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Physical Variable Analysis Involved in Head-Up Display Systems Applied to Automobiles

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1. Introduction

The command dashboard of an automobile is the instrument where most of the information related to the current state of the vehicle is displayed, and visually it is the way the driver can have access to that information. Nowadays, it is a great risk not only for the driver, but also for the passengers that the driver has to focus his attention off the road to focus on the dashboard information; on situations like this, are when Head-Up Display (HUD) systems represent a significant breakthrough in terms of automotive safety.

The kind of HUDs here analyzed are the Optical See-through Augmented Reality systems, where the objects of an outer environment are combined with previously structured additional information, and the result is visualized by mean of a translucent display (combiner), which is generally the windshield of an automobile. On this type of system, what we want to accomplish is an interaction with the user through a series of visual stimuli and artificial scenes.

This chapter focuses on the approach of the functional design requirements that must include an HUD system applied to current automobiles, in which the fast acquisition of the vehicle's available functional information in its panel would imply a positive impact in terms of the vehicle's simplicity to be driven, security, handling information, communication, among others. The analysis of the functional aspects of this technology will be covered by the theoretical analysis and the instrumental implementation, so that we can understand the behavior of optic phenomena that are involved in these systems, in order to be able to determine which parameters are the most critical in the possible construction of an HUD. The appreciations and considerations expressed in this chapter are defined after several years of applied and exploratory research that gathers documental fields and laboratory aspects, using the characteristics from the scientific method as aid, determining what is transcendent and what is possible from the facts.

The general objective of this chapter is to evaluate the scientific and engineering phenomena from an HUD, in order to set main characteristics and crucial parameters in terms of physics, thus, determining what considerations are fundamental for the proper functioning of these types of augmented reality systems, and identifying the functional and physical characteristics from the basic optical elements of HUD's visualization systems adapted to automobiles.

This chapter is addressed in four phases: the first phase approaches the analysis of the conceptual information about what is currently structured like HUDs applied to

automobiles; the second phase focuses on describing design alternatives for the conception of an HUD applied to an automobile; the third stage is where all the ideas presented in the previous stages (according to their real development potential) converge in a structured design proposal; finally, on the fourth phase we reach conclusions related to the most relevant data depicted in the chapter, reporting interpretations, relationships, reaches, and the structuring of a possible application.

Something very notorious in current HUD's applications is the degree of shyness in these systems in terms of images projected, since a level of sophistication has not been reached yet that allow to discard completely the tachometer and the different instruments clusters, by projected images on the windshield or on another type of element that works as a combiner; this situation proves that although significant goals have been achieved within the last few years, it is an understatement that more analysis and numerous resources are still needed with the intention of commercialize these type of devices to a higher level.

Finally, the HUDs technologies applied to automobile industries, should not only be considered as their exclusive field of application, since the use of augmented reality systems such as these are being incorporated into daily activities, i.e. answering the phone, studying, etc.

The study and the appropriation of concepts referred to this technology is appealing because it contributes to the design and redesign of several visual mobile technologies, and according to previous researches (Amezquita, 2010; Dawson et al., 2001; Betancur, 2010; Pinkus & Task, 1989), a tendency in most visualization devices to adopt the elements and the configurations that are present in HUD systems is noted.

2. Definition and justification of HUDs

Nowadays, we find a notable tendency in automobiles to offer a lot more information to the driver, which has its own direct repercussions in terms of driving, due to the lack of concentration that implies when having so many options, reason why, it is necessary to think in proposing a quick way to access the information that an automobile offers.

Starting from this point, we must think about a much more efficient communication interface between the user and the automobile that will not interfere with the user's driving; thus, augmented reality devices are born as facilitators and boosters that will give us application ideas to significantly reduce the time needed to be able to interact with the vehicle's diverse options (Brown et al., 1988).

Up until now, the best way to supply the need that we previously mentioned is with the augmented reality devices HUDs and HDDs (Head-Down Displays), which can be set up in a way that will provide to the driver the quick acquisition of information about vehicle's state, thus, obtaining a direct repercussion in the elimination of several risk situations.

In this chapter, we are looking to explain in a sequential way some coherent alternatives to link the driver to the systems and options offered by an automobile through the use of HUDs (being these systems our main subject of study) and HDDs. The operation context of these technologies can be seen in the Figure 1, where it is clear how the driver is influenced by the surroundings of an augmented reality through an image generated from an opto-electronic system.
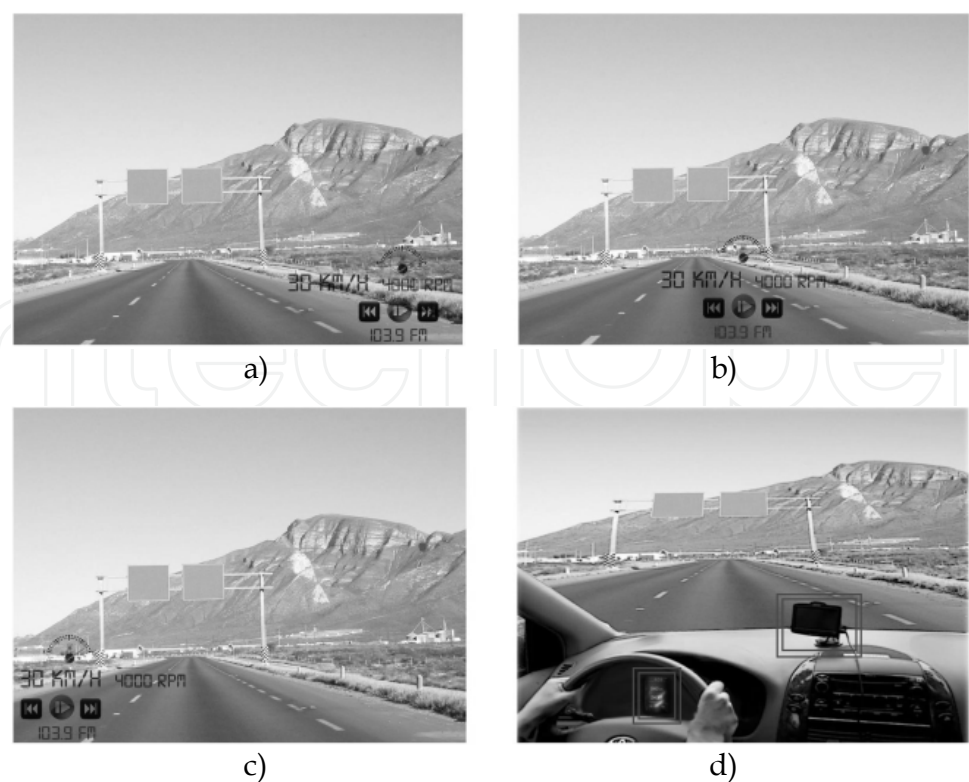
Fig. 1. (a) Right HUD; (b) Middle HUD; (c) Left HUD; (d) HDDs.

Although, there is still a lot more analysis to be done in these augmented reality systems with the intention of establishing regulation and utilization rules, it must be settled that the quantity of HUDs and HDDs applications found so far in automobiles are really efficient in terms of the driver's safety.

Next, Figure 2 represents the flow of information between the main sections of many augmented reality system; this, as a starting point to begin a discussion about the main considerations that must be taken into account in the configuration of the HUD system here proposed.

Fig. 2. Sections of the augmented reality system proposed.

3. Classification of physical components

The HUD system that is suggested here uses catadioptric elements as the main resource for the presentation of the information to the observer; according to Figure 2, it must be considered that independently from the principle of functioning of the HUD, three (3) essential sections are present in this kind of augmented reality system, which are detailed here below.

3.1 Opto-electronical system

Currently, a large quantity of options for emissive displays can be found, some of which will be mentioned on Table 1, where some essential relations and comparisons are included.

Emissive display	Functioning principle	Relations
SLM (Spatial Light Modulator)	It is a device that is based on the modulation of the intensity and/or phase of a light beam; this modulation depends on the position of incidence of the previously mentioned beam onto the recording mean of the SLM (Amezquita, 2010).	Only 1% of the generated light from LEDs (under daytime operating conditions) will get to the user. Due to the energy loss by transmission on the windshield, less than 10% of the luminescence produced by a LCD will reach the user's eyes.
Mini-CRT (Cathode Ray Tube)	It is a device that projects a beam of electrons over a phosphorus covered screen (this material lights up when impacted by electrons beams). The mini colored CRTs are made out of three (3) phosphorus layers: red, green and blue.	Although the LCDs usually have better poly-chromatic contrast than Mini CRTs, this last one usually has a higher mono-chromatic contrast than LCDs. LCD panels tend to have a limited vision angle in relation to Mini CRT screens and plasma screens.
LED (Light Emitted Diode) array	It is a semi-conductive device that emits a reduced light spectrum when polarized in a direct way and electric current flows through it.	The organic layers of OLEDs are much more luminescent, malleable and thin than crystalline layers of a TFT-LCD, which results in saving space as well as energy consumption.
LCD (Liquid Cristal Display)	It is a screen made up of a number of color or mono chrome pixels placed in front of a light source. It is based on a layer of aligned molecules between two (2) transparent electrodes and two (2) polarization filters.	When emitting their own light, an OLED screen is much more visible under standard daytime lighting conditions than a LCD, in addition to offering a higher chromatic and contrast range.
TFT-LCD (Thin-Film Transistors)	It is the result of a liquid crystal screen (LCD) with a better image quality than the later due to the use of thin-film transistors (TFT).	*"AMOLED screens are very thin and light with an enormous flexibility, with the possibility of "enrolling", even when being active, which is an interesting point of view when creating a display with self-distorted images"* (Dawson, 1998).
OLED (Organic Light Emitting Diode)	It is a diode that uses an organic component film that reacts to a specific electric stimulation, generating and emitting light by themselves (Dawson & Kane, 2001).	
AMOLED (Active Matrix OLED)	It is a group of OLED pixels that are made up of an assembly of Thin-Film Transistors (TFT) in order to form a pixel matrix (Dawson & Kane, 2001).	

Table 1. Types of opto-electronical devices.

It is important to mention that an inefficient system in terms of illumination could have a direct repercussion in a large quantity of consumed energy by the emissive display, and consequently, in the use of refrigeration systems due to the generation of heat, making the HUD systems more complex and expensive (Pinkus & Task, 1989).
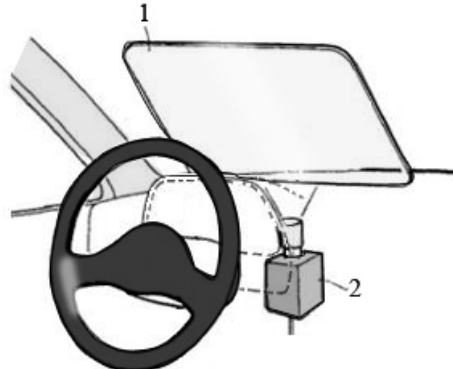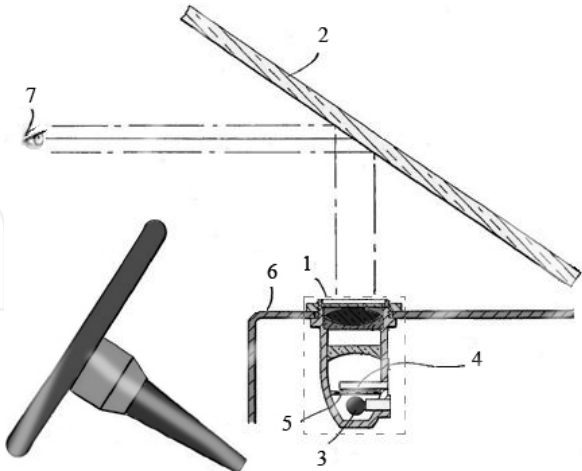
3.2 Optical system

Next, on Table 2 a description of the potential general stages of an HUD optical system is made, with the purpose of examining and inquiring about the importance of some optical considerations to take into account in this type of augmented reality systems.
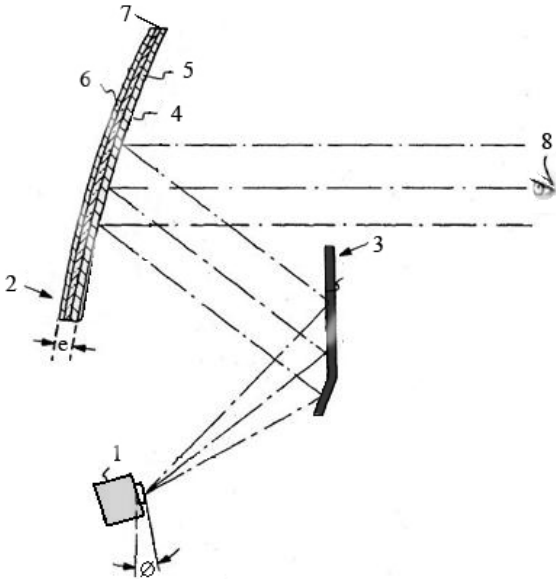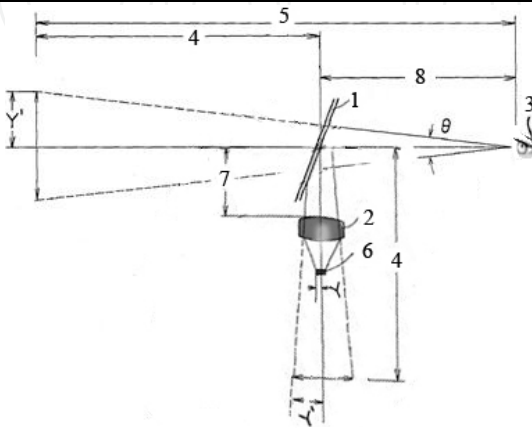
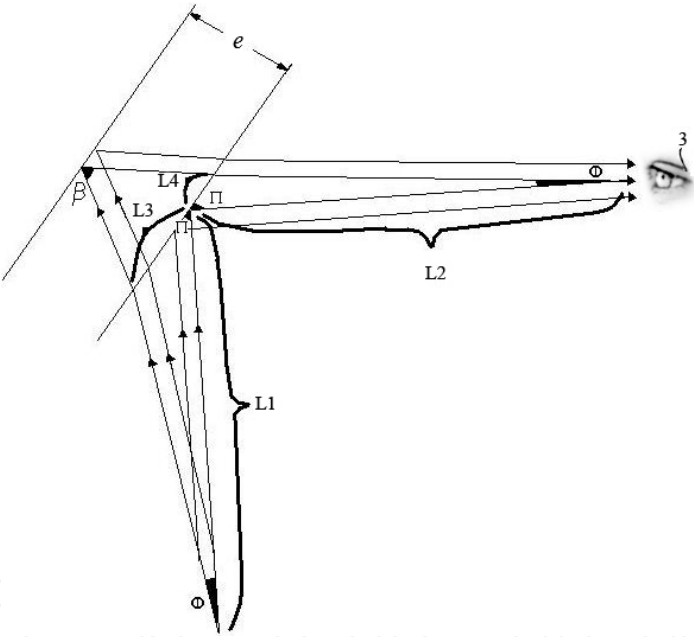| General stages of the optical system	Description
Determination of the position and the occupied space by the optical system.	It is necessary to determine the location of the HUD inside the vehicle, since 95% of the subsequent configurations depend on this initial parameter.
Positioning of the emissive display	The position of the emissive display in relation to the suggested optical system is critical in terms of the augmentation of the generated image, if it is real, virtual, straight or inverted.
Collimation of the image coming from the emissive display	The light generated by the emissive display that can be assumed as omni-directional in 180°, must become collimated light in order to be manipulated easier in further stages.
Introduction of aberrations to the projected images	- No matter the nature of the projected image, if it is collimated from mirrors, chromatic aberrations are not generated. - Some effects such as double refraction can be treated with the use of anti-refractive coatings. - A way to solve the astigmatism in this kind of systems is through Fresnel lenses (which are an excellent option in these systems due to their low volume) that can be configured to cancel the astigmatic aberration introduced by the windshield. - The projected images over an aspherical geometry like in a windshield, mainly are affected by distortion and astigmatism effects, so the option of introducing pre-distortion effects in projected images, is suggested through lenses, mirrors and systems of digital imaging pre-processing. - The use of cylindrical lenses is proposed in order to cancel the astigmatic effect introduced by the surface of the windshield; it must be clarified that the use of cylindrical lenses is appropriate depending on the windshield area that wants to be used to generate the virtual image visualized by the observer; such area has to be approximately spherical.
Compensation of the projected image	The aberrations introduced in the image through an optical system are compensated through the windshield, reason why a legible image would be appreciated.
Generation of the final image	The image generated by the HUD system must have some specified visual requirements that guarantee their own integrity and acceptance from the user, considering that independently from the quality of the image showed to the observer, we are looking to obtain a virtual, augmented, straight and collimated image.

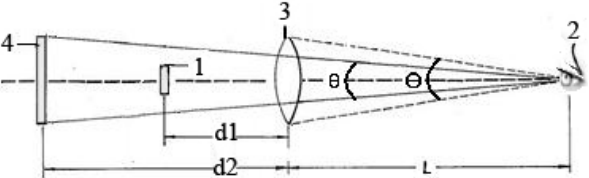Table 2. General optical stages in HUD systems.

3.2.1 Image forming optical system

The type of HUD system here described is an Optical see-through augmented reality, where the objects of an external environment are combined with additional information previously configured (avatars: overlapped objects on the scene), the result is visualized through a translucent screen or combiner; next, on Table 3, different types of configurations imposed to these HUD systems are analyzed in order to highlight the main elements that shapes these types of systems.

Configuration 1	
Elements	
1. Flat combiner external to the windshield. 2. Emissive display.	
Observations	
In this type of configuration, astigmatism aberrations are not present, nor distortion, but a geometrical deformity is present, consequently, the projected image is visualized with a trapezoidal profile according to the incidence angle of the projected image over the combiner.	Fig. 3. Configuration 1 (Furukawa, 1991).

Configuration 2	
Elements	
1. Optical system. 2. Windshield. 3. Incandescent lamp. 4. Diffusing screen. 5. Projected image. 6. Exit platform. 7. Observer.	
Observations	
It could be considered that certain region in the windshield might possess approximately spherical geometry (its central region), where the α angle formed between the chief ray of the projected image and the optical axis of the spherical region is considered, then, this angle defines the degree of astigmatism in the image presented to the observer. Under this previous spherical consideration, we could think of cylindrical lenses to eliminate the astigmatic effect presented in the image projected to the user.	Fig. 4. Configuration 2 (Griffiths & Friedemann, 1975).

Configuration 3	
Elements	
1. Emissive display. 2. Combiner. 3. Mirror. 4. Back surface of the combiner. 5. Reflective coating (aspheric surface). 6. Frontal surface of the combiner. 7. Body of the combiner. 8. Observer.	 Fig. 5. Configuration 3 (Frithiof, 1972).
Observations	
The surface of mirror (3) is covered with an aluminum semi-reflective coating (25%). The surface (4) is a hyperboloid, and it is covered with an anti-reflective magnesium fluoride coating (5), its objective is to reflect a percentage of light that was reflected by the surface of mirror (3), and to additionally establish that a percentage from light of the outside is not transmitted towards the observer, thus, the outer light and the projected image by the combiner compete at an equal level. The thickness of the combiner is defined as e, but sometimes that parameter cannot be assumed as a constant, since surfaces (4) and (6) that define the combiner are considered as none parallel, making the windshield behaves as a wedge. The surfaces used to collimate the light from the emissive display are (3), (4) and (6), these surfaces are proposed to satisfy the requirement that an image is formed from combiner (2) with the same sagittal and southern magnification. The angle ø is determined to correct the parallax errors on the image presented to the observer.	
Configuration 4	
Elements	
1. Combiner. 2. Optical system. 3. User. 4. Distance of the virtual image. 5. Distance between the virtual image (showed by the combiner) and the observer. 6. Emissive display. 7. Distance between the combiner and the optical system. 8. Distance between the combiner and the observer.	 Fig. 6. Configuration 4 (Suzuki et al., 1988).

Observations
It assumes that it wants to generate a virtual image Y´ over a flat combiner, which characteristics include being augmented, straight, collimated and without double refraction (or an acceptable parallax), so an optical system is configured (represented due to reasons of ease through a single lens).
There is also an attempt to reduce the parallax of the visualized image making sure the light beams of the projected image are as parallel as possible among them. We are looking to find, based on certain considerations of the geometrical optics, a way to get closer to the designing requirements: distance of the virtual image=infinite, L1/L2=0, and the minimum angle β, as it is observed on figures 6 and 7.
The binocular parallax is the horizontal and vertical dephase that the reflected image by the first interface of the windshield (air-glass) has in relation to the reflection of its second interface (glass-air); it can be corrected with a prism which works as a wedge, redirecting the light. As found on literature (Betancur, 2010), horizontal parallax is not corrected since it produces stereoscopic images that are tolerable by the user.
Fig. 7. Detail Figure 6 (Suzuki et al., 1988).

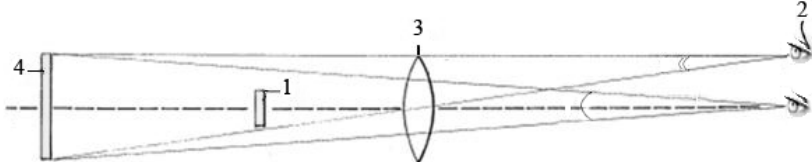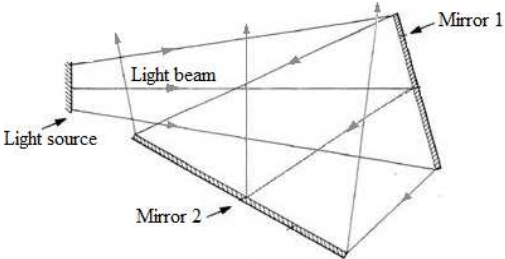| Configuration 5	
Elements	
1. Emissive display. 2. Observer. 3. Optical system. 4. Virtual image. θ. Total Field Of View (TFOV). ϴ. Instant Field Of View (IFOV).	 Fig. 8. Configuration 5 (Brown et al., 1988).

Observations
The position of emissive display (1) in relation to optical system (3) (a convergent lens for this type of configuration) defines the augmentation of the virtual image (augmentation = focal distance of the optical system / d1) that is visualized by the observer and the distance that it is going to be visualized from the optical system (d2). The length of the lenses largely determines the exit-pupil of the optical system, for this application a squared formatted lens is used, to be able to generate a squared formatted exit-pupil that will adapt better to the head movements of the driver in the automobile. Next, on Figure 9, the IFOV effect can be appreciated, since due to from its extension the eye-box also increases (defined as the volumetric space where the user can place his/her head and see the whole extension of the virtual image); it is noticeable on Figure 9 that with the IFOV's angle, the user may move and will continue seeing the whole virtual image generated, it also must be noted that the user will generally move his/her head in X and Y dimensions, reason why the eye-box must be rectangular, thus, rectangular lenses must be used. As a requirement, it is set out that the IFOV must be at least 1.5 times bigger than the TFOV.   Fig. 9. Visual representation of the eye-box applied to configuration 5 (Brown et al., 1988). The optical trajectory of this kind of HUD system might be fold through the use of mirrors as shown on Figure 10, which implies a reduction in the space needed to contain the elements of the optical system.   Fig. 10. Folding of the optical trajectory on configuration 5 (Brown et al., 1988).

Table 3. Types of configurations of an HUD.

3.3 User

In these devices, binocular vision is involved; this vision handles a horizontal FOV of 120° and vertical of 130° (being 60° upwards and 70° downwards).

The first requirement for good binocular vision is that the eyes converge to a single spot of the visual range, by using binocular vision inappropriately to see the outside scene and the generated image by the HUD device, may cause stress and vision difficulties such as diplophia (when the user sees two separate images at the same time).

On the other hand, with binocular vision if the luminance level is the same for both eyes, the scene that is being observed will be perceived brighter than what it really is, otherwise, if

one of the eyes is subjected to more illumination than the other one, the visualized image might look less bright than what it is, thus, the importance of keeping constant illumination on the image that the HUD generates.

Additionally, the spectral sensibility of the eye must be considered in order to generate the maximum luminescence possible in HUD devices, that is, when the luminescence levels are higher than $3.18*10^{0.5}$ Cd/m^2 we talk about Photopic vision; on the other hand, for luminance levels under $3.18*10^{-3.5}$ Cd/m^2 we talk about Scotopic vision; when the eye is being used in one of these two regions its spectral sensibility changes, being higher for the Photopic region in 505nm and for the Scotopic region in 555nm, between the region that covers the spectrums of green and yellow respectively, that is why these colors tend to be used in HUD devices. If the wavelength emitted by the emissive display cannot be changed, it might be used a wavelength that is common on both levels of luminescence (525nm approximately).

Otherwise, retinal illumination is mentioned as the quantity of light that goes through the eye in relation to the scene's luminescence, this concept describes the Stiles and Crawford effect that talks about the visual sensation of the user, which is different for equal quantities of light in different places of the retina, being the rays that go through the center of the pupil (and which impact on the retina) more effective by a factor of 8 (Betancur, 2010).

In relation to visual sharpness (negatively affected by Scotopic vision and the little graphic details that the projected information by the emissive display has), we notice for the projected image that a user with low visual sharpness would not be able to differentiate the fine details that it possesses, therefore, this parameter should be considered when defining the type of image that the HUD device will generate.

Next, on Table 4 is detailed some of the most important visual requirements to be taken into account when an image is being presented in these HUD systems (Betancur, 2011; Díaz, 2005).

Requirements	Value	Description
Chromatic aberration	≈ 0	Considering that the projected image is polychromatic, the use of mirrors is necessary to avoid the chromatic aberration, or apochromatic doublets for the correction of such aberration (Velger, 1997).
Astigmatism aberration	≤ 0.25 Dpt	It is present by the toroidal geometry of the windshield and it is compensated commonly with cylindrical lenses. This aberration tends to null itself when the angle α (which defines the degree of astigmatism in the presented image to the observer) formed between the chief ray of the projected image and the optical axis of the projection region of the windshield (considered as spherical) tends to zero (Freeman, 1998).
Distortion aberration	≤ 1.5 %	This is especially noticeable when observing the image on the eye-box limit, where the visualized image is generated by the optical system's periphery, here the formation of the image is not as good as the center of itself.

Requirements	Value	Description
Vertical binocular parallax	≈ 0	Depending on the location of the display source in relation to the user, the horizontal binocular parallax produces stereoscopic images that can be acceptable, but the vertical binocular parallax produces fatigue on the user's sight, due to it is intended to be minimized by the use of prisms specially configured (Frithiof, 1972).
Double refraction	≈ 0	It must be minimized, looking to diminish the angle of incidence between the emissive display (with collimated light) and the combiner, and additionally using an anti-reflective coating over the inner surface of the combiner; on the other hand, this effect may be eliminated by including a wedge effect into the combiner, eliminating the parallelism between it inner and outer surface.
Accommodation	$\leq \pm 0.25$ Dpt	Depends on the visual capacity of the user (Hecht & Zajac, 2005).
Deformity	≈ 0	Related to the trapezoidal deformity effects on the image seen by the user.
Daylight luminescence	≤ 9000 ft-L	In relation to the literature (Velger, 1997; Brown et al., 1988), if we consider a system with a combiner reflectance of 30%, an optical system transmittance of 85%, and a contrast appropriate (1.3:1) for the view on a sunny day (10.000 ft-L), the image luminescence value (viewed by the user) may be calculated.
Night luminescence	≥ 3639 ft-L	Considering the night luminescence of 4000 ft-L, together with the optical and contrast parameters indicated in daylight luminescence, a value of night luminescence in the image viewed by the user may be proposed.

Table 4. Primordial visual requirements.

Also, here below, an analysis on perceptual factors must be done to those HUDs applied to automobiles:

3.3.1 Increase of visual time on the road

Most of the time that the driver spends on driving, his attention is directed to the road, however, there are short periods of time where the driver looks at the command board of the vehicle, which although very small, might mean the loss of a critical event; the use of an HUD while driving allows the reduction of observation time for the variables in the vehicle's panel from 0.25 to 1 second, that time can be crucial on a dangerous situation.

3.3.2 Reduction of re-accommodation time

The virtual image generated that is visualized by the user is typically located at a higher distance from the observer than the command dashboard and within the visual range of the user (looking towards the road), then, less accommodation is required when the driver switches to focus the virtual image of the HUD to the outside environment.

3.3.3 Distance of the virtual image

The distance of the virtual image must be between 2.5 and 4 meters from the eyes of the driver, in order to increase the time of recognition and accommodation.

3.3.4 Accommodation effect

When superimposed objects are located within the observer FOV, the object that has a shorter distance from the observer's focus, tends to dominate the accommodation answer, this situation is shown in HUD systems when using an external combiner instead of the windshield.

3.3.5 Intolerance to visual disorder

The results of case studies of drivers whose vehicles had an HUD system, showed that sometimes these system could be uncomfortable due to the quantity of information that is displayed toward the driver; although, this is currently discussed, because the analysis of this uncomfortable situation is highly related to the type of information being displayed, its organization and relevance to the driver.

3.3.6 Illumination interference

The overlapping of the symbology generated by the HUD over the driver's external scene, will tend to hide the outside objects via illumination interference, which results if the luminance of the symbology of the HUD is higher than the luminance of the outer objects of the vehicle, this can be a big problem according to the quantity of information shown by the HUD.

3.3.7 Cognitive capture

Under high working conditions there is a high level of temporary uncertainty for the unexpected appearance of outer objects, consequently, it is likely that a cognitive capture occurs by the HUD operation, that is, an attention deficiency to the surroundings due to the exposed symbology by the HUD, generating delays in the answers to outside events, which can result in the loss of external objectives.

3.3.8 Symbology of the display

The figures of the conformation symbology move with the elements of the outside world, this kind of symbology increases the acceptance of HUD systems among drivers.

3.3.9 Location

It is not appealing that the HUD simbology is located in the middle of the driver's visual range; many research documents suggest that the drivers prefer to locate this symbology below the line of the horizon, in a more peripheral position.

4. Implementations

Based on what was previously mentioned and as a starting point for this chapter proposal, an augmented reality system was set out based on phases, components and flows, as indicated on Figure 11.
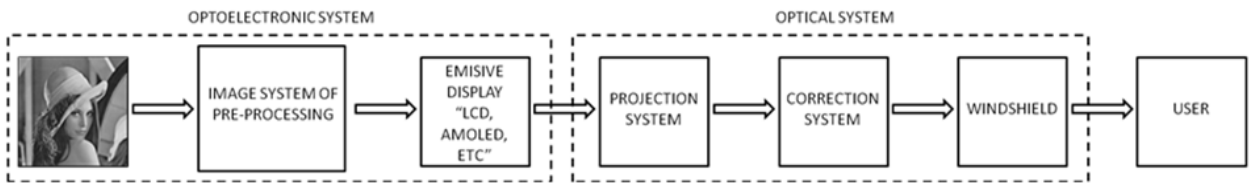
Fig. 11. Proposed augmented reality system.

As it can be appreciated, Figure 11 is a detailed view of Figure 2 previously described, being this last one the starting point for the design of any HUD. From the opto-electronical stage on Figure 11, the digital pre-processing stage of the projected image stands out, which is not very common in this type of augmented reality system, and its effect and reach is better appreciated next on Figure 12.
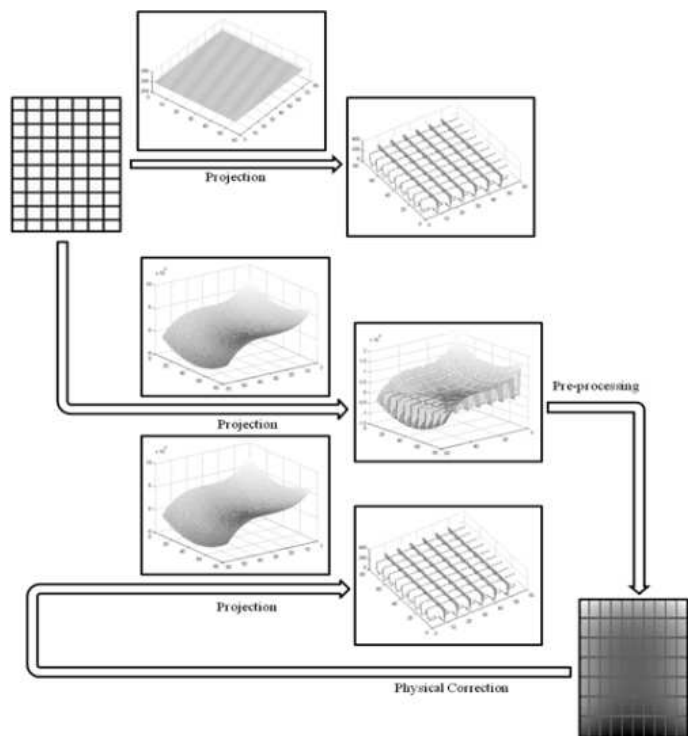

Fig. 12. Corrective pre-processing of images in the HUD system proposed (Betancur, 2011).

Now, based on the previously established considerations and in order to test other additional ones, the instrumental set up described on Figure 13 was developed.

From the instrumental set up described on Figure 13, these components are specially highlighted:

1. Windshield holder: this allows the rotation of the windshield in two of its axes.
2. Windshield: corresponding to the RENAULT LOGAN 2009 model reference G000463620_V02_01.
3. Projection system: as a result of the evaluation of the previously indicated alternatives on Table 3, an optical system proposal was established; whose designing requirements are detailed next on Table 5 and it is also represented schematically in figures 14 and 15.
4. User's position.

Fig. 13. Instrumental set up proposed.

Requirement	Description
Quantity of lenses in the optical system	It is proposed as a starting point, an optical system configured by two converging lenses.
Object distance of the system's first lens (S_{o1})	The main goal is that the object distance of the system's first lens to be as lower as possible (a maximum of 15 cm), so that this lens will collect as much light as possible and can consequently generate a brighter final image (S_{i2}).
Image distance of the system's first lens (S_{i1})	It is intended that this image distance be generated near the focal distance of the system's second lens.
Object distance of the system's second lens (S_{o2})	The definition for this system is: the distance (D) that separates the two lenses of the system minus the image distance of the first lens (S_{i1}).
Image distance of the system's second lens (S_{i2})	It is intended that this parameter, that is the distance from which the driver will see the final image due to its reflection in the combiner, will be minimally of 1.8 meters.
Longitudinal augmentation (M)	It is intended that the image is augmented by a maximum factor of 9, since, if the image's original dimensions are augmented, its resolution will be drastically decreased.

Requirement	Description
Distance between the system's lenses (D)	It is intended that the distance between the optical system's lenses is never higher than 40 cm.
Entrance pupil (En.P.)	The entrance pupil is where light enters to the optical system, in this configuration is located in the first lens.
Exit pupil (Ex.P.)	The exit pupil represents the produced image from the system's first lens (opening diaphragm) by the system's second lens, and additionally, according to its size, it limits the cone of rays of the virtual image that the user can observe.
Diaphragm of aperture (D.A.)	It is the element that limits the entrance of light from the object to the optical system, in this configuration is represented by the first lens of such system.
User distance (U.D.)	It is proposed in relation to previous conducted researches (Wood et al., 1990; Velger, 1997) that there is a distance of 0.8 meters from the user of the system's second lens.
The exit's pupil diameter (D1)	To know the size of the exit pupil, the distance between both lenses of the optical system (D) must be known, which (for the exit's pupil diameter calculation) will be recognized as the object distance of the second lens (S_{o2}), and it is also necessary to know the focal distance of the second lens (f_2); this way, by applying Gauss' equation for thin lenses we will be able to know the image's distance of the second lens (S_{i2}), then, through the longitudinal augmentation relation ($M=-S_{i2}/S_{o2}$) the augmentation can be known; finally, since the object and image distances are proportional to their heights, and knowing the opening diaphragm's diameter, it is possible to know the exit pupil's diameter (D1).
Image size generated by the optical system. (D2)	To know the size of the virtual image generated by the configuration of this particular optical system, it is necessary to multiply the generated augmentations for each of the lenses $M_t=M_1*M_2$ ($M_1 =-S_{i1}/S_{o1}$, $M_2 =-S_{i2}/S_{o2}$).
User distance from the exit pupil (U.D.1)	For the configuration of the optical system indicated a distance of 0.5 meter must be established.
User distance from the generated image (U.D.2)	According to previous research (Griffiths & Friedemann, 1975; Suzuki et al., 1988) and to preserve a good response from the user, it is established that this distance must not be lower than 2.5 meters.
Vertical visual range from the generated image (FOV-θ)	In relation to the optical system that was proposed, the FOV-θ is defined as the vision angle necessary that the user must have to visualize the vertical extension of the virtual image generated.
Vertical visual range generated by the exit pupil (FOV-α)	In relation to the optical system that is proposed here, the FOV-α is defined as the vision angle that the exit pupil allows the user to have of the vertical extension of the virtual image generated. In relation to Figure 15, it can be noticed that the higher the FOV-α is to the FOV-θ, then, the bigger will the system's eye-box be.

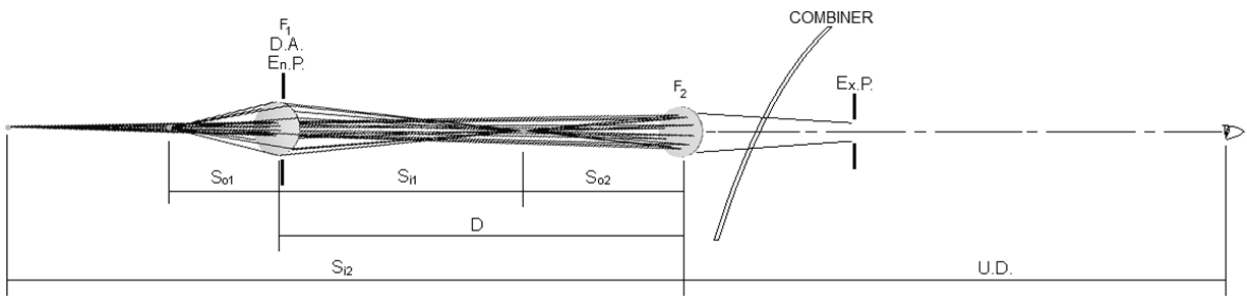Table 5. Designing requirements of the optical system proposed.

Fig. 14. Optical system proposal.

Fig. 15. FOV-θ in comparison to FOV-α.

The values used for the set up of the proposed optical system (figures 15 and 16), are indicated here below on Table 6.

Parameter	Value
S_{o1}	249 mm
f_1	135 mm
D	400 mm
f_2	110 mm
S_{i2}	2375.4 mm
M_t	8,7
Ex.P.	151 mm
D1	41,525 mm
D2	261 mm
U.D.	551 mm
U.D.1	551 mm
U.D.2	2926,4 mm
FOV-θ	2,35°
FOV-α	2,96°

Table 6. Values for the optical system proposed.

Next, on Figure 16, it can be seen the proposed optical system described on figures 14 and 15; Fresnel lenses were used due to their low bulkiness, with a squared format in order to accomplish a squared exit pupil that is more appropriate in relation to the user's movements.
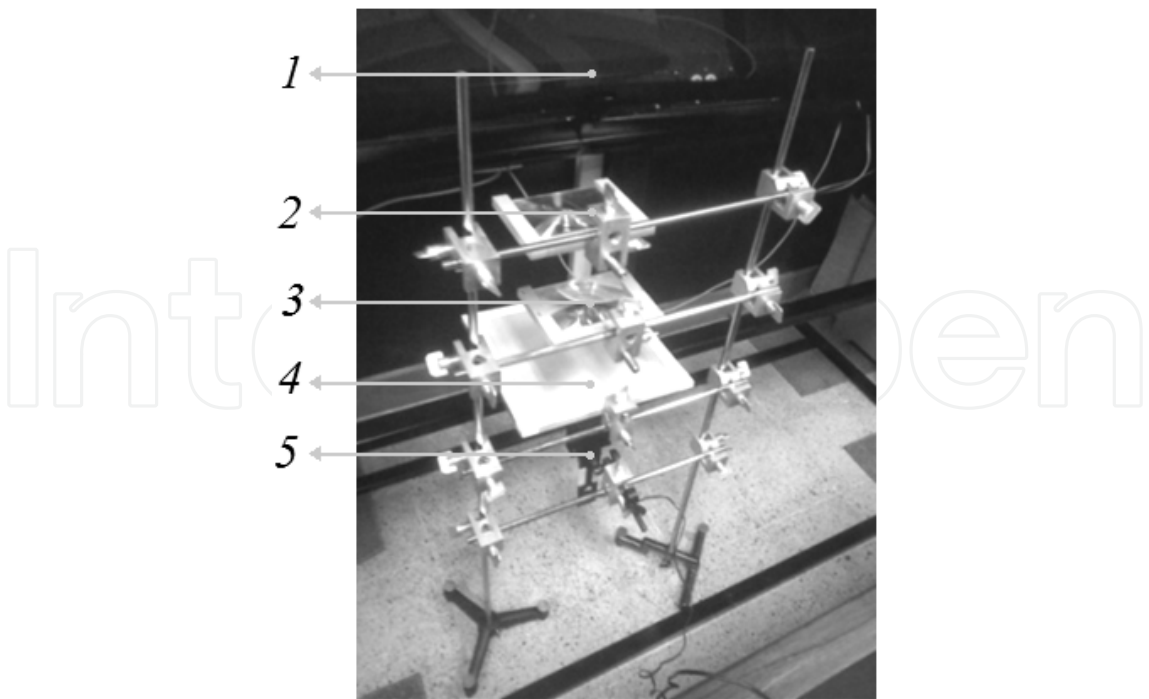
Fig. 16. Development of the optical system proposed.

1. Windshield.
2. Lens 1.
3. Lens 2.
4. Diffusing screen: that creates an image of the emissive display.
5. Emissive display: for this analysis a Pico-projector from MICROSYSTEMS ® was used, where the image of the projection is transferred from a computer that pre-processes the image according to the specific design parameters previously indicated.

Next, in order to show what the user would perceive from his/her driving position and under the implementations that were proposed previously; here below on Figure 17 a) and b) the proposed visualization of the HUD and the real visualization of the HUD are shown respectively.

a)   b)
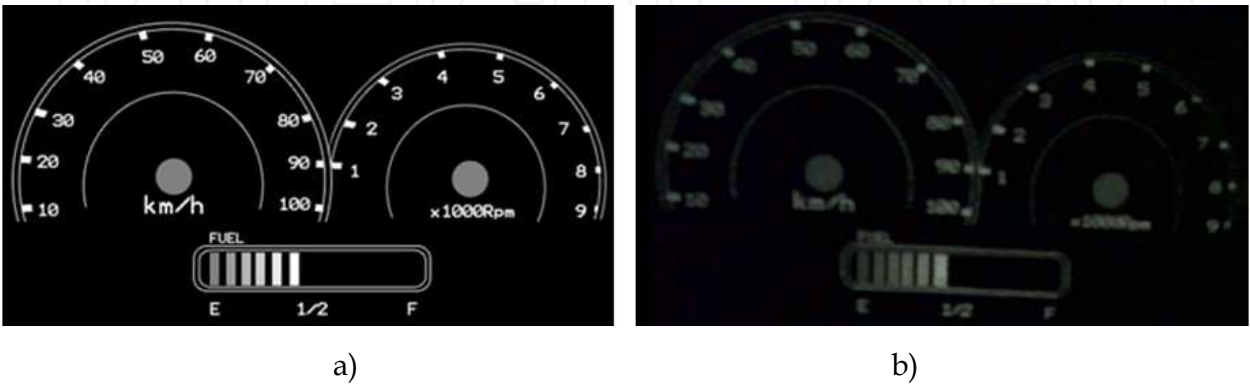
Fig. 17. (a) Proposed image; (b) Visualization of the proposed image under previously described implementations (Betancur, 2011).

5. Applications

Next on Figure 18, a possible automotive configuration for this type of augmented reality systems is proposed.
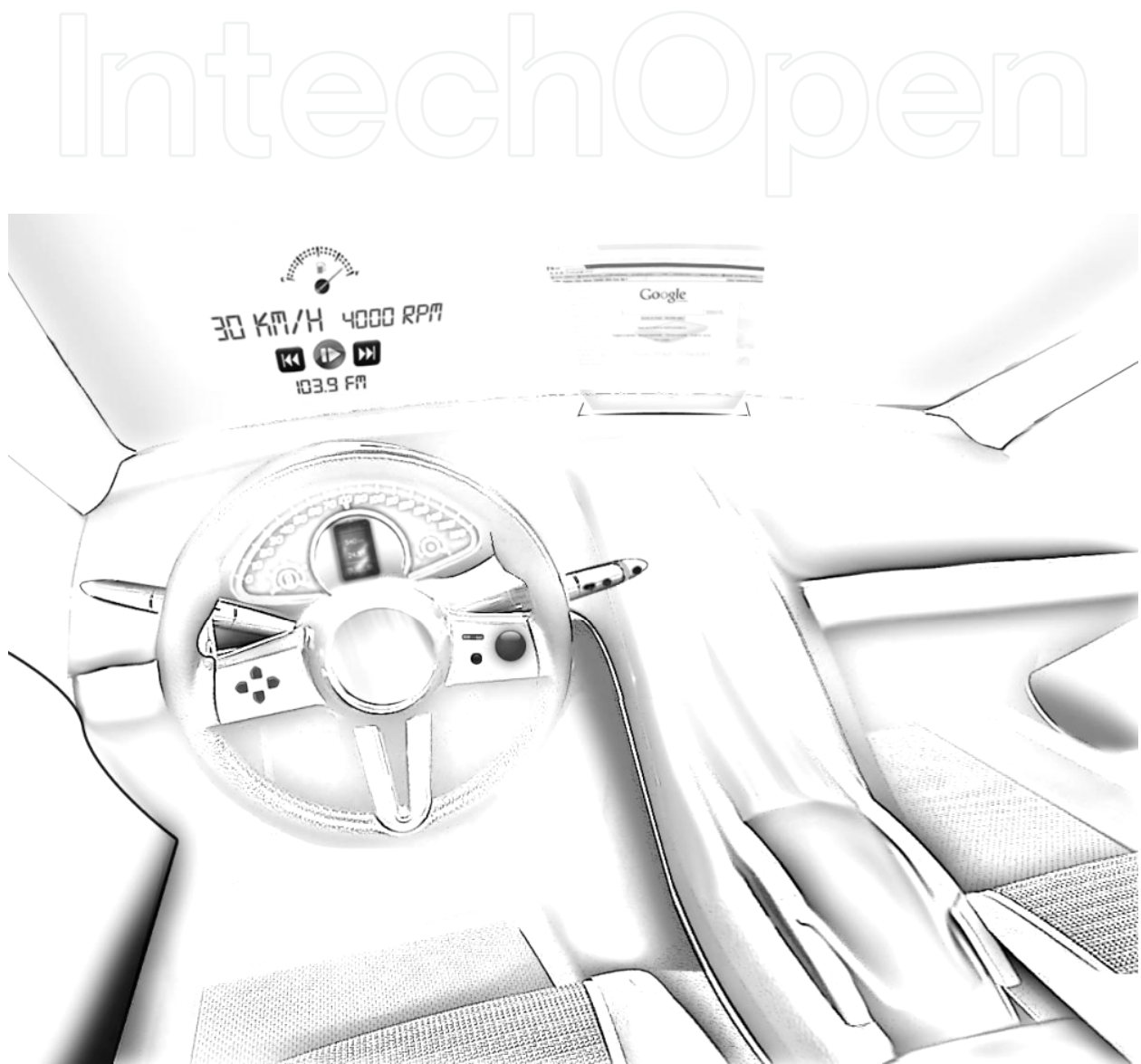
Fig. 18. General set up for the proposed HUD system.

Then, on Figure 19 we specify some of the main options that an augmented reality system should have under the configuration from Figure 18.
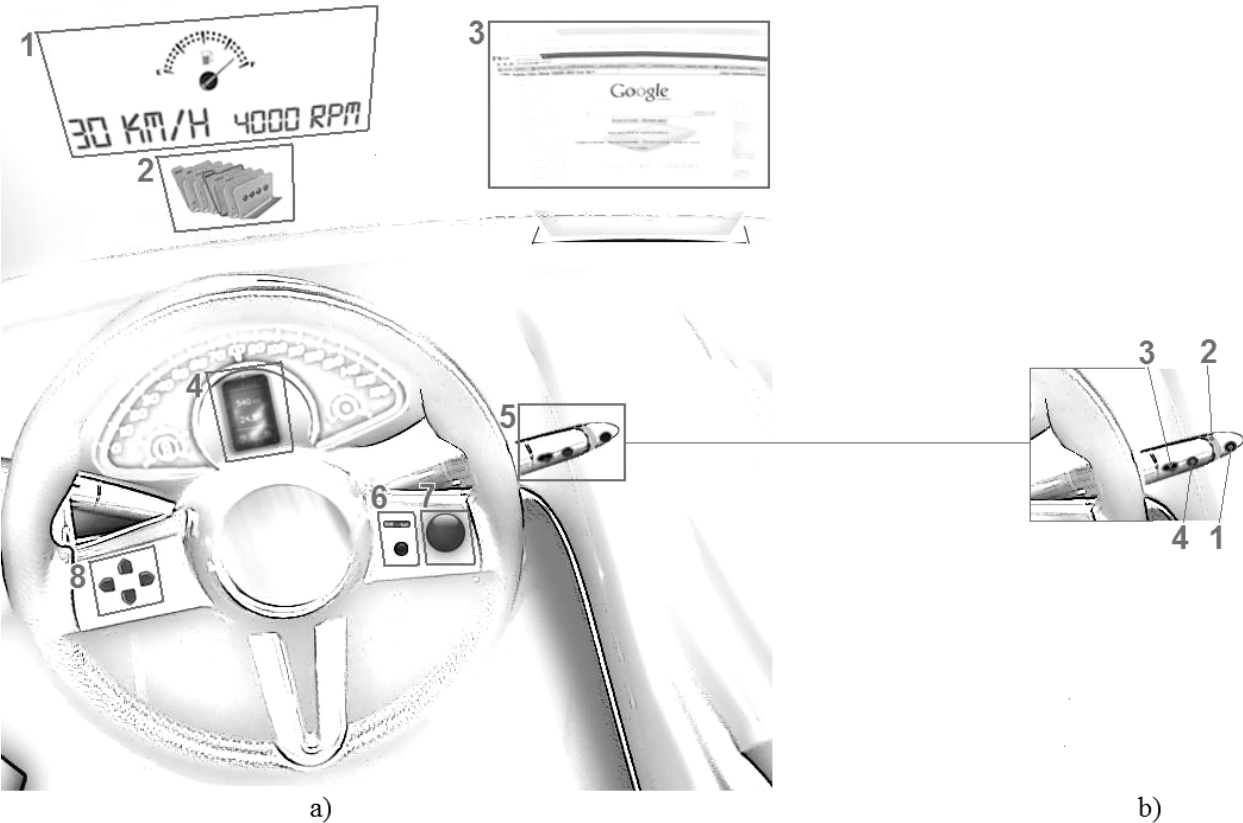
Fig. 19. (a) Specific configuration for the HUD system proposed; (b) Detail of the operation mode from the HUD system proposed.

From Figure 19.a) the following items stand out:

1. HUD 1.
2. HUD 2.
3. HUD 3.
4. HDD 1.
5. Controls for HUD 1.
6. Controls for HUD 2.
7. Controls for HUD 3 (spherical scroll button –Mouse-).
8. Command buttons for the HDD 1.

From Figure 19.b) the following items stand out:

1. On/Off HUD 1.
2. Illumination of the presented image.
3. Proximity of the presented image.
4. Handling of the information from HUD 1 (Enter button).

Now, as a complement for Figure 19, it is proposed through Figure 20 to determine what other options should be taken into account specifically for this type of augmented reality system and under the interaction of a companion.
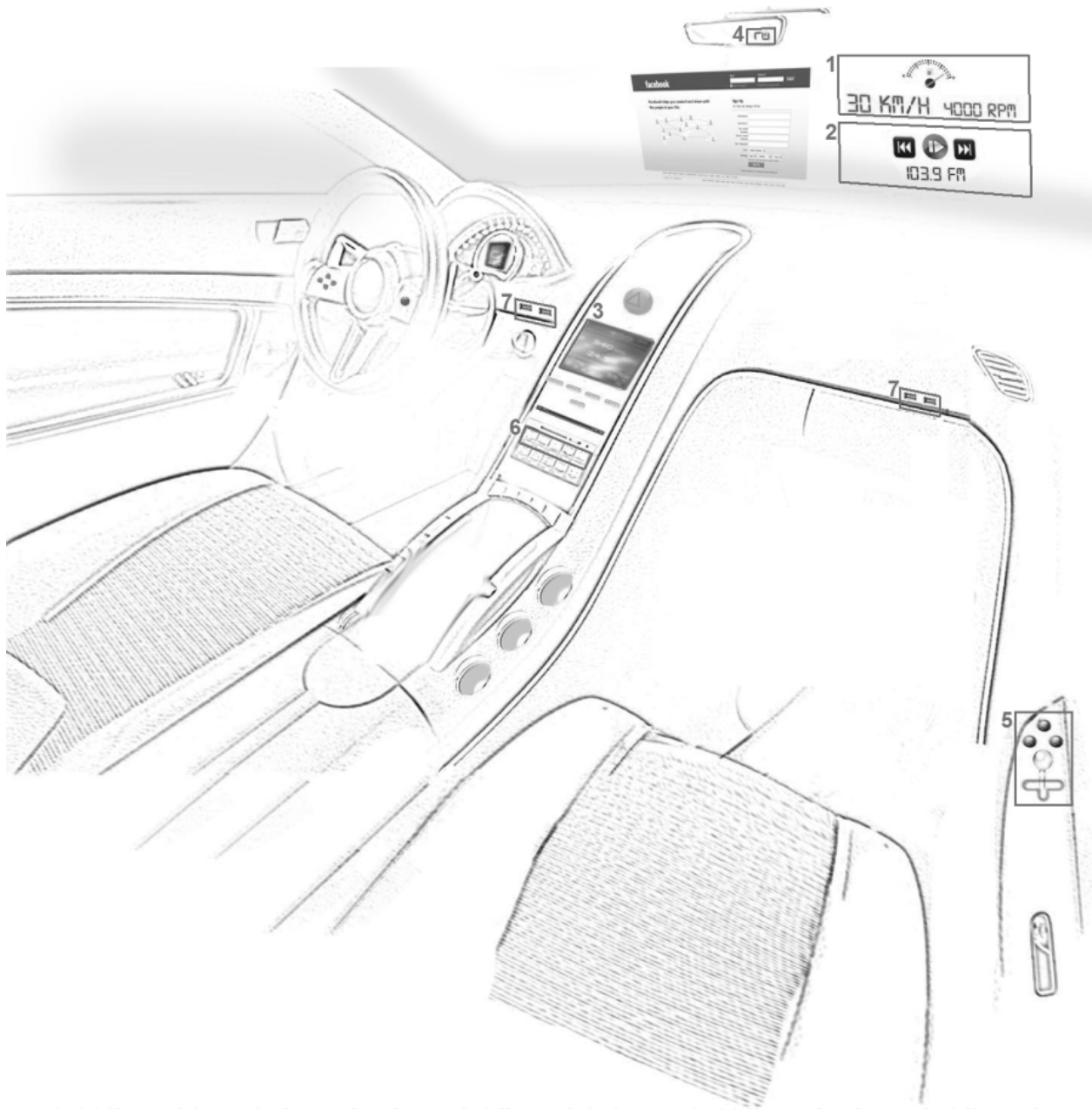
Fig. 20. Specific set up for the HUD system proposed.

From Figure 20 the following items stand out:

1. HUD 4 is the same HUD 1.
2. HUD 5 is the same HUD 2.
3. HUD 3 on the command panel is the HDD 2 (handled by touch screen).
4. Reticules projected onto the central driving mirror.
5. Control for the HUD 4 and HUD 5.
6. On/Off buttons for all the HUDs.
7. USB ports to connect a keyboard or any other device that helps the co-driver to manipulate the HUD 3 (this is not recommendable for the driver due to the big risk that could represent).

The projection configurations of the HUD 1 and 2 are indicated here below on Figure 21.

a)   b)

c)
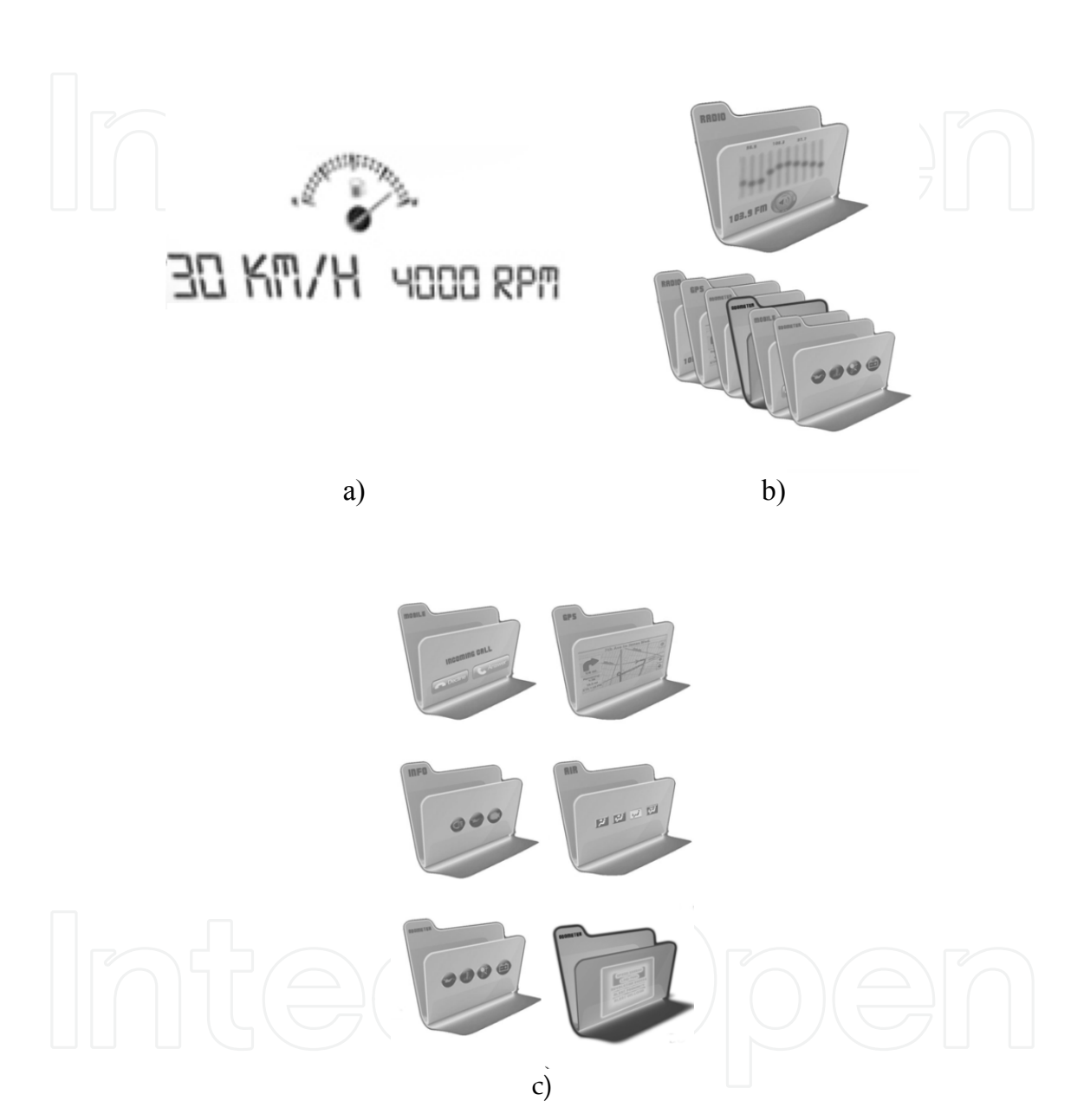
Fig. 21. (a) Configuration of the projections of the HUD 1; (b) Configuration of the projections of the HUD 2; (c) Kind of projections in the HUD 2.

The considerations taken into account from figures 18 to 21 are imposed on Figure 22, which is considered as a good approximation to the functional design of the augmented reality system proposed in this chapter.
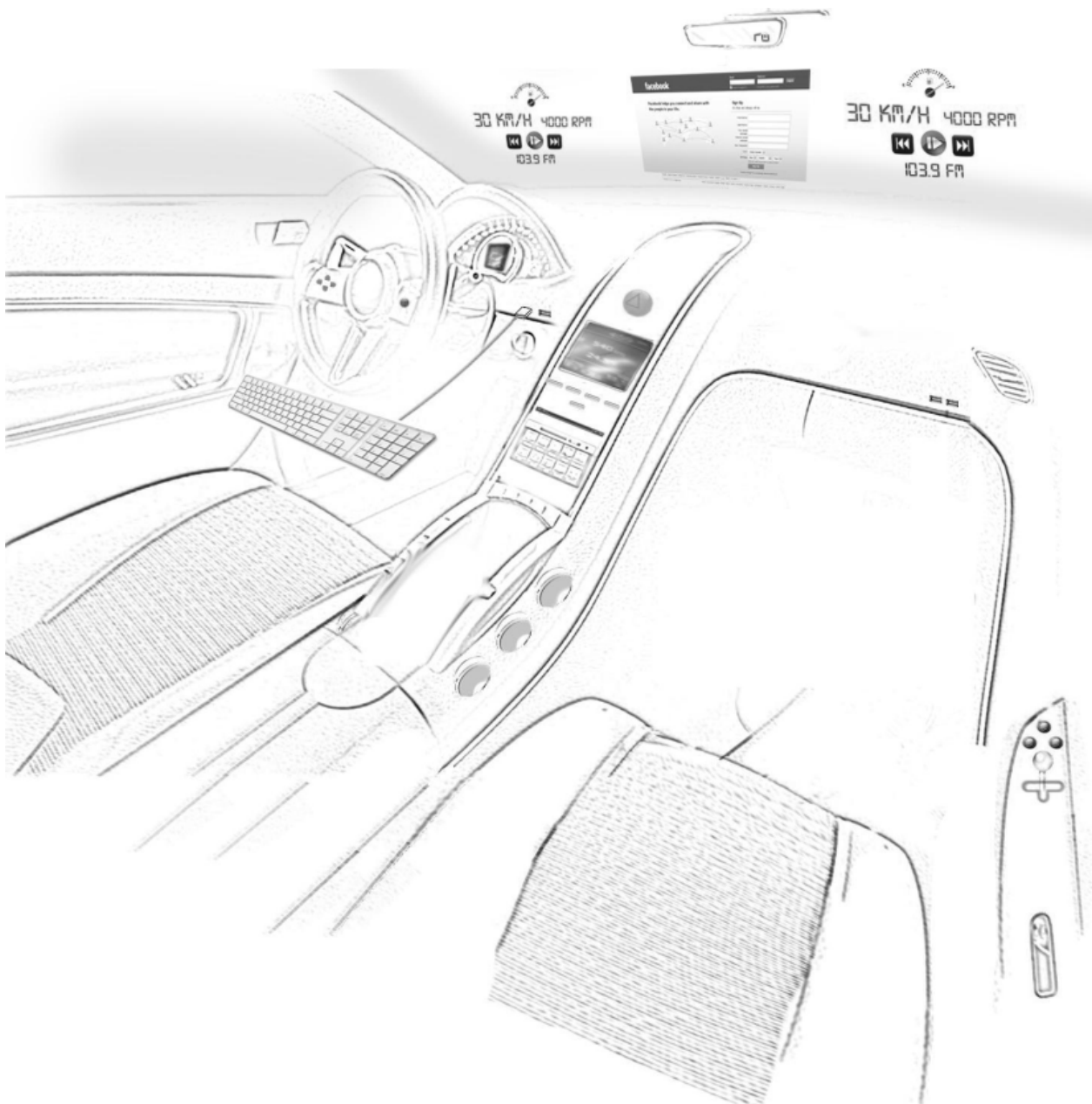
Fig. 22. Configuration of HUDs and HDDs in the augmented reality system proposed.

6. Conclusions

1. On the Figure 17 it is barely noticeable the aberrant component over the final image presented to the observer, in the same way, even if the virtual image presented is not perfectly coherent to the one initially proposed, it is adequately and without any major problem recognizable by the user; then, this image has not overcome the limits established as appropriate for the presentation of the information in HUD systems.

2. The optical qualities used to set up an HUD are diverse, being the needs required by the driver their main parameter of design; this way, the instrumental proposal here depicted, mainly focuses on presenting a virtual image to the user that is straight, augmented and

collimated, this group of qualities are the main requirements (demanded by the user) that these augmented reality systems must satisfy.

3. The approach of a two lens optical system is interesting when satisfying the established requirements between the longitudinal augmentation, the size and the exit pupil's position, the generated virtual image, the object location in relation to the optical system, among others; since, for a lens, to accomplish these requirements the same way the optical system proposed does, may be very complex and expensive; also, a three lens system for this type of application might be unnecessary, since, as it can be appreciated, a two lens system is enough to provide the basic requirements demanded.

4. The use of lenses with a squared format becomes necessary when trying to obtain a more appropriate eye-box in relation to the user's movements; in the same way, this format allows a presentation of images to the user, according to the square projection shapes from most of the emissive displays.

5. It is clear that the presence of optical aberrations (astigmatism, double refraction, chromatic, distortion, etc.) it is notorious in these kinds of systems, the way it corrects from analogical elements and through the stages of digital pre-processing are not yet completely generalized, so in consequence, being able to present a tolerable image in terms of such aberrations implies much more analysis and research.

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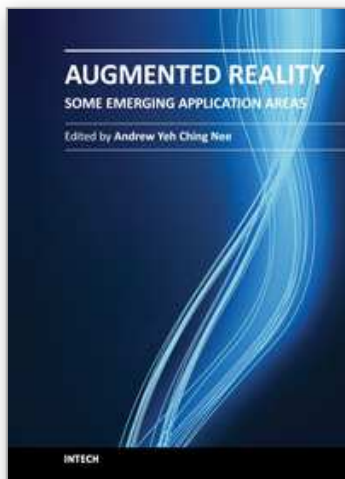
Augmented Reality - Some Emerging Application Areas

Edited by Dr. Andrew Yeh Ching Nee

Augmented Reality (AR) is a natural development from virtual reality (VR), which was developed several decades earlier. AR complements VR in many ways. Due to the advantages of the user being able to see both the real and virtual objects simultaneously, AR is far more intuitive, but it's not completely detached from human factors and other restrictions. AR doesn't consume as much time and effort in the applications because it's not required to construct the entire virtual scene and the environment. In this book, several new and emerging application areas of AR are presented and divided into three sections. The first section contains applications in outdoor and mobile AR, such as construction, restoration, security and surveillance. The second section deals with AR in medical, biological, and human bodies. The third and final section contains a number of new and useful applications in daily living and learning.

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