DYNA
ISSN: 0012-7353
Universidad Nacional de Colombia

Villa-Espinal, Jesús; Osorio-Gómez, Gilberto
Methodology for the design of automotive HUD graphical interfaces
DYNA, vol. 85, no. 207, 2018, October-December, pp. 161-167
Universidad Nacional de Colombia

DOI: https://doi.org/10.15446/dyna.v85n207.71437

UNIVERSIDAD NACIONAL DE COLOMBIA
SEDE MEDELLÍN
FACULTAD DE MINAS

DYNA
http://dyna.medellin.unal.edu.co/

Methodology for the design of automotive HUD graphical interfaces

Jesús Villa-Espinal & Gilberto Osorio-Gómez

Design Engineering Research Group (GRID), Universidad EAFIT, Medellín, Colombia. jvillae@eafit.edu.co, gosoriog@eafit.edu.co

Received: April 3rd, de 2018. Received in revised form: October 1rd, 2018. Accepted: October 17th, 2018

Abstract
The use of mobile devices inside vehicles while driving is generating an imminent safety risk. Due to this situation, one of the most relevant solutions is the Head-Up Display (HUD) system, which displays information about the system, status, and aids of the vehicle and a little data of the in-vehicle entertainment in the driver's field of view during the driving activity. In fact, it is important to establish some guidelines or parameters to design HUD interfaces, since the automakers do not disclose their guidelines for the overall design of these interfaces. The main approach of this article is to propose a methodology for the design of automotive HUD interfaces, considering information from the ADAS, IVIS and external devices that meet the current needs of drivers. A validation of the methodology was made with product design engineers and computer engineers. It was concluded that predominantly in the designs the classification of information depending on the level of importance is clear. In this case, driving information is the most relevant in the whole design. An important aspect concerning the implementation of HUD devices is that this technology has more relevance in automotive interior design looking for a perfect balance between the primary task, driving, and the secondary task, multitasking activities on nomadic devices.

Keywords: head-up display; in-vehicle systems; interface; ecological interface design; methodology.

Metodología para el diseño de interfaces graficas HUD en automóviles

Resumen
El uso de dispositivos móviles dentro de los vehículos mientras se conduce genera un riesgo de seguridad inminente. Debido a esta situación, una de las soluciones que están tomando relevancia son los sistemas Head-Up Display (HUD), que muestran información sobre el sistema, el estado y las ayudas del vehículo y un poco de información sobre el entretenimiento en el vehículo, en el campo de visión del conductor durante la actividad de conducción. Por lo tanto, es importante establecer algunas pautas o parámetros para diseñar interfaces de HUD, ya que los fabricantes de automóviles no divulgan sus directrices para el diseño general de estas interfaces. El enfoque principal de este artículo es proponer una metodología para el diseño de interfaces automotrices HUD, teniendo en cuenta información de ADAS, IVIS y dispositivos externos que satisfagan las necesidades actuales de los conductores. Se realizó una validación de la metodología con ingenieros de diseño de productos e ingenieros informáticos. A partir de la validación de la metodología propuesta para el diseño de interfaces automotrices HUD, se pudo concluir que, predominantemente, en los diseños, está clara la clasificación de la información según el nivel de importancia, en este caso la información de conducción es la más relevante en el conjunto diseño. Un aspecto importante relacionado con la implementación de los dispositivos HUD es que esta tecnología adquiere más relevancia en el diseño de interiores de automóviles, buscando un equilibrio perfecto entre la tarea principal, la conducción y la tarea secundaria, actividades multitarea en dispositivos externos.

Palabras clave: pantallas de visualización frontal; sistemas de vehículo; interface; metodología

1. Introduction

The World Health Organization (WHO) recognizes vehicular accidents as the 9th cause of death, which represents 1.3 million deaths; 2.2% of all deaths in the world. These accidents are the leading cause of death among 15 to 29-year-old youths around the world [1]. The most common road injuries/accidents are due to speeding, drunk driving, red light running, fatigue, aggressive driving and distracted driving, the latter currently being the number one cause of accidents in the U.S.

How to cite: Villa-Espinal, J. & Osorio-Gómez, G., Methodology for the design of automotive HUD graphical interfaces. DYNA, 85(207), pp. 161-167, Octubre - Diciembre, 2018.

Some evidence indicates driver distraction (caused by digital communication devices such as mobile phones or in-vehicle systems devices) as one of the main reasons for accidents. The estimated number of drivers who use electronic devices while driving is 660,000 [2]. One of the biggest dilemmas the drivers have is that they want to stay connected and be safe at the same time while they perform the action of driving. We could say that the current users are always connected to his/her smartphone/cell phone, and just as they want to get all this information simply and intelligently within the vehicle, it is advisable to use the latest technology in automotive systems. The most responsible solution would be to ban the use of these devices inside the vehicle during the driving task, but this situation is difficult to control and so, technology could be used to reduce the risk for safer driving.

During the evolution of automobiles, especially in the last decade, the amount of information presented to the driver has grown considerably [3]. In some way, this is due to the evolution of the dashboard (vehicle information, infotainment, active safety supports, etc.), the use of external devices (smartphones, tablets, among others), and, especially, due to the enhancement and popularization of the ADAS (Advanced Driver Assistance Systems) and IVIS (In-Vehicle Information Systems) [4]. On the other hand, due to technological advances in displays and vehicle systems, the placement of the information is no longer physically limited to a particular location in the instrument cluster. Instead of physical displays, digital displays can present more information and several different layouts of information in the same area, opening a new trend of design solutions for the way to display information related to the vehicle and multimedia.

Those systems are designed to improve the user experience in the performance of a secondary task while driving [5]. The usefulness of IVIS is influenced by the Human-Machine Interface (HMI), which determines how well a driver enters, receives and interprets the information provided by the system [6,7]. However, due to the increasing in-vehicle interface complexity, there is an imminent need for integration of these sub-systems in the car´s driver interface in a consistent manner such that the driver can safely and efficiently operate the vehicle [8].

Hence, some issues about the cognitive effects produced in drivers by so much information have arisen, e.g., is there too much information from ADAS increasing cognitive workload? Which in-vehicle functions could affect the driver's behavior negatively? This phenomenon is called visual clutter [9].

At this point, the HUD (Head-Up Display) systems appear in the automotive context as one of the best performing displays for interaction in a safe way with the ADAS, dashboard and infotainment devices. In 1988, the Oldsmobile Cutlass Supreme became the first production car with a HUD, the only information that was shown was the speed. Today, one of these devices could display navigation guides, warnings from the vehicle, even answer calls and play music. Besides, there is a growing market focused on this technology, especially from automotive manufacturers and aftermarket companies, which know that the future of in-vehicle systems information would be displayed on those devices. On the other hand, HUDs are going to be indispensable gadgets for most of the drivers, as they are driving safely while looking for information to make quick decisions.

The theory behind the design of HUD interfaces in automobiles is not often presented in the literature, and, also, related commercial industries do not disclose their design processes. Regardless, some technological and design trends are distinguished from the commercial products and patents. That is why the design of multimodal interfaces is so important and has taken so much value now, since the entire vehicle is considered to be an interface where drivers must be able to be focused on driving and understanding, using and answering the given information.

This article presents a methodology for the design of automotive HUD interfaces, considering information from the ADAS, IVIS and external devices, usually used by the driver while driving, through the integration of guidelines of HMI and UX (User Experience).

The organization of this paper is as follows. The current problematic, related to the overload of information to the drivers and the implementation of new technologies, is presented in Section 2 in order to justify the case for a design methodology of automotive HUD interfaces. Section 3 gives an overview of the proposed methodology based on some established parameters. Section 4 verifies the validity of the method using four HUD designs. Finally, Section 5 offers conclusions and recommendations for future work about the proposed design methodology for automotive HUD graphical interfaces.

2. Managing information while driving

Driving a car involves three levels of skill: operational, tactical and strategic. Operational control refers to operating the vehicle. Tactical control relates to maneuvering a vehicle in response to a roadway situation. Strategic control refers to planning the route and how-to response to events in real-time traffic [10]. Failures in these levels of the driving process can lead to crashes or near-crashes.

The massification of in-vehicle systems, communication devices, aftermarket, and nomadic devices has demonstrated the insufficiency of drivers to perform secondary tasks while driving, triggering bad driving performance or driving while distracted. Nevertheless, the automotive industry continues to develop new technologies for this growing market, navigation systems, integrated telephones, driver information systems, instrument clusters and many other systems. Although these systems are designed to assist the driver while performing the driving task, some of these systems do not comply with the main concept of today's world transport: they minimize diversion of attention, and they could become a source of distraction. For example, HUD images may clutter or block the driver's view and affect their visual attention [11].

According to Tingvall et al. [12], the probability of having an accident depends on three factors: the driver (age, experience, motivation, travel patterns), the environment (road type, curvature, road condition, time of day, weather), and the vehicle (type, age, maintenance, safety features, HMI). In fact, relating to the vehicle factor, the primary goal is to design an HMI that provides a perfect balance between the secondary task and driving.

Two trends define the interior of tomorrow's vehicle, turn it into an airplane cabin full of buttons and little displays, or make it simple by applying technologies like hand gestures, voice control, HUD interfaces, and digital instrument clusters, among others. Hence, following the guidelines on HMI design for information and communication systems and the basis of ergonomics, the user will be induced to learn and comprehend how to use the system.

Therefore, automotive designers should consider distraction as a primary design factor, since it is considered to be a worldwide public health problem. On the other hand, designers must consider that the driver wants a vehicle with an HMI offering a unique experience regarding comfort, pleasure, and productivity, specifically with mobile devices, all of these in safe driving form. Those factors are becoming strong reasons for deciding which car to buy.

A primary design effort should be focused on analyzing the implementation of technologies that allow anticipating the actions concerning visual, auditory and cognitive distraction, specifically related to the interaction with cell phones while the driving task is being performed. Secondly, the design of the interface should also be related to allow the driver to minimize his/her efforts during the driving tasks. It is important to know how drivers divide their attention between the information on the HUD interface and the main task, which is "operate and control the vehicle", seeking to know where the driver places his/her attention. It could be selective, focused or divided, depending on the type of performed task. On the other hand, the interaction and balance between the information characteristics and the design parameters determine both the attention and performance requirements, which are essential for a clever design interface that fulfills its function.

An HUD is a current solution to reduce driver errors originated from distracted interfaces, such as onboard entertainment displays or IVIS [13], and, its usage has some relevance in the automotive market. Mostly, luxury automotive brands such as BMW, AUDI, and CONTINENTAL AG, among others, are interested in this technology and are continuously developing new systems to enhance the experience and the interaction of driving. These systems project information related to the state of the vehicle and driving aids (ADAS), for example, navigation guides, speed, gear, traffic sign recognition, lane pathway and, lead vehicle. However, on the other hand, entertainment and communication content remains limited, for example, the BMW's HUD interface has a small space dedicated to this information, such as incoming or outcoming calls from the mobile and the multimedia system titles.

According to Betancur et al. [14], from the scientific and technological point of view, the branch of commercial solutions is still open and there is an interesting research field oriented to decreasing distractions while driving using HUD systems and implementing ADAS technologies. However, there is not much information available for developing HUD interfaces, specifically for automobiles. Some research is oriented to the evaluation of predefined HUD interfaces in order to validate their functionality or interaction with the driver, but there are no established design parameters or methodologies conducting to the final design. Smith & Fu [15] explore the relationship between HUD presentation image designs and drivers' kansei, considering the image as a decision and emotional factor for the driver, and propose a prediction model for design of automotive HUD interfaces including kansei factors, but they do not propose a design methodology and their designs are not focused on safety issues or aesthetic aspects, dismissing the functionality of the HUD and the importance of the information presented in the interface.

Considering all these issues, this research seeks to establish a set of guidelines or parameters and to propose an approach for the design of automotive HUD interfaces, complying with current regulations for the implementation of these devices and integrating guidelines of HMI and UX.

3. Design guidelines and methodology for automotive HUD interface

Currently, there is not much information about how to design a graphical interface for an automotive HUD. Nevertheless, there are some relevant processes for the general design of graphical interfaces, such as the Ecological Interface Design, a framework that is based on the skills, rules and knowledge taxonomy of cognitive control [16]. This has been developed for complex human-machine systems with direct manipulation interfaces. Besides, there is a group of recommendations for designing a HUD interface proposed by authors and transport organizations. Mainly, our proposed guidelines for designing HUD graphical interfaces are focused on vehicles and the displayed information is related to in-vehicle systems, auxiliary devices, and other similar data, which is explained in detail in the following section.

3.1. General design guidelines for HUD

Recommendations or parameters suggested in the literature about design and development of HUD systems are the following:

- Do not present images in the driver's field of view
- HUD information should be coupled with an auditory alert
- Information should be displayed temporarily, not continuously.
- HUD displays should not be used to present detailed information
- Use well-saturated colors
- Adjust font size according to placement and amount of text

Some design principles for the correct development of the HUD interface are:

- Hierarchy: Transform data into information
- Integration: Integrate these subsystems in the car drivers' interface.
- Distribution: Special emphasis on allocation of informational elements.

3.2. Design guidelines for HUD graphical interface

The graphical interface of a HUD device must be designed following the next guidelines, based on Human-Machine Interface (HMI) and Graphical User Interface (GUI):

1. Characterization of vehicle information: Identify and classify the most relevant information to be displayed, related to the type of activity and information, urgency, timeliness, frequency, and duration of interaction, importance, response requirement and activation mode.
2. Allocation of information: Prioritize the list in terms of information type considering warning first, alert second, state third and status fourth.
3. Structure of HUD information: A standardized structure for HUD information was proposed by Heymann & Degani [17], which includes four levels, as shown in Figure 1.
    - First level: related to the action of driving that basically consists of operating the vehicle and maneuvering, as well as object/event detection and response.
    - Second level: it presents information about navigation demands, turn by turn, maneuvering & overall orientation.
    - Third level: it is mainly about warnings, alerts and state and status about the vehicle information about the operational environment.
    - Fourth level: it gives support to auxiliary activities such as entertainment, communication, comfort and other related activities to these. It makes the driver's emotional state remain as pleasant as possible during the trip.

Heymann & Deganni [17] proposed a way to choose and show the information. This information is specifically gathered and adapted for the design of automotive HUD graphical interfaces in the following section.

3.3. Design methodology for automotive HUD graphical interface

Considering previous design guidelines and principles, the following methodology for specific automotive HUD interface design has been structured, as presented in Figure 2.

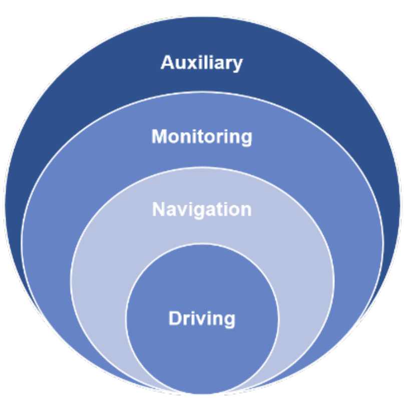

Figure 1. Structure of HUD Information
Source: [17]

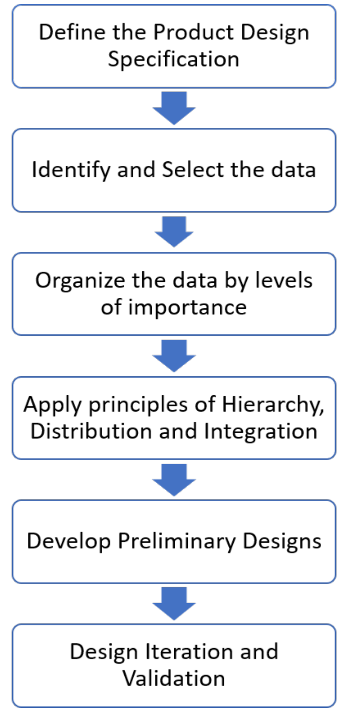

Figure 2. HUD Interface Methodology.
Source: Own authorship

- Define the Product Design Specifications (PDS): First, in terms of the HUD hardware, the designer should establish what the Virtual Image Size, the colors, and the projection distance will be. In this way, when the interface is displayed, the driver should see the information with the same proportions, measurements, and colors, and avoid problems of visualization. Next, the designer should define the type of the letters, the size, icons to be used, colors, number of layouts, in summary, define how the interface will be seen in terms of graphic design.
- Identify and select the data: Data to be displayed should be defined and classified in terms of activity, information, urgency and activation mode. Also, this step is directly related to the users, since they choose what information they would like to see in the HUD.
- Organize the data by levels of importance: the designer should organize the information selected in a hierarchical manner. This means prioritizing the information in primary and secondary levels. Primary information oriented to safety and support driving action. Secondary information, in terms of convenience and auxiliary data (entertainment and communication) as shown in Figure 1.
- Apply principles of Hierarchy, Distribution, and Integration: the designer should apply the principles of interface development, such as hierarchy, integration, consistency, focus and emphasis, interaction time, attractive design, balance, symmetry, simplicity and sequence.
- Graphical interface design: the designer starts with some preliminary sketches about the interface; mixing colors, forms, icons, fonts, and sizes, among other parameters

related to the graphical interface. This process involves the parallel design process, in which the designers made assorted designs from which only one is selected.

- Design iteration and validation: the iterative design process starts with the preliminary sketches of the designer. This means a cyclic process of design, prototyping, testing, analyzing and refining the interface design. Finally, the interface is ready to be tested on an HUD device and in real conditions.

4. Validation of the methodology

A series of exercises were carried out to validate the methodology. Figure 3 and Figure 4 present the interfaces designed by two product design engineers and Figure 5 and Figure 6 present the results from two computer engineers. In both cases they applied the proposed approach to design an automotive HUD graphical interface, following each parameter or guideline proposed.

According to the methodology presented in Fig.2, the participants define detailed requirements first, specifying the size of the interface (general dimensions), colors, font type, and icons among other graphical elements. Both product design and computer engineers apply this step correctly, which can be seen in the general view of the interface.

In the next step, they identify and select the essential information to be displayed, related to driving status and state of the vehicle, navigation systems, monitoring in-vehicle systems and auxiliary devices such as smartphones. This step was fully accomplished since they identify and select the most relevant information, like speed, rpm, speed limit signal, navigation paths and push notifications from mobile applications, such as WhatsApp, Facebook, and Spotify, among others.

Figure 3. Product Design Engineer Example 1.
Source: Own authorship.

Figure 4. Product Design Engineer Example 2
Source: Own authorship.

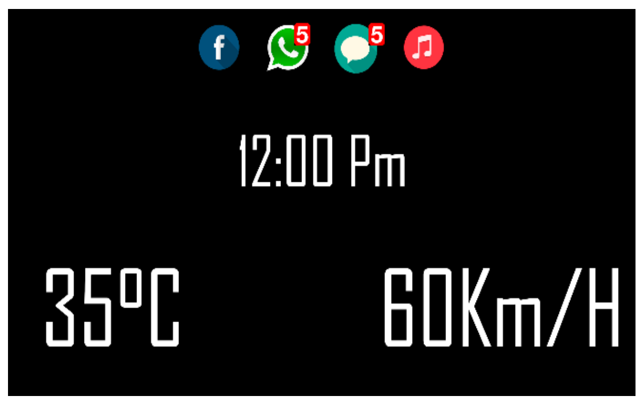

Figure 5. Computer Engineer Example 1
Source: Own authorship.

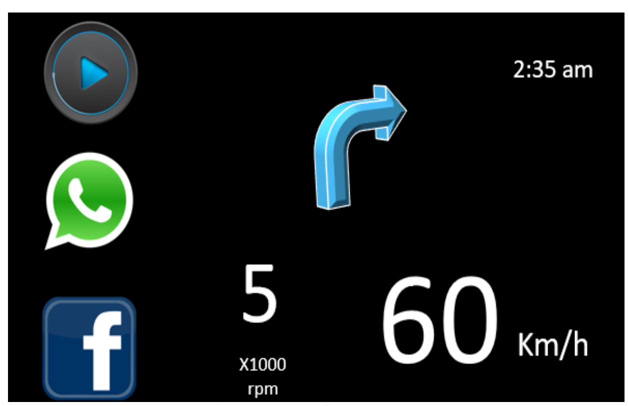

Figure 6. Computer Engineer Example 2
Source: Own authorship

Then, participants organize selected information according to relevance and the levels of importance. In the results of product design engineers, the implementation of this step is very clear, in contrast to the results of the computer engineers where their interfaces do not have an order or structure as proposed in the methodology.

Finally, the step related to the principles of hierarchy, distribution, and integration can be clearly seen in the results of the product design engineers, unlike the results of the systems engineers, where there seems to be no evidence of the implementation of these general principles of interface design.

In general, there are common points in the design of the HUD graphical interface following the established guidelines. The most important feature is the classification of the information based on the hierarchy levels, such as driving, navigation, warnings, and auxiliary info, among others. This classification indicates the relevance of the type of information that must be displayed on HUD devices which looks for a safer interface that finds the balance between the car information, additional information of mobile devices and, finally, the real environment that is visualized through the windshield. On the other hand, there is another point related to the design and to how the interface looks, which can be seen clearly among the results, where, apart from the guidelines for the HUD interfaces, the guidelines of design of interfaces, related to the type of color, font, icons, and symmetry, among other parameters must be considered.

The visual design of the interfaces tries to evoke an integration of the instrument cluster, center stack, and cell phone in just one place, on the horizon field of view. These interfaces, along with an essential factor of HUDs interfaces, accomplish the following: the hierarchy of in-vehicle information systems (IVIS), that display the most relevant driving information combined with some auxiliary information, making sure that drivers do not divert their attention from other systems inside the vehicle and focus on the primary task, driving the vehicle.

5. Conclusions

According to results obtained from the validation of the proposed methodology for designing automotive HUD interfaces, it can be concluded that predominantly, in the four designs, the classification of information depending on the level of importance is clear, in this case driving information is the most relevant in the whole design. In this way, the information that will be displayed in the field of view is related to the status and state of the vehicle, in order not to compromise the driving performance and the safety of the driver and their passengers.

On the other hand, information related to external devices such as smartphones is becoming relevant, specifically, text message apps, navigation apps, social networks apps, and streaming music among other multitasking activities that current drivers are using with more frequency, even when they are driving. Hence, with the implementation of HUD systems, accessing such information is much easier and safer while driving a vehicle. In this order of ideas, such information is the last on the hierarchy scale according to Heymann & Deganni [17].

Finally, an important aspect concerning the implementation of HUD devices is that this technology is becoming more relevant in automotive interior design, mainly focused on the user experience of the driver instead of giving more relevance to look for a safe way to put drivers in touch with the digital world while driving. Hence, it is important to generate and to improve the actual parameters established for the visual organization of the information given to the driver.

Future work should focus on generating more guidelines or parameters for the design of automotive HUD graphical interfaces, looking for a perfect balance between the primary task, driving, and secondary task, multitasking activities on nomadic devices.

References

[1] WHO., Top ten leading causes of death in the world. 2017.

[2] NHTSA., National highway transportation safety administration [Online]. Available at: https://www.nhtsa.gov/risky-driving/distracted-driving. 2017

[3] Volkswagen., The connected vehicle: from communications to collective knowledge. Viavision [Online], Wolfsburg, 2015. Available at: http://www.viavision.org.uk/ftp/1920.pdf

[4] Deloitte., Trends and outlook of the auto electronics industry. Deloitte China Automotive Practice, China, 2013.

[5] Regan, M.A., Lee, J.D. and Young, K.L., Defining driver distraction. Driver distraction: Theory, effects, and mitigation, 13(4), pp. 31-40, 2008.

[6] Daimon, T. and. Kawashima, H., New viewpoints for evaluation of in-vehicle information systems: applying methods in cognitive engineering. JSAE review, 17(2), pp. 151-157, 1996. DOI: 10.1016/0389-4304(95)00061-5

[7] Stanton, N.A. and Salmon, P.M., Human error taxonomies applied to driving: A generic driver error taxonomy and its implications for intelligent transport systems. Safety Science, 47(2), pp. 227-237, 2009. DOI: 10.1016/j.ssci.2008.03.006

[8] Dingus, T.A. and Hulse, M.C., Some human factors design issues and recommendations for automobile navigation information systems. Transportation Research Part C: Emerging Technologies, 1(2), pp. 119-131, 1993. DOI: 10.1016/0968-090X(93)90009-5

[9] Wickens, C.D. and Horrey, W.J., Models of attention, distraction, and highway hazard avoidance. In: Driver distraction: Theory, effects, and mitigation, CRC Press, pp. 249-279, 2008.

[10] Michon, J.A., A critical view of driver behavior models: What do we know, what should we do?. Human behavior and traffic safety, pp. 485-524, 1985. DOI: 10.1007/978-1-4613-2173-6_19

[11] Tufano, D.R., Automotive HUDs: The overlooked safety issues. Human factors, 39(2), pp. 303-311, 1997. DOI: 10.1518/001872097778543840

[12] Tingvall, C., Eckstein, L. and Hammer, M., Government and industry perspectives on driver distraction. In: Driver distraction: Theory, effects, and mitigation, CRC Press, pp. 603-618, 2009.

[13] Jakus, G., Dicke, C. and Sodnik, J., A user study of auditory, head-up and multi-modal displays in vehicles. Applied ergonomics, pp. 184-192, 2015. DOI: 10.1016/j.apergo.2014.08.008

[14] Betancur, J.A., Villa-Espinal, J., Osorio-Gómez, G., Cuellar, S. and Suarez, D., Research topics and implementation trends on automotive head-up display systems. International Journal on Interactive Design and Manufacturing (IJIDeM), pp. 1-16, 2017. DOI: 10.1007/s12008-016-0350-3

[15] Smith, S. and Fu, S.H., The relationships between automobile head-up display presentation images and drivers' Kansei. Displays, 32, pp. 58-68, 2011. DOI: 10.1016/j.displa.2010.12.001

[16] Burns, C.M. and Hajdukiewicz, J.R., Ecological interface design, CRC Press, 2004.

[17] Heymann, M. and Degani, A., Classification and organization of information. In: Design of multimodal mobile interfaces, DE GRUYTER, pp. 195-217, 2016.

J. Villa-Espinal, received the BSc. in Product Design Engineer in 2015, and the MSc. degree in Research Engineering in 2018, all of them from the Universidad EAFIT - Medellin, Colombia. Since 2014, he worked for the Design Engineering Research Group (GRID) of the Universidad EAFIT, as a research assistant, working on collaborative projects. From 2016, he started his master's degree and worked as a researcher, with interests on automotive and transportation technologies.
ORCID: 0000-0003-2713-9662

G. Osorio-Gómez, received the BSc. in Mechanical Engineer in 2003 from the Universidad Nacional de Colombia. In 2009 got his PhD degree in Mechanic Systems from the Politecnico di Milano, Italy. Since 2002 until 2006 worked on design, maintenance and assembly companies. He is a full professor at the Universidad EAFIT since 2009, a senior researcher at Colciencias (Conv.781) and a member of the Design Engineering Research Group (GRID), classified A1 at Colciencias (Conv. 781). Currently, his areas of interest include: i) new applications with renewable energies, ii) transportation systems and electric mobility, iii) design methodologies applied to assembly and manufacturing; and iv) virtual and augmented reality applied to the product design process. He has developed research and consulting projects since 2006 in these subjects and is the author of more than 50 publications in international specialized journals and international conferences.
ORCID: 0000-0002-8760-3335