Document submitted to the congress:

17th ITS World Congress. (Busan, 25-29 October 2010). Bélgica: ERTICO, 2010. pp. 1-12. Source of the document http://www.ertico.com/

SPECIFICATION AND DEVELOPMENT OF A HMI FOR ADAS, BASED IN USABILITY AND ACCESSIBILITY PRINCIPLES

José E. Naranjo[1*], F. Jiménez[2], F. García[3], J.M. Armingol[3], J. Zato[1], A. Quero[1]
[1]Universidad Politécnica de Madrid. E.U. de Informática
Carretera de Valencia, km.7, 28031 Madrid. Spain.
Telephone: +34 91 301 30 29. E-mail: joseeugenio.naranjo@upm.es
[2]Universidad Politécnica de Madrid. INSIA
Carretera de Valencia, km.7, 28031 Madrid. Spain.
[3]Universidad Carlos III de Madrid. Laboratorio de Sistemas Inteligentes
Avda. De La Universidad 30, 28911 Leganés (Madrid). Spain.

ABSTRACT

Traditionally, the design of road vehicle HMI is based in esthetic principles, maintaining it as an attractive factor for possible clients when buying a car. Only recently, ergonomic benefits have been applied to the design of HMIs, mainly following institutional impulses like the European Union one, but whose contribution is not clearly stated nowadays in commercial products. In this paper we present a study of the design of a HMI, based in usability and accessibility premises, centering the design in the user, as method to improve safety, making natural the communication with the driver as well as being able of transmitting information to the driver, from basic to the generated by ADAS installed in the car. Following these specifications a set of prototypes have been designed in order to develop a testbed that could be evaluated for a large set of drivers.

INTRODUCTION

We can define the human driving as a complex control task of a mobile mechanism over continuous change, with a parallel execution of a large set of subtasks. However a human does not require special capacities for driving a vehicle. This is mainly caused by the information that is acquired by human senses, provided by the environment, actuators and on-vehicle information systems. Additionally, processing and manipulation human limitations must be taken into account when designing the vehicle and the circulation environment in order to allow a safe and efficient management.

If we analyze the human driving task such an artificial control system, we can define three different activity levels: control level, tactic level and strategic level [1]. The first level implies to maintain the vehicle in a defined trajectory (accelerating, braking, moving steering,…). The second level includes the execution of complex maneuvers (yield, overtaking, safety headway,…) and the strategic level is the conscious planning of the route to track. Additionally, the complexity of each one of these levels varies, being to maintain the car in a lane less complex (less brain processing) than to plan an alternative route. There also exists a temporal difference among the three levels; control level actions duration is about milliseconds, the tactical level one is about seconds and the duration of strategic level actions is much higher.

On the other hand, the human driver has limited its processing capacity and a time penalty appears during the execution of the different subtasks related to driving, when driver switch from one to other [2]. This fragmenting of the attention causes actuation delays over determined situations like, for example, the preceding car braking perception or the impossibility of a stable safety headway [3].

These facts means that the information required to execute actions in these three levels should be different and should be received by the driver in different ways in order to improve safety and efficiency, and consequently, have to be taken into account when designing the new generation of HMI. Additionally, the anticipation of information to the driver can clearly reduce the loss of time produced when some tasks are executed in parallel.

The application of usability and accessibility and user centered design principles can provide information to the driver in a natural way, improving the efficiency of the new ADAS generation.

VISUAL INPUT

It is well known that the visual input is the main information source for the human driver in order to anticipate his actions when is driving a vehicle.

This fact should be considered incomplete today since the application of ITS technologies, able of provide the driver of information about future situations, far away of his visual horizon. However, it is clear that the visual input provides the driver information about:

- Environment features
- Relative position in time and space
- Circulation speed
- Circulation direction
- Time to contact with a circulation situation.

It is important to take into account that this information is acquired by the driver by watching though the windscreen of the car. Extra information source, including the driving console, additional consoles or any other visual media, should be considered secondary. This extra data must be totally controlled and the transmission media must be selected carefully in order not to distract the driver of his main task, the driving, which must consume the majority of his

visual resources. Consequently, it is necessary that the presentation of the information to the driver in the way that it requires the minimum degree of resources.
From the three possible information entrances, sight, hearing and tact, we will center, in this paper, in visual information, which must receive the vehicle information as less intrusively as possible and with the minor interference.
Nowadays, the technological solution broadly used to transmit to the driver visual data is the Head Up Display (HUD), that presents this information on a screen or the windscreen of the car in the driver sight direction. This way, the driver never needs to turn aside the sight from the road.
However, the design of the presented information in the HUD is not a trivial problem. An incorrect information presentation may cause the distraction of the driver or the ignoring of the presented information when driving. This is a classical HMI problem when it presents complex information.
First studies about installing HUD in road vehicles and the best way of presenting relevant information was held at the end of 80s and the beginning of 90s, as part of the European Project PROMETHEUS [4]. Additionally, there exists a series of recommendations for the design of the HMI presented information in road vehicles at European level [5]. These recommendations are a priority defined in i2010 Intelligent Vehicle Initiative. There also exists a working group under the European Initiative eSafety (eSafety – HMI Working Group) that has recently finished its activities with the publication of a final report with recommendations for the design for this kind of systems.

DESIGN PRINCIPLES FOR HMI DESIGN

We can define usability as the perception of a target user of the effectiveness (fit for purpose) and efficiency (work or time required to use) of the interface. This discipline is derived from the psychology and ergonomics and deeply focused to computer science. However nowadays, the design of HMIs is a process that is based in computer technology, even to be applied to any field, in our case, the automotive. Some standards in the area have been developed like, for example [6] , that are used as the basis of our work. One important part of usability is the accessibility, defined as the degree to which a product (e.g., device, service, environment) is accessible by as many people as possible, including disables and elderly people.
Following these disciplines, we have applied computer science usability concepts to HMI design of road vehicles in order to develop a set of prototypes that improve safety and sustainability in transport.
It is clear that any concurrent task can interfere with the monitoring and processing of the main driver task, this is, to safely maintain the vehicle in the road and to complete the desired route. Additive, cognitive or motor subtasks (lightning a cigarette of speaking through cellular) may cause interferences with the primary driving task. However, some of these

interferences are unavoidable, for example, the road stimulus. Other interferences like the ones that provide additional on-vehicle information can be avoidable but the caused perturbation is less than the added benefit. Speed or RPM dials, GPS navigators, safe headway warnings or passive driving assistances are nowadays considered as indispensable. This is the reason why these secondary stimulus generated by the vehicle must not be removed but adapted in order to cause the minimum interference in the driving task. In consequence, it is critically important to focus two premises in the human machine interfaces design: learning capability and efficiency, this is usability.

We have defined five fundamental principles to be followed in the design of vehicles HMIs:

- Do not disturb. The system must increase (or at least must not reduce) the circulation safety. It must avoid producing potentially dangerous behaviors for the drivers or any other road actor.
- The attention required to the driver when he is interacting with the HMI must be compatible with the attention demanded by the driving task. Both tasks must be compatibilized in order to avoid distractions or to reduce the driving focus. We need to foresee the necessary attention that will demand the secondary tasks in HMI interacting.
- The HMI must not to visually disturb the driver. It must be concrete and precise. It is important to guarantee the minimum distraction of the driver when receiving and using the information provided by the HMI.
- The content of the information must not incite the driver to adopt a behavior that may increase the risk of accident.
- The interface must be coherent and compatible. The coherence affect to the aspect of the design with elements like colors, icons, sounds that allow the equilibrium between similarity and differentiation of the presented information.

INFORMATION PRESENTATION

Visual information must be designed in order to the driver were able of assume the information a quick as possible and without negative effects over driving. For example, if the driver obtains information through an image, the maximum delay in receiving and interpreting the message must be lower than one second.

Nowadays, almost all GPS navigators do not comply with this aspect, since they generate very detailed graphics that force the driver to maintain an intense and prolonged attention, for example in identifying a mobile objective in a map.

In order to make easy the probability of an easy understanding of the information, international standards in legibility, audibility and signal must be followed (for example, standard traffic signals instead of proprietary signals). Additionally, presented information must be precise and shown in the right moment to help the driver to correctly face off the situation. For example, the instructions of a navigation system for one maneuver cannot be presented after the maneuver execution. These instructions have to be presented to the driver in that way that the driver could evaluate the kind of maneuver and whether he can execute it. In this sense, it is important to determine priorities in the message set showed to the driver. Then, messages like "Imminent Collision" must appear with preference than other messages like "Incoming Call".

INTERACTION PRINCIPLES

The main interaction principle is that the driver never has to hand off the steering wheel to manage the HMI. This device should be placed as nearest as possible to the driver but without blocking his line of sight. At the same time, this HMI must be safely placed in the way that the driver needs not to hang it to manage.

Similarly, it is not adequate that the system demands a prolonged interaction to perform a task. In this sense, it is highly recommended that the actions can be performed in several steps. Then, if we are inserting data, the system must allow to stop the operation and to continue later. Likewise it is important to avoid timeouts to interact with the system since this requirement should center in the HMI excessive attention by the driver. This interaction also depends of the design of the controls of the vehicle. These controls must allow managing the HMI with a minimum interference in driving. For example, if the controls are installed on the steering wheel, their management must not disturb its management in driving. At the same time, the feedback returned to the driver must be quick clearly perceptible. If the system requires a significant amount of time to execute its task, it is important to inform the driver about the processing in order to avoid unnecessary distractions and system overacts.

LOCATION OF HMI IN VEHICLES

Two main premises are defined about HMI location in vehicles: on one hand, the system must show the information to the driver in the best way. On the other hand, the device must not obstruct the line of sight of the driver. At the same time, it must not hide controls and indicators of the vehicle. In any case, one unique HMI should integrate all the information panels of the vehicle in order not to disperse the driver attention.

However, it is recommended to install the HMI near driver's line of sight of the road in that way that, without obstacle his vision, no sight deviation is necessary to acquire HMI information.

About the behavior of the system, it is important to disable the HMI interaction functions when the vehicle is moving in order to prevent distracting behaviors of the driver. It is also important that the system indicate the vehicle status in real time as well as fails directly related to safety messages.

METHODOLOGY

The specification and development of a HMI for ADAS, based in usability and accessibility principles is based in the application of a set of methodologies that allow carrying out a right implementation. These techniques are based in software HMI design using usability methods but applied to automotive field. Three stages form this process (figure 1):

- Necessities definition
- Design
- Design evaluation

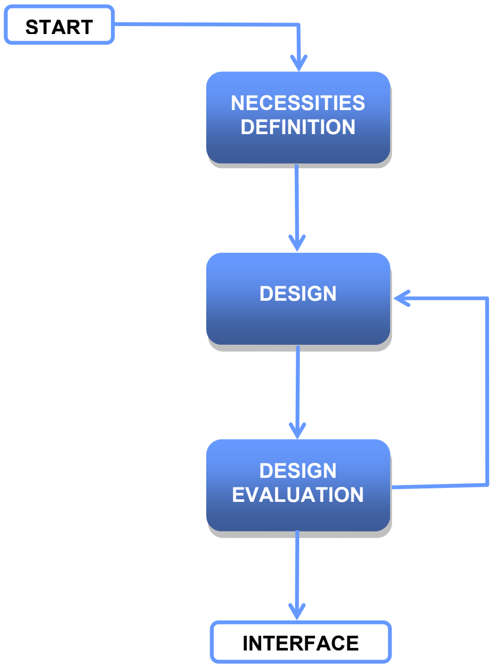

Figure 1. Design methodology sequence.

The first stage consists on the definition of the mission of the software and the recommended features. To do that, it is necessary to clearly identify the objective users of the HMI. In our case and following the user analysis of [7], under the premises of "design for all", including every kind of drivers, including disabled persons.

Following this, the designed HMI follows four fundamental principles (figure 2):

- Equitable use: is the equity in the use of the system. The aim is to obtain the best equitability among every user that will manage the application. This way discrimination is avoided in any user collective.
- Flexibility of use: Adaptation of the interface to the circumstances around the user, the environment and the right use of the application.
- Simple and intuitive use: The design of the interface must be of easy understanding, with independence to the user experience. If the HMI is easy and intuitive, the learning time is considerably reduced.

- Perceptible information: The interface must effectively communicate the information, taking into account environmental conditions and sensorial capacities of the user. The HMI must represent the information in several ways in order to a user that cannot perceive in one way could receive it through another.

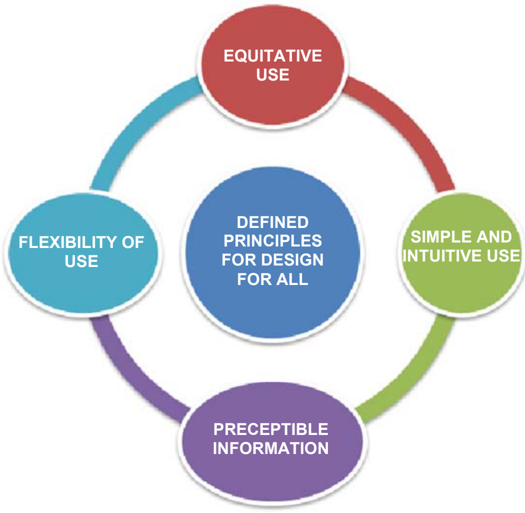

Figure 2. Main principles applied to design

COLOR ANALYSIS

Color is a powerful tool for improving the functionality of a human-interaction system. Inversely, an inappropriate use of color may reduce seriously the communication functionalities [8]. Color is the main component of HMIs, and its correct use may help to improve the memory capacities of the users as well as the mental model building.

Some principles have been used for the HMI specification: the use of the color quickly communicate to the user facts and ideas. However, more than six simultaneous colors may promote confusion since they all claim for the attention of the user. Other applied design principle is the clarity. The search time to locate an information piece is lower as its color is anticipatively known and if only is applied to this information.

Another important feature to be taken into account is the contrast of colors. For example, a B&W color schema increase the process information time efficiency and increase the memory performance. In consequence, we have selected a B&W background color pattern because its contrast properties and the light absorption. Additionally, the interface have been designed following a color code that motivates the user and that assures that does not require previous training, because the driver faces off color association previously known in other mental process like, for example, the warning messages are shown in red.

INTERFACE DESIGN

Two fundamental aspects have been used in the interface design stage, additionally to the previously mentioned:

- The physical media.
- Emotional design based concept.

DISPLAY

In order to develop a fast prototype of HMI, we have selected as display physical media a 7" Xenarc 705 LCD tactile monitor. This display allows an easy integration in automotives environment and can directly receive VGA signal from a computer. Other displays like windscreen projectors have been initially discarded because its difficulty of connection and integration in a standard testbed vehicle.

The tactile feature of the selected display enable the development of user friendly interfaces, being nowadays of more common use, comfortable and of easy use.

This display also equips speakers that allow emitting voice warnings without necessity of other device.

The designed interface uses the full screen to focus the user attention, with a resolution of 1024x768 pixel that make easy the message reading and the image visualization.

EMOTIONAL DESIGN

Recent researches establish that the attractiveness perception cause secondary effects like better performance and easiness sensation [9]. When a person uses a system, our sensations on its management is determined, not only for a correct performance but for its perceptible aspect.

In our design of HMI, our aim is to create an interface aesthetically agreeable and friendly that causes in the user a positive sensation from the first use.

FINAL USERS

We focus this research in the development of a HMI interface based in usability and accessibility, following the premise of design for all. In a first stage maybe appear that only one interface will solve the necessity of the numerous collectives that drive a car. However, after a deep analysis on different collectives [7] we have concluded that, although the information presented should be the same in any case, a specific adaptation for several collectives will increase the efficiency and safety of the HMI. This possibility is possible thank to the usage of a LCD display as HMI physic support that allow the representation of a highly adapted interface.

Then, we can define four kind of user, the application targets that will make use of the developed HMI. These users are: general drivers (default), disabled drivers, elderly drivers, and young (novel) drivers. This classification has been made basing in two concepts. On one hand, these groups are clearly separable, with different skills and on the other; they are the groups with more possibilities to suffer an accident, providing more benefit for them the use of ADAS as well as adapted HMI systems.

- General drivers: is the default group and includes drivers with experience and with their sensorial and cognitive faculties perfectly operatives. They can receive an important amount of information since they are able of perceiving it faster and more concise that other group. However, the definition of a message priority is necessary in order not to saturate the driver.
- Disabled drivers: This interface design tries to surpass barriers that found drivers with visual or hearing deficiencies.
- Elderly drivers: This group may have sensorial limitations, similarly to disabled drivers but their main lack is the cognitive limitation caused for the age, that generates problems for centering the attention as well as for make some tasks at the same time. In this collective, the presented information must be clear and simple and must be recognized quickly. The interface must not saturate the users since their capacity to process the presented information is lower than in other groups.
- Young (novel) drivers: They are the collective that commit the most of the recklessness. Consequently, it is a priority to show them the necessary information to avoid the surpassing of speed limits or driving over alcohol effects [10].

PRESENTED INFORMATION

The information shown in the HMI is divided in two groups in a simple and clear way. On one hand, the interface shows the information related to the vehicle dynamics: speed, temperature, RPM, oil and fuel.

On the other hand, it is shown information generated by ADAS installed in the testbed vehicle: collision warning, lane departure, pedestrian warning, speed limit surpassed.

In the design of the presentation of this information we have taken into account the learning and management easiness, following some standard design and icons that classical vehicle HMI equips and that the users usually manage. This way, the icons that signal the danger situations appear shadowed in the screen and only illuminate when they are active. This is the classical behavior that a driver expects when he manages a car. It is also important that the icons are in the same place of the display because, although the driver does not watch directly to the screen, thank to the peripheral vision and the position and color of the icon, the user can determine the driver situation. In this sense, each risk situation icon has associated a graphic clearly different one to other. Additionally, a message in the screen is also shown in risk situation, hiding non-critical information in order to increase the safety.

There are two additional alerts included in the HMI: Excessively long driving period that alerts the driver if he maintains driving for more than two hours, indicating the necessity of resting. And finally, as part of a project on sustainability research, we have included a programmable warning for excessive RPM that indicated the best moment to change the gear following a map of fuel consumption.

IMPLEMENTATION AND RESULTS

The HMI implementation has been performed using C++ under the operative system Windows XP. The software runs in a dedicated computer that receive all the information that need to show in the display from multiple computers installed in the car and that send the information through TCP/IP sockets.

Four different HMI have been implemented in order to optimally inform the four collectives studied in the previous sections.

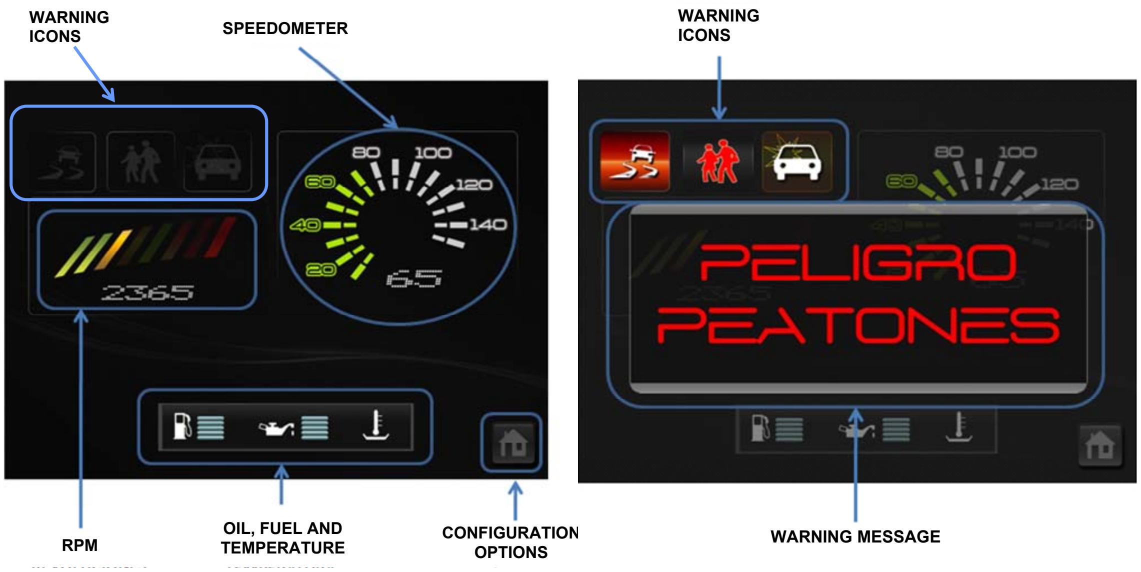

Figure 3. HMI design for default drivers.

Figure 3 shows the aspect of the interface for default drivers, with analog and digital speedometer placed in the right of the image, designed in order to maintain the aspect of classical displays. The RPM are shown in the left of the image, with the numerical value and a color bar that indicated the optimum instant to change the gear.

In the bottom of the interface are shown the different levels of the car and in the top appear the icons for the three ADAS installed in the car. In the case that one (or some) of these alerts are launched, a superimposed warning message will appear in the screen, at the same time that the related icons switch on.

The interface for young (novel) drivers, shown in figure 4 left, differs from the general in the way that it advises not to drive under alcohol effects when the engine of the car starts. Additionally, the speedometer has only a numerical value and with a big size compared to the other displays. The reason of this design is avoid disturbing drivers with low experience as well as to improve the visibility. Similarly, the emergency icons have been distributed along the display in order to improve the uniformity and visibility.

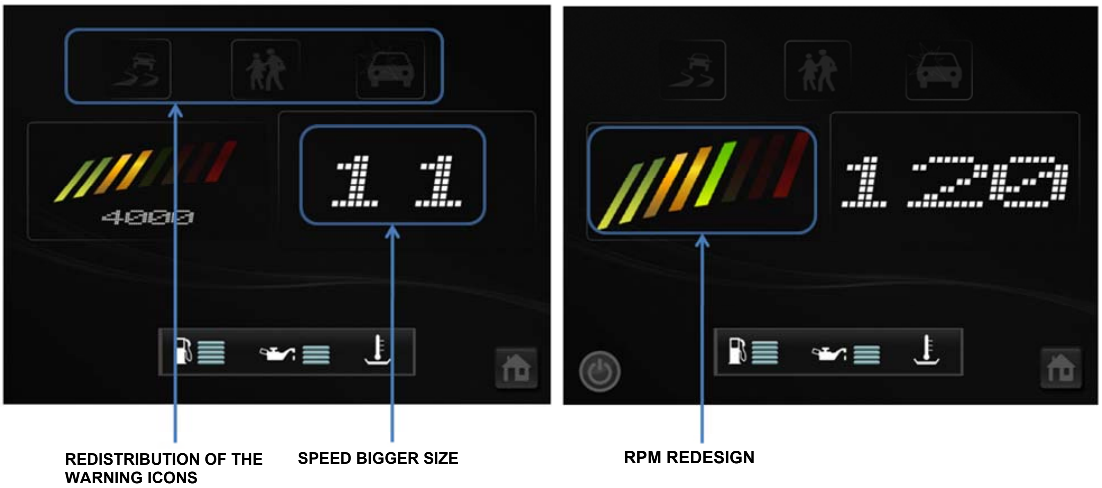

Figure 4. HMI design for young (novel) and elder/disabled drivers (left and right respectively).

The interface designed for disabled drivers maintains the big size for the numeric speedometer, because the same reasons than the novel driver. Additionally and to help people with hearing disability, the RPM marker is only graphic and color based, indicating the optimum instant to change the gear. Additionally, the size of every elements of the screen has been extended, having into account users with limited visual input.

It is assumed that elder drivers may have less cognitive capacities and, consequently, messages shown in the screen must be clear and of easy reading. Consequently, danger messages shown in the interface have been highlighted in order to capture the attention of the driver. On the other hand, this collective may have similar sensorial limitations than disabled collective and the same display elements distribution have been applied.

PRIORITY AND INTERPRETATION OF THE RISKS

One of the main challenges of this work is to create a hierarchy of messages that indicates which information is shown in each instant. In a first approximation, every component on the screen can appear in a simultaneous way; however it is important to establish information priorities in order to guarantee the data legibility and, in consequence, the user safety. The highest priority messages refers to risk situations and imminent danger for the user, this is, collision risk, lane departure or pedestrian. If some risky situations are produced at the same time, these three messages are priority organized and only one message will appear in the front of the display. However, the correspondent emergency icons will be highlighted in the background. Following this reasoning, the most priority danger situation is the warning of nearby pedestrians, since this event puts in danger to others besides the driver himself. Next priority risk is danger of collision and finally, danger of lane departure.

On a second level of priority, appear messages related to excessive speed and traffic signals that although are linked to danger situations, do not imply an imminent danger of accident.

Finally, in a third level of priority, appear messages of comfort of vehicle status like, excessive number of time driving, excessive temperature, oil level, fuel level and excessive RPM. These messages only appear as icons in the display since they are not enough important to represent a screen message that could disturb the driver.

CONCLUSIONS

In this paper we have presented the design and implementation of a human machine interface for intelligent vehicles, able of receiving and presenting information from new generation ADAS, maintaining a high level of comfort and safety. This interface have been designed using software usability and accessibility concepts that, under the premise of "design for all" tries to develop a general display but with the capacity of adapting to different user collectives in order to improve the efficiency and utility results. This work is part of Spanish National Research Foundation's SIAC project, (sensorial integral onboard system for automobile driving help) whose main aim is to develop a set of ADAS to be integrated testbed vehicle, including sensors, interfaces and decision mechanisms.

ACKNOWLEDGEMENTS

This work has been supported by the Spanish Ministry of Science and Innovation (TRA2007-67786 and TRA2009-07505) and the CAM project SEGVAUTO-II.

REFERENCES

[1]. Michon, J. A. *A critical view of driver behavior models: What do we know, what should we do? Human behavior and traffic safety*. New York: Plenum Press. 1985

[2]. Groeger, J.A., *Understanding Driving*, Psychology Press Ltd., USA, 2000.

[3]. Lamble, D., Laakso, M., & Summala, H. "Detection thresholds in car following situations and peripheral vision: implications for positioning of visually demanding in-car displays". *Ergonomics*, 42(6), 1999, pp 807−815.

[4]. Eliasson, A.; Groves, D, "A Prometheus Head-up Display Demonstrator Vehicle", The 3rd *Int. Conf. on Vehicle Navigation and Inf. Syst*. Vol., Iss., 2-4 Sep 1992 Pp.:233 - 239

[5]. Recommendation 7125 of 2006 on safe and efficient in-vehicle information and communication systems: Update of the European Statement Principles on HMI.

[6]. ISO/TR 16982:2002 "Ergonomics of human-system interaction -- Usability methods supporting human-centered design"

[7]. Ariza, M., Zato, J., Naranjo, J. E. "HMI design based in usability and accesibility concepts", *EUROCAST 2009*, Las Palmas de Gran Canaria, Spain, February, 2009.

[8]. Murch, G. "Color graphics - Blessing or Ballyhoo (Excerpt)". In Baecker, R. M., Buxton, W., & J. Grudin (Eds.) Readings in Human-Computer Interaction: Toward the Year 2000. San Francisco, CA: Morgan Kaufmann, 1995

[9]. Norman, D. A. *Emotional design*. New York: Basic Books. 2004

[10]. Lee, J. D. "Technology and teen drivers", *Jour. of Safety Res.* 38, 2007, pp 203–213.