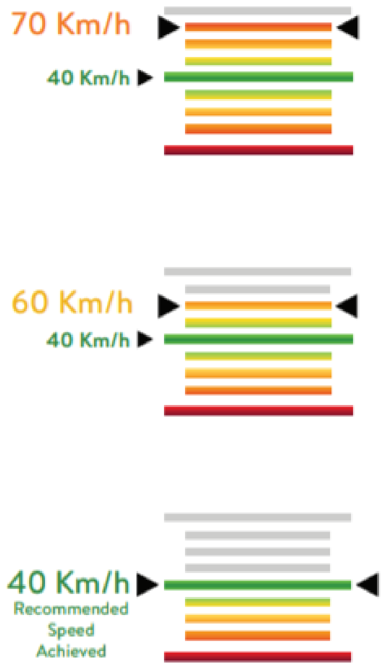


Fig. 4. Negotiation-based HMI approach 3

VII. Conclusions and Future Works

This paper presented an innovative interaction concept developed in the SAFE STRIP project, based on a negotiation-based approach. This approach aims at exploiting the potentiality provided by the distributed sensing system to improve the driver-vehicle cooperation, e.g. by negotiating the time slot and cooperating in performing manoeuvres.

At the moment, a preliminary test to select the most appropriate HMI elements has been performed. This experiment has been performed at driving simulator, in RE:Lab, Fraunhofer IAO and CERTH/HIT premises. The elements, i.e. the audios and the icons used to warn the drivers/riders and to suggest the most appropriate behavior will be integrated into the mobile application and embedded systems.

Next steps will foresee the iterative validation of this interaction approach, in order to measure, at driving simulators and with a significant user sample, the effectiveness of this overall interaction modality, evaluating also the impact on users' workload and acceptance.

Moreover, several tests will be performed to evaluate what kind of communication, based on analogue metaphors or request of deceleration through target speed, can be considered as the most effective to lead the driver to a safer driving behaviour.

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