Augmented Reality Head-Up-Display for Advanced Driver Assistance System: A Driving Simulation Study

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ABSTRACT

Research and technological advance in the field of Augmented Reality (AR) is growing rapidly (Mas, 2011). One of the new application domains is the automobile industry, linked to the necessary men machine aspects of Advanced Driving Assistance Systems (ADAS). Relevant road traffic as well as useful navigation or path planning information may be displayed using partially or totally the windshield surface thanks to these emerging technologies. However, the way road traffic, signs or vehicle information is displayed impacts strongly driver's attention with increased mental workload and safety concerns. Research in perceptual and human factors assessment is needed for relevant and correct display of this information for maximal road traffic safety as well as optimal driver comfort.

At Renault, research is carried out in a number of automotive AR domains: the used information type and visual grammar, visual perception for the displayed information (depth, localization), and real time mixed reality, that is matching virtual and real environment. The main goal of this presented experiment was to study whether head movement impacts AR depth perception and thus modifying displayed image quality and decreasing driver performance. For this purpose, a driving simulator experiment, carried out in the CAVE Immersive Integration Platform (P2I) Driving Simulator, we analyzed: driver head movements during different realistic situations, preferences scale in each specific situation, and thus with and without head tracked conditions. Primary data shows a strong preference for the tracked system condition and the statistical scale factor was very significant.

Keywords: Augmented Reality (AR), Head-Up-Display (HUD), Head Motion Parallax, Advanced Driver Assistance Systems (ADAS), Driving Simulation, Cognitive Psychology, Human Factors, Ergonomics.

INTRODUCTION

Many clues are used in everyday life for depth perception and estimation. Some of them are binocular cues requiring combined information from both eyes, while others are monocular, requiring information from one eye alone. The research study done by Faubert in 2001, illustrates several approaches where motion parallax cue is used to better perceive objects depth. Movement parallax can be defined as the optical change of the visual field of an observer which results from a change in his viewing position (Gibson et al., 1959). This optical motion, described by Gibson, can be divided into 2 different categories: the apparent motion due to the object motion and the movement of the observer (Gibson, 1968). When the observer is in motion and focuses on a point in the scene, objects that are in front of the focal point will appear to move in the opposite direction from the observer, and objects behind that point will appear to follow the same direction as the observer. The motion of each point on the retina depends on the relative position and relative motion of the object and the observer (Kemeny et al., 2003). Analyzing the movement parallax cue is even more complex in a driving environment; especially when we come to highlight some information in the scene using Augmented Reality (AR). In fact, the driving environment is usually rich with static and dynamic objects. Dynamic objects, for example cars and pedestrians, move at different speeds, and the vehicle moves at a variable speed. Adding to that, errors may be caused by driver’s head movements.

A previous study carried out by Andersson Hultgren et al. in 2012, showed that subjects moved their head when positioned behind another vehicle trying to get a better view of the oncoming traffic. This study has been recently perused by Lisa et al. in 2013, and the results were much more promising when they adapted the experimental conditions. This later work was very inspiring and we find similar approaches in the presented work. Another case where drivers tend to tilt their head is during curve driving. Mestre et al. 2007, concluded in their study that subjects exhibit systematic head roll tilts toward the interior of curves, and the angle tilt is accentuated with the increase of road curvature.

Our research, therefore sought to analyze the impact of motion parallax, generated by the driver, while he moves his head horizontally and vertically from his initial frontal position, thus in a driving environment with a virtual Head-Up-Display (HUD) that serves as an Advanced Driving Assistance System (ADAS), during reduced visibility conditions on the road. The innovative method of Charissis et al. in 2007, revealed that focusing ability is less apparent in very low visibility situations, because the distance between the farthest visible object and the HUD plane was less pronounced. In another study, done by the same group the optimal operational distance of the HUD was investigated, participants preferred the longer focal distance. Thus because, it reduces refocusing strain on the eyes, but it was much less pronounced under very low visibility (Charissis et al., 2007). They also concluded that when the HUD was used under good visibility, it was distracting and it clutters the driving scene, and in this case all users preferred driving without the HUD.

Building on our initial work, the present document describes our success at enhancing the precision of an AR-HUD by adding the Head Tracking function so as to allow better perception of Bounding-Box alignment with the corresponding vehicle. Within this research we integrated different realistic road situations in the scenario (straight lines, curves, intersections, overtaking), and we introduced two secondary tasks (reaching the phone and hang out, opening and closing the glove box). This experiment was done by using virtual simulation, which is a cost-effective way for identifying design limitations before physical mock-ups (Charissis et al., 2007).

During all the diverse situations, we analyzed head displacement, and through a written questionnaire we have asked the subjects to evaluate the precision of the AR-HUD when Head-Motion-Parallax was taken in consideration and when it wasn’t, and they therefore evaluated the difference scale and preferences. We found out a significant preference for the AR-HUD with Head Tracking conditions, and in comparison between the two systems those participants judged that there was a large difference between the two systems. For those participants, we also evaluated the degree of precision of each system they tested, grades are significantly better for the AR-HUD with Head Tracking conditions.

EXPERIMENTAL DESIGN OF AUGMENTED REALITY HUD FOR MOTION PARALLAX EVALUATION

When virtual information is superimposed to the real environment it is important to align them correctly. Accordingly, in the present problematic we are concerned on whether we should consider or not head movements during the driving task, while we display the Augmented Reality (AR) information on a Head-Up-Display (HUD) Layer. The main objective of this experiment, was to demonstrate the impact of motion parallax generated by driver's head movements, in the context of Advanced Driving Assistance System (ADAS) with an Augmented Reality (AR) Head-Up-Display (HUD). Results of this study could be exploited to investigate whether the driver needs to be tracked in order to display AR information adapted to his perspective, when such a technology is used in the car.

Purpose of the Study

During bad weather conditions and reduced visibility, the driver has more difficulties to perceive information around his environment. The workload is more important when driving in reduced visibility conditions (McLean et Hoffmann, 1975). In this experiment, we wanted to better show one type of information for the driver using Augmented Reality (AR) technology, without cluttering his vision and saturating his mental workload. The augmented reality information is here to increase visual saliency and attract driver's attention to the proximity of the next and coming vehicle. When driving in reduced visibility conditions, we tend to leave less inter-distance with the next vehicle and the preceding vehicle serves as a landmark for trajectory control (Caro, 2008). In our case, our concern is to check if the fact that we highlight the next vehicle differently (with and without head motion parallax integration) will change our perception of the road and have an impact on the vehicle trajectory. We are assuming in this study that we know the respective positions of the different vehicles to highlight all the time, thus to display virtual information and overlay them in real-time. We are not concerned about predicting functions to estimate successive positions of objects.

A virtual Head-Up-Display is used in this study to project information directly in the driver's view. The experiment was implemented in order to compare two approaches for displaying the augmented reality information. The purpose is to compare driver's perception and performances, and quantify this difference, if there is any, with statistical study. This study emphasis on driver's behavior, trajectory control with respect to the experimental conditions in different situations. To measure the precision of the system we rely on the questionnaires completed by each participant after each session. The virtual plane was projected 3 meters in front of the driver, no color code is associated to a hazardous vehicle. In fact, a neutral color was chosen to not interfere with the driver's judgment and the distance he keeps with the next vehicle.

Driving Simulator and Virtual Environment

The methodological tool used in this experiment is one of Renault's CAVE, an Immersive Integration Platform (P2I), with 4 display surfaces (3m x 2.5m). It allows virtual stereoscopic vision from the tracked position (thanks to ART Tracking), with a resolution of 1024 x 768 per face. A static Driving Simulator was installed in the middle of the P2I CAVE to conduct the presented experiment. Virtual information were embedded in the driving scene through the driving simulation software SCANeR, it gave the impression that Augmented Reality Information was projected on a virtual plane between the vehicle cockpit and the driving scene. The next vehicle in the same lane, and the left lane (for cars coming on the opposite direction), were framed by an adaptive bounding box. Two bounding boxes in maximum are framed simultaneously.

Figure 1: P2I CAVE Driving Simulator

Participants

27 participants were invited to participate to this experiment, about half man and half women and their age ranges from 22 to 58 years old. Out of the 27 persons, 4 of them had to stop the experiment because of motion sickness. In order to avoid bias due to the learning effect the order of the two tested systems was altered each time. Subjects ignored totally the changing condition between the two tested systems. They were only ask to evaluate them relatively to their precision and indicate which system they preferred.

Calibration Phase

Calibration is required in accordance to driver's body and driving position, and this can be done manually or automatically (Charissis et al., 2007). In our study, the initial frontal position is recorded before taking off, then head displacement is measured all the way, but no feedback was present for the driver concerning his movements.

Driving Scenario and Instructions

The driving path is defined in an urban environment, where realistic traffic conditions are reproduced. The scenario was thought as it reproduces different driving perspectives. Considering that motion sickness is generally higher in static simulator, the time of the driving sessions was purposely limited. In fact the training session lasted about 3 minutes and the two driving sessions about 6 minutes each. Participants were asked to express any discomfort during the experiment. We had four cases of dizziness, and they were stopped as soon as they reported it to avoid further motion illness. The two driving sessions were identical with the same traffic conditions, same road events and instructions. This allowed us to have a maximum consistency for results analysis and comparison. However, in order to avoid bias due to the learning effect the two conditions order were counterbalanced. Participants were asked to follow the police vehicle as an itinerary indication. The police vehicle was chosen just because it was easy to recognize. It was indicated to the participants that if they happen to lose the vehicle to not rush to catch up, because the vehicle waits for them anyway. They were also asked to be careful during the sessions just like they would behave in real life.

Secondary Tasks during the Driving Sessions

The main goal during the experiment was to reproduce different driver's positions, we explicitly asked drivers to stress on their safety as they would act in their car, so they were asked to remain cautions and look at the road while doing the task. Participants were asked to do two secondary tasks at specific moments (defined through the scenario). They were told to take their time to accomplish it and especially to keep an eye on the road while doing it.

Task 1: participants were asked to perform this task when they hear the phone ring. The phone was initially placed on the copilot seat, and they were asked to reach up and grab the phone, while they keep looking at the road. Then they were supposed to hang up and hand it over to its initial position.
Task 2: participants were asked to perform this task when they hear the beep sound. Thanks to the stereovision it was possible to visualize the dashboard of the car and the glove box. The instruction for this task was to move and reach out to the glove box as if they would open it or close it.

Hypothesis

In the driving session with head tracking, the AR-HUD was updated relatively to driver's view point, so even when they moved considerably their head, the bounding-box followed the target car. This wasn't the case in the other driving session without head tracking, instead the AR-HUD was all the way displayed relatively to the measured initial frontal position. Consequently, if drivers tend to tilt their head from their initial positions they were expected to more likely observe misalignments of bounding-boxes with the corresponding cars. We expected a large difference in the perception of precision when head movements were important. For example, when drivers approach an intersection, measures of driver's head movement were expected to increase, thus modifying the perception of the none-Tracked HUD system. This led us to divide the session into 6 different intervals of interest: straight lines, curves, intersections, overtaking, and secondary tasks. In fact, this has allowed us to compare driver's perception in different situations relatively to his head movements. We didn't expect the AR-HUD to obscure other important information in both experimental conditions.

Protocol Validation Phase

This phase was achieved before convening participants to evaluate the difference between our two display prototypes. This first stage of the experiment was done by interacting with Engineers and Experts at Renault Technical Center for Simulation (CTS), to provide us with their expertise about some of the simulation aspects. The aim was to adapt the content of the experience to better answer the problematic. During this phase, it has been decided to project the virtual information 3 meters away from the driver. The projection distance is maintained constant during all the sessions. We also realized that if the driver is far behind the police vehicle he follows, the driver doesn't necessarily pay match attention to the bounding box alignment, even while doing the secondary tasks. Besides, if we happen to use this system, it will mostly find its interest when the front vehicle is somehow close to us. For those reasons, we decided to add a supplementary analysis hypothesis, which is that the difference will only be visible when the driver is not very far apart from the preceding vehicle.

Conducting the Experiment

Participants were first asked to read a presentation sheet, which contained the object of the study and the content. This was to guarantee that all subjects had the same quantity of information and not influence their judgment. They were told that the goal of the experiment was to compare two approaches for calculating the bounding boxes and that we wanted to evaluate the two prototypes relatively to their precisions. They were not informed about the changing condition between the two driving sessions. After that, the experimenter made an oral summary of the different stages of the experiment and clarified instructions. A training session was necessary: to experience the virtual environment, make sure the participant doesn't feel motion sickness, rehearse secondary tasks, and get a first idea of what will the bounding box look like so the participant is not surprised during the experimental sessions. This later consisted of 6 minutes drives, each integrated 6 important situations of interest: straight lines, curves, intersections, overtaking, and secondary tasks. After each the two driving session, participants answered a written questionnaire. A final questionnaire was field in to compare the two display prototypes and participants were asked to evaluate their preferences. The experiment lasted about 45 minutes including all stages. (Below is a summary of the various stages of the experiment)

1 - Presentation Sheet
2 - Oral Overview
3 - Training Session (about 3 minutes)
4 - Driving Session N °1 (about 6 minutes)
5 - Questionnaire « Part 1 »

6 - Driving Session N °2 (about 6 minutes)
7 - Questionnaire « Part 2 » & « Part 3 »

Drivers were asked to adapt a natural behavior, and drive as if they were in their car, obeying all road's rules. However, they weren't supposed to consider the clutch pedal but drive instead with an automatic gearbox. For each participant, measures of the frontal position were taken before starting the two driving sessions, which permitted to record head movements for both conditions (with and without head tracking).

Motion Sickness

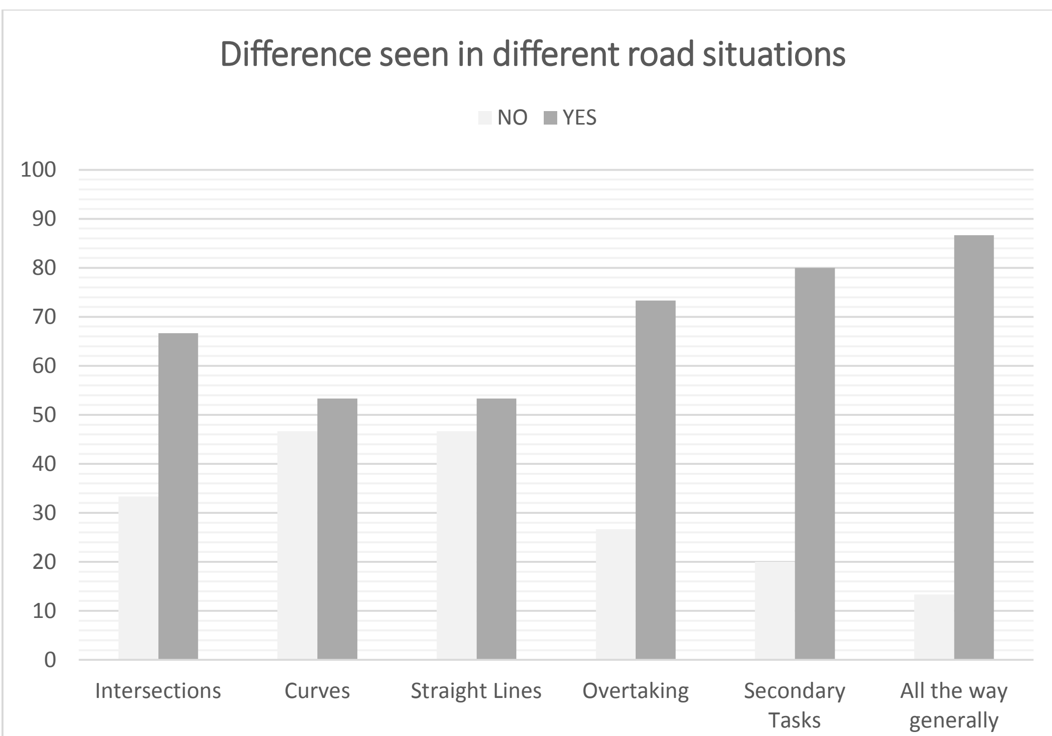
Participants were asked to inform the experimenter quickly if they felt any discomfort (nausea, headaches, heart palpitation, sweating, or any other symptom), and thus no matter at what stage of the experiment they were in. Four persons out of 27 participants had to stop the experiment because of discomfort apparition due to motion sickness.

RESULTS EVALUATION

Questionnaire Analysis

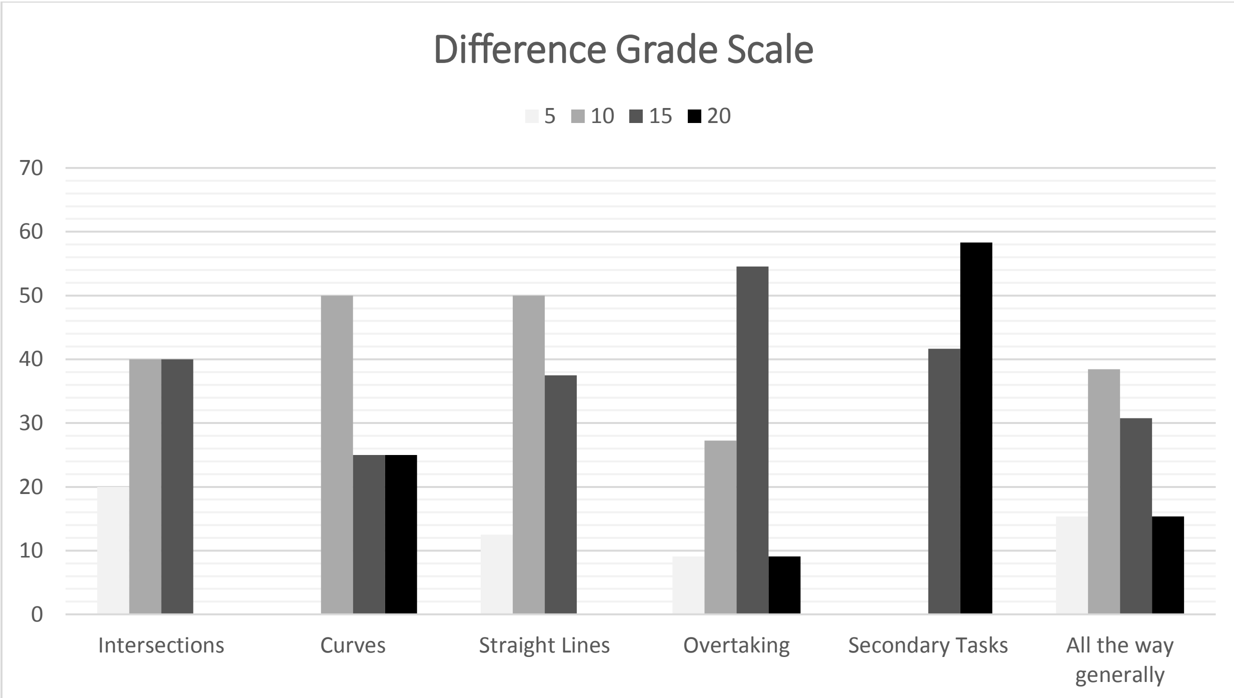
Questionnaires were used to gather subjective ratings as how they perceived the AR-HUD and how they felt during the experiment. Out of 23 subjects in total, 15 persons had a preference for AR-HUD with tracking conditions (65.5%), 4 of them had a preference for the none-tracked system and the last 4 didn't have any preference. The AR-HUD with tracking conditions had 15 as median grade with a standard deviation of 6.5 (average = ~13), and the none-tracked system 10 median grade with a standard deviation of 2.5 (average= ~11).

Let's start by looking further into the 15 people that had a preference for the AR-HUD with Tracking Conditions. The first question that rises, is whether they have seen the difference all the way or only in specific situations. The histogram below shows the percentage of persons that have seen/ have not seen the difference between the two systems in different road situations.



After that, we wanted to look further into the scale factor in the case where the difference was seen between the two systems. In the graph below, we can see the number of persons with respective ranks for each specific road situation.

The grades go from 5 (weak difference) to 20 (strong difference).



Statistical Test Results «Wilcoxon Ranksum»

For the 65.5% people that preferred the HUD with Tracking, our initial hypothesis was that the precision difference would be significant between the two systems and that imprecision ranks would be different in all of the following situations: intersections, curves, straight lines, overtaking manoeuvers, secondary tasks, and all the way in general . In order to measure this difference we used “Wilcoxon Statistical Test”, which is a non-parametric statistical test. In our case, we used the matched data for two tasks (driving session with tracking and driving session without tracking). This test yielded the following results:

Intersections: $p = 7.1901e-004$, $z = 3.3822$, Curves: $p = 0.0246$, $z = 2.2479$, Straight Lines: $p = 7.1901e-004$, $z = 3.3822$, Overtaking: $p = 0.0025$, $z = 3.0225$, Secondary Tasks: $p = 8.1464e-005$, $z = 3.9401$, All the way in General: $p = 0.0019$, $z = 3.1116$.

As we can see p values are $<<0.05$, which means that the difference judged by the 15 participants is very significant. When taking all ranks for the same conditions (Tracking ON/ Tracking OFF) the global p value yielded by the same test is highly significant: $p = 4.5667e-008$ with $z = 5.4674$.

As mentioned above, a large majority preferred the AR-HUD with tracking conditions, and those participants evaluated the system to be more precise in all different road situations than the other system. It was surprising that some persons (8 of them) didn’t manage to see the difference between the two systems. On closer examination, it was found that the majority of these drivers left a significant gap with the front vehicle, so they either had no preference or preferred the second configuration system. For the 4 persons that preferred the none-tracked system, 3 of them started the experiment with this system and only one person started with the tracked system. All of them reported a better adaptation for the system they preferred and less eyestrain. When a person leaves a large gap with the vehicle in front and the same vehicle is highlighted at 3 meters there is an adaptation problem due to eye confusion to make the focus. The order factor was significant because eyestrain was more important in those cases. In the debriefing phase, some of them admitted that they didn’t pay much attention to system alignment since it was far, and all of them complained that it was hard to focus when the car was far away. Furthermore, head movement data has been explored and primary analysis show that while head movements varied significantly between test subjects, those that didn’t see the difference were less likely moving their head during the driving session.

DISCUSSION

As we have seen, results were most significant when participants didn't leave too much gap with the preceding vehicle. At present, results for other participants who either showed no preference or preferred the other system remain to be fully assessed over time. We can, however, say that early observations show that most of these participants had more eyestrain problems due to the significant gap they left with the preceding vehicle and some of them didn't even pay attention to the Bounding-Box alignment with the corresponding car. Adding to that, only few participants showed a preference for the non-tracked AR-HUD, and this preference was weak. We thus find every reason to believe that this was due to the order effect since almost all of them showed a preference for the first system they started with.

It is generally accepted that using Augmented Reality to highlight some information might result in ignoring other important information. Even though it was not the purpose of our study, this idea was verified for many participants. This was noticed when the front vehicle was framed all the time, if a vehicle was present in an intersection and was not framed (in our system depends on the gap distance the driver keeps with the front vehicle, the virtual HUD is only provided on the front face of the CAVE for technical limitations), we have observed that driver's attention was most of the time diverted (considering a subject average). Even though the simulator offered a large stereoscopic view, it actually lacks other important cues, and the image resolution (**1024** x **768** par face) was not sufficient in the yield study and most likely weakens the results, as many participants reported it and others confirmed when they were asked about it at the debriefing phase. Many participants reported that the image resolution was low and it makes it hard to focus properly, and this was even more pronounced when the person wears glasses. Some participants indicated that they were confused in some situations because it was distracting to have the system activated all the time. Four participants withdraw due to motion sickness. Two persons reported that the noise was not realistic. Future work will be carried out using Renault's new CAVE like dynamic Driving Simulator CCARDS, which offers a better image resolution. It is equipped with a motion platform and it allows reproducing acceleration sensation and the steering wheel force-feedback, thus increasing the level of immersion and decreasing motion sickness.

CONCLUSIONS

Augmented Reality Technologies are the new tends in many domain. One of the new application field is the Automobile Industry, linked to the necessary men machine aspects of Advanced Driving Aid Systems (ADAS) is Augmented Reality (AR). The experiment aimed to compare the perception between two prototypes of Augmented Reality Head-Up-Display (Head-Up-Display) with and without Head Tracking.

Our research has shown that the majority of participants saw a precision difference between the two AR-HUD prototypes, and preferred the one with Head-Tracking function. Indeed, these participants noticed that this system was meaningfully more precise in all road situations, even if they didn't know the experimental conditions. As discussed above, comparing the statistical data in the two experimental conditions allows us to say that the large majority of drivers that preferred the AR-HUD with tracking condition saw a significant precision difference between the two AR-HUD prototypes. Subjects that had either no preference or preferred the other system left a significant gap with the leading vehicle. We are firmly convinced that this was due to this gap, which undoubtedly inhibited them from seeing the Bounding-Box over highlighted cars. As for the participants that preferred the non-Tracked system, we think that the order effect might have influenced their choice since the more they tried to focus the more eyestrain was important.

According to our experimental results, taking in consideration Head Motion Parallax improved the precision of the AR-HUD. Our future work will be carried out on performance parameters analysis related to trajectory control, lateral position, and steering wheel, relatively to head movements in different road situations using Renault's new CAVE like dynamic Driving Simulator CCARDS.

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REFERENCES

Caro, S. (2008). *"Perception et contrôle de la distance intervéhiculaire en condition de brouillard: Etude sur simulateur".* (Doctoral dissertation, Université Pierre Mendès-France-Grenoble II).

Charissis, V., Naef, M., & Patera, M. (2007, January). *"Calibration requirements of an automotive HUD Interface using a Virtual Environment: Methodology and Implementation"*. In Proceedings of: International Conference in Graphics and Visualisation in Engineering,(GVE'07), Clearwater, Florida, USA.

Charissis, V., & Naef, M. (2007, June). "*Evaluation of prototype automotive head-up display interface: testing driver's focusing ability through a VR simulation"*. In Intelligent Vehicles Symposium, 2007 IEEE (pp. 560-565). IEEE.

Gibson, E. J., Gibson, J., Smith, O. W., Flock, H. (1959). *"Motional Parallax as a Determinant of Perceived Depth"*. Journal of Experimental Psychology. Vol. 58, pp. 40-51.

Gibson, J. J. (1968). *"What gives rise to the perception of motion?".* Psychological Review, 75(4), 335.

Hultgren, J. A., Blissing, B., & Jansson, J. "Effects of motion parallax in driving simulators".

Kemeny, A., & Panerai, F. (2003). "*Evaluating perception in driving simulation experiments.* Trends in cognitive sciences, 7(1), 31-37.

Mas, A., Merienne, F., & Kemeny, A. (2011). *"Lateral control assistance and driver behavior in emergency situations".* Advances in Transportation Studies RSS2011 Special Issue, 149-15

McLean, J.R. & Hoffman, E.R. (1975). "*Steering wheel reversals as a measure of driver performance and steering task difficulty*". Human Factors 17,248-256.

Mestre, D.R. & Lepecq, J.C. (2007). *"Assessments of head roll during simulated driving"*. In A.G. Gale (Ed.), Vision in Vehicles XI, Elsevier Science B.V. (North-Holland) (in press)

Palmqvist, L. (2013). *"DEPTH PERCEPTION IN DRIVING SIMULATORS: Observer-produced motion parallax, how it affects car drivers' position and perceived presence"*. Bachelor's thesis