Simulation sickness comparison between a limited field of view virtual reality head mounted display (Oculus) and a medium range field of view static ecological driving simulator (Eco2)

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Abstract – In this article, an experimental procedure is presented in order to evaluate the role of having HMD oculus and (Eco2 driving simulator) in terms of driving simulation sickness. The driving simulation sickness is investigated with respect to SSQ (simulator sickness questionnaire) and vestibular dynamics (head movements) of the driver participants for a specific driving scenario. The scenario of driving task is created by using open source "iiVR (institut image virtual reality)" software which is developed by Institut Image Arts et Métiers ParisTech. The experiments are executed in static mode for the driving simulators.

Key words: Driving simulation, simulation sickness, virtual reality, field of view, visuo-vestibular cues

1. Introduction

The driving simulators are getting more and more benefited to evaluate the vehicle dynamics, advanced vehicle control systems such as ESP, ABS, ACC, etc.… Powertrain systems (such as gasoline, diesel internal combustion engined, hybrid or electric vehicles) for the first prototypes of the new developed cars. Not only the vehicle concepts but also the driver behavior are of interest. In general, there are two different types of driving simulators as [Ayk1, Ayk2]:

- static driving simulators (without motion platform or motion platform is inactivated)
- dynamic driving simulators (with motion platform or motion platform is activated)

In driving simulation, simulation sickness is an inevitable topic to study further on and therefor it is required to develop systems and/or methods to decrease it.

An important issue to deal with, in terms of driving simulation sickness, is the transport latency. In moving based driving simulators with fixed visual systems, a compensation of display system is essential to provide a visual stability for the driver. A delay in visuo-inertial cues shrinks the coherence and might induce a bias (incoherence) in the driver's behaviour. Even though drivers are able to compensate those delays and to ensure the control of the car, those latencies have to be declined. A simple linear prediction model was shown inappropriate. Transfer functions based algorithms of the motion platform were revealed to be more efficient to detract this delay [Kem1, Dag1].

Motion cueing algorithms are used to represent the physical motion at dynamic simulators. The results of a multi-partner European collaborative project were described, which examined different scale factors in a slalom-driving maneuver. The results from four comparable experiments at driving simulator, which were acquired with 65 subjects, denote a predilection for motion scale factors below 1, within a wide range of acceptable values (0.4-0.75). However, so much reduced or absent motion cues significantly degrade the driving performance [Ber1].

"CAVE" is a multi-sided box with displays on each surface used in virtual reality (VR) environments. It has been sufficient and enough for so long as the "immersive" simulation of VR resulting from the inadequate head-mounted displays (HMDs) in that domain [Man1 , Sha1, Tos1, Kim1]. However, current HMDs are able to compete with many CAVEs and actually have started to take over them [Hav1].

A study had been made in order to compare the levels of presence and anxiety in an acrophobic environment that was visualized by using a computer automatic virtual environment (CAVE) and a head-mounted display (HMD) [Jua1]. In that environment, the floor was falling away and the walls were rising up. So as to specify whether any of these two visualization systems provoke a greater sense of presence/anxiety in non-phobic users, the experiments for the two visualization systems had been performed to compare their influences on the subjects.

Twenty-five participants had joined in the study of [Jua1]. After having used each visualization system (HMD or CAVE), the participants had been asked to complete an adapted Slater et al. questionnaire [Sla1, Jua1], and a *t* test had been utilized to the registered data for assessing whether a significance in difference of the yielded results. According to [Jua1], the CAVE induces a more elevated level of presence in users. The mean score had been 5.01 (where 7 is the maximum value), which had been more elevated than the score obtained using the HMD which had been 3.59. The *t* test had also revealed that there had been significant statistical differences. The anxiety stage had also been examined at different times during the experiments. The results emphasize that both visualization systems provoke anxiety, however that the CAVE provokes anxiety more than the HMD does. The animation in which the floor fell away was the most important reason that had caused a higher provocation of the anxiety. [Jua1].

In our study, the effect of using Oculus Rift HMD and the Eco2 driving simulator has been discussed.

2. Methods and materials

Fig. 1. Oculus rift HMD in driving simulation experiments

Fig. 2. Eco2 driving simulator in driving simulation experiments

The aim of the experiments is to differentiate the influence of having HMD oculus and the Eco2 driving simulator for the driving simulation aspect and to compare the convergence to the reality for each condition. Hence, a scenario has been created in the software iiVR that enables generating a specific driving incidence. The scenario is composed of several roundabouts and curvatures.

Fig.1 illustrates the playseat low cost static driving simulator with use of HMD Oculus and the computer screen also depicts the driver view of the driving scene during the operation by the driver, whereas Fig. 2 indicates a real-time driving experiment in the ECO_2 driving simulator.

For each type (HMD and Eco2 simulator), the vestibular dynamics related motion sickness (objective metrics) and the psychophysical situations (subjective measures through questionnaires) of the drivers' are measured. Fig. 2 also illustrates the sensor that is used to measure the head (vestibular related) dynamics data (attached to the headphone from right).

The effect of having a different visual interface is explained statistically for the driving simulation and the proximity to the reality for the subjects who participated in the experiments.

3. Objective measures

The dynamic information of vehicle and movement of head are all recorded in files. By building a model of Simulink, we could get the acceleration of vehicle and head (vestibular). In order to evaluate the conflict of these two accelerations as longitudinal and lateral, Pearson correlation and Mann-Whitney U test are employed in Matlab.

Pearson correlation between sets of data is for measuring how related they are, which is to show the linear relationship of two sets of accelerations. In Pearson correlation, two values are presented in final calculation results: in Matlab, [r, p] = corrcoef (X, Y), in which r is coefficient of correlation; p is the probability; X and Y are respectively the matrix of accelerations of vehicle and head. If r is between 0.5 and 1.0 or -0.5 and -1.0, that means high correlation; otherwise low correlation. If r is 0.0 to -1.0, there is a negative correlation.

In order to analyze the significance in differences between the head and vehicle data, another analysis method (bilateral Mann-Whitney U test) is used in Matlab. Mann-Whitney U test can evaluate two sets of data without condition on sample size. In Matlab, [p, h, stats] =ranksum (X, Y), p value is the probability; h indicates a rejection or accept of the null hypothesis; stats includes information about the test statistic. Therefore if $p > 0.05$ or h=0, null hypothesis is accepted, in other words, there is no significant difference between two sets of data. If $p < 0.05$ or h=1, null hypothesis is rejected, in other words, there is a significant difference between two sets of data.

4. Subjective measures

The subjective measure is to conduct a questionnaire for subject at the end of each driving simulation phase. These issues are related to the subject feelings. Questions focus on the degree of experienced nausea, possible dizziness, headaches, fear, uneasiness…etc. Table 1 lists the questions in this report after each driving phase. The purposed questionnaire in this report has been built and modified from the following articles [Ken1, Kim2, Xse1]. Different from the questions in resources above, in this report two questions about the visual and immersive quality of scene are included. The questionnaire permits to evaluate the disorientation and the response range from 1 to 10, which is a modified SSQ (simulator sickness questionnaire) from 1 to 4 (SSQ). Our range allows more possible choice.

Table 1. List of questions

Questions	Expression of question
Q1	Have you felt nausea?
Q2	Have you felt dizziness?
Q3	Have you felt eyestrain?
Q4	Have you felt headache?
Q5	Have you felt mental pressure?
Q6	Have you felt fear when you face the critical situation?
Q7	Have you felt uneasiness?
Q8	How do you evaluate the visual quality?
Q9	How do you evaluate the immersive quality?

The subject had to answer each of these questions with a value. This value should reflect psychophysical perception of the experiment (1: too little, 10: too strong for the questions 1 to 7; 1: very bad, 10: very good for the questions 8 and 9). Subsequently, these values were statistically analyzed.

Before the subject answers these questions, they should have firstly written down some personnel information, which allows analyzing the data more deeply. Here is the list these questions: *your name; your age; driving experience; type of driving license; experience of game playing (first-person); experience of virtual reality (VR)*.

In all subjects, 12 of them are men and 2 are women. Age varies from 20 to 36 (Mean ± SD = 24.4. ± 2.3; SD: standard deviation) 6 of them do not play first-person game, 4 of them sometimes play and 4 of them often play. 9 of them have no experience of virtual reality and 5 of them often work in VR environment.

5. Results

We want to explain our results about the study, which is related to comparison between Oculus HMD and Eco2 simulator. The MATLAB/Simulink is used to calculate the data and present the results.

5.1. Results of objective analysis

Fig. 3 presents a protocol of vehicle speed with respect to time. The speed condition in the experiments is maximum 60 km/h.

Fig.4 describes the vehicle trajectory during the experimental phase.

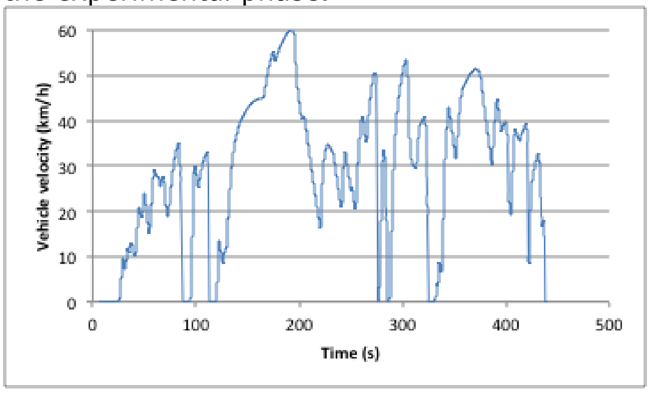

Fig. 3. Vehicle velocity

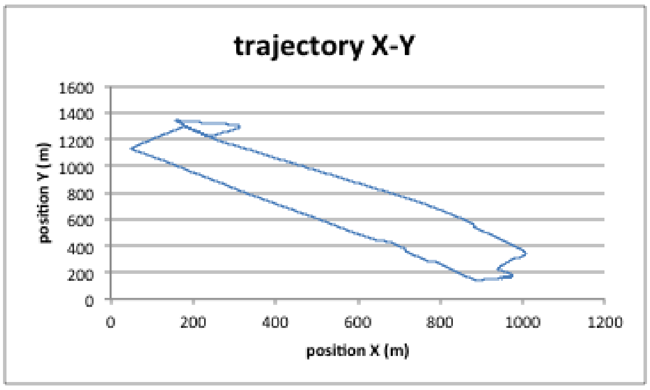

Fig.4. Trajectory X-Y of the vehicle for the experiment protocol

For Oculus, Fig. 5 and Pearson correlation show that there is a significant negative correlation between a_{x_veh} (longitudinal vehicle acceleration) and a_{x_vest} (head dynamic) (r(14)= -0.2729 and p=0.0000). This means that Oculus has a trend for increase in simulator sickness in longitudinal acceleration.

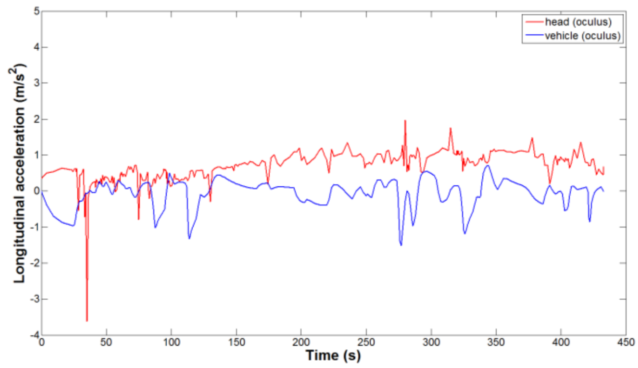

Fig. 5. Longitudinal acceleration of vehicle and vestibular of Oculus in real-time (m/s^2)

Fig. 6 indicates the result of bilateral test of Mann-Whitney U: U(14); h=1, p=3.0795×10^{-243}. Zval: 33.3068. Ranksum: 1370364. This means there is a significant difference between a_{x_veh} and a_{x_vest}.

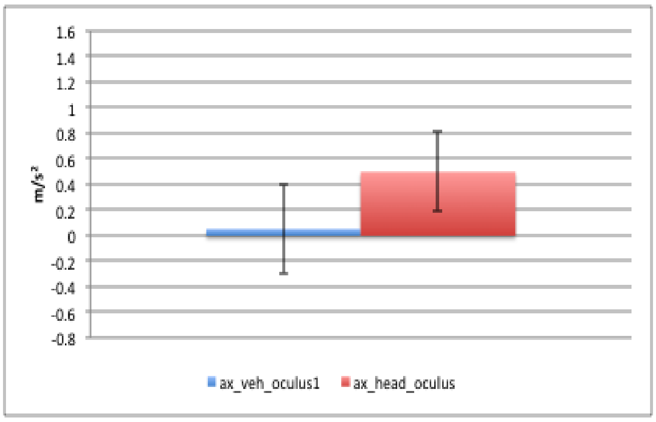

Fig. 6. Longitudinal acceleration of vehicle and vestibular of Oculus in real-time (m/s^2)

For Eco2, Fig. 7 and Pearson correlation show that there is a significant positive correlation between a_{x_veh} and a_{x_vest} (r(14)=0.2512 and p=0.0000). This means that Eco2 has a trend to avoid simulator sickness in longitudinal acceleration.

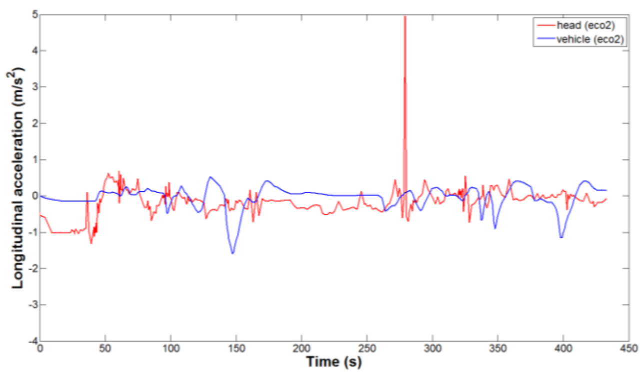

Fig. 7. Longitudinal acceleration of vehicle and vestibular of Eco2 in real-time (m/s^2)

Fig. 8 indicates the result of bilateral test of Mann-Whitney U: U(14); h=1, $p=2.0730\times10^{-13}$. Zval: 7.3440. Ranksum: 1046600. This means there is a significant difference between a_{x_veh} and a_{x_vest}.

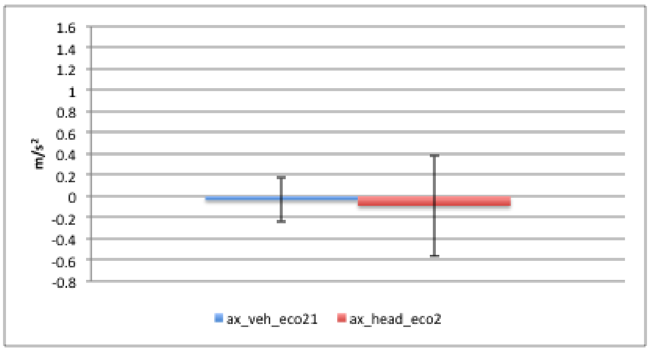

Fig. 8. Longitudinal acceleration of vehicle and vestibular of Eco2 in real-time (m/s^2)

For Oculus, Fig. 9 and Pearson correlation show that there is a significant negative correlation between a_{y_veh} (lateral vehicle acceleration) and a_{y_vest} (head dynamic) (r(14)= -0.4093 and p=0.0000). This means that Oculus has a trend to raise simulator sickness in lateral acceleration.

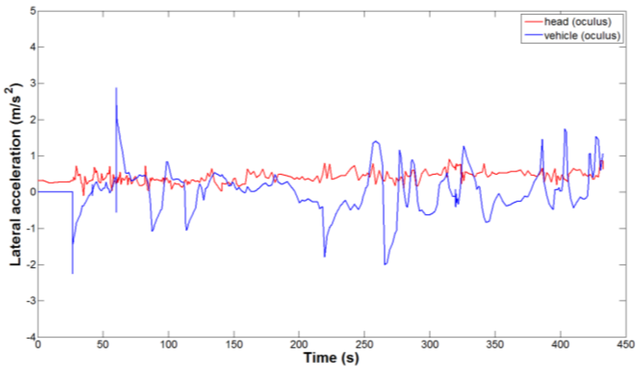

Fig. 9. Lateral acceleration of vehicle and vestibular of Oculus in real-time (m/s^2)

Fig. 10 indicates the result of bilateral test of Mann-Whitney U: U(14); h=0, p=0.3687. Zval: 0.8989. Ranksum: 966227. This means there is no significant difference between a_{y_veh} and a_{y_vest}. (Avoidance of simulator sickness)

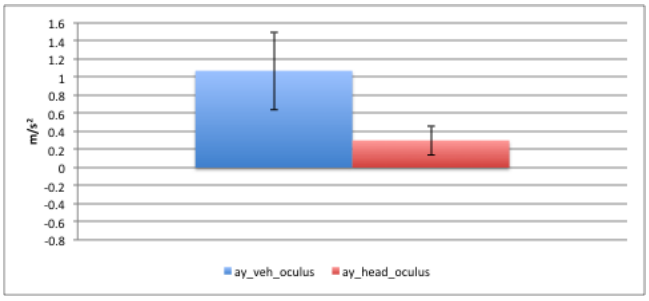

Fig. 10. Lateral acceleration of vehicle and vestibular of Oculus in real-time (m/s^2)

For Eco2, Fig. 11 and Pearson correlation show that there is a significant positive correlation between a_{y_veh} and a_{y_vest} (head dynamic) (r(14)=0.2855 and p=0.0000). This means that Eco2 has a trend to avoid simulator sickness in lateral acceleration.

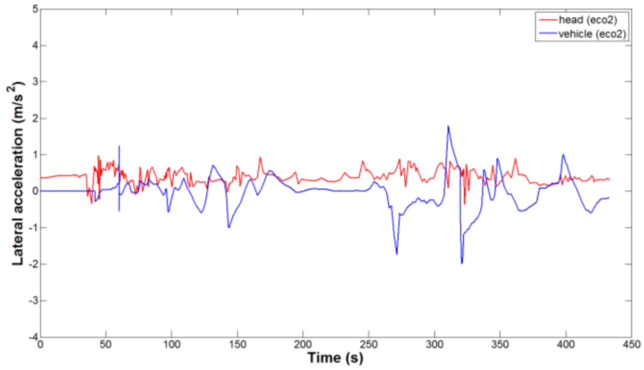

Fig. 11. Lateral acceleration of vehicle and vestibular of Eco2 in real-time (m/s^2)

Fig.12 indicates the result of bilateral test of Mann-Whitney U: U(14); h=1, $p=2.6036\times10^{-177}$. Zval: 28.3911. Ranksum: 1309026. This means there is a significant difference between a_{y_veh} and a_{y_vest}.

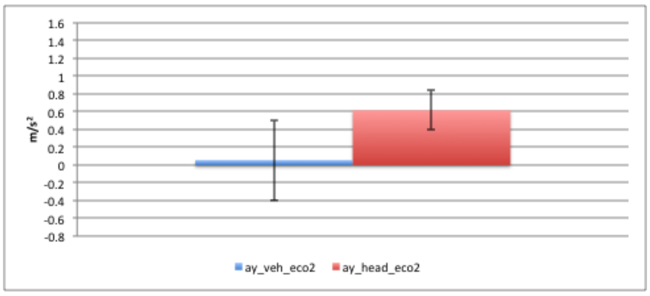

Fig. 12. Lateral acceleration of vehicle and vestibular of Eco2 in real-time (m/s^2)

5.2. Results of subjective analysis

Fig.13 presents the results of subjective evaluation that has been accomplished according to the self-report of the participants just after each experiment session.

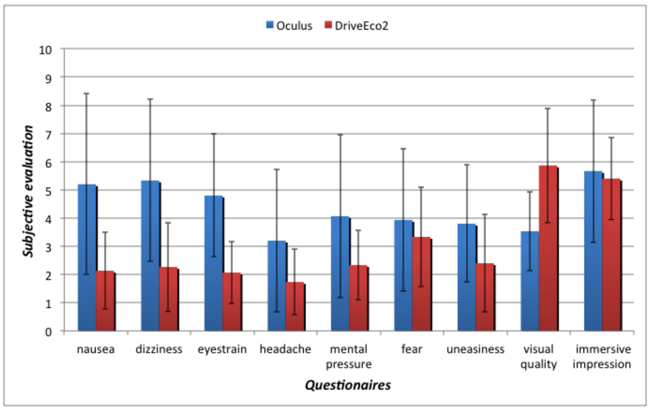

Fig. 13. Subjective evaluation

Q1) Nausea (1: too little, 10: too strong): ($U(14)$, $p=0.012<0.05$)

There is a significant difference between Oculus and Eco2 with respect to feeling of nausea. Nausea with Oculus is significantly stronger than Eco2.

Q2) Dizziness (1: too little, 10: too strong): ($U(14)$, $p=0.005<0.05$)

There is a significant difference between Oculus and Eco2 with respect to feeling of dizziness. Dizziness with Oculus is significantly stronger than Eco2.

Q3) Eyestrain (1: too little, 10: too strong): ($U(14)$, $p=0.002<0.05$)

There is a significant difference between Oculus and Eco2 with respect to feeling of eyestrain. Eyestrain with Oculus is significantly stronger than Eco2.

Q4) Headache (1: too little, 10: too strong): ($U(14)$, $p=0.082>0.05$)

There is no significant difference between Oculus and Eco2 with respect to feeling of headache. Headache with Oculus is non-significantly stronger than Eco2.

Q5) Mental pressure (1: too little, 10: too strong): ($U(14)$, $p=0.142>0.05$)

There is no significant difference between Oculus and Eco2 with respect to feeling of mental pressure. Mental pressure with Oculus is non-significantly stronger than Eco2.

Q6) Fear (1: too little, 10: too strong): ($U(14)$, $p=0.657>0.05$)

There is no significant difference between Oculus and Eco2 with respect to feeling of fear. Fear with Oculus is non-significantly stronger than Eco2.

Q7) Uneasiness (1: too little, 10: too strong): ($U(14)$, $p=0.097>0.05$)

There is no significant difference between Oculus and Eco2 with respect to feeling of uneasiness. Uneasiness with Oculus is non-significantly stronger than Eco2.

Q8) Visual quality (1: very bad, 10: very good): ($U(14)$, $p=0.005<0.05$)

There is a significant difference between Oculus and Eco2 with respect to visual quality. The visual quality of Eco2 is significantly better than Oculus.

Q9) immersive impression (1: very bad, 10: very good): ($U(14)$, $p=0.798>0.05$)

There is no significant difference between Oculus and Eco2 with respect to immersive impression. The immersive impression of Oculus is non-significantly better than Eco2.

6. Conclusion

We compared the longitudinal and lateral accelerations of vehicle and head. The feelings after experiments are also analyzed by Mann-Whitney U test and Pearson correlation methods to evaluate the significant difference.

Deviation between vehicle and head accelerations depends on the scale factor (vertical to horizontal field of view) and especially the limited field of view static driving simulator. If it had a broader horizontal field of view, the simulation sickness when going from 60° to 150°, would probably be doubled the rate of simulator sickness (40° vertical – Eco2 very low).

For Oculus, these two longitudinal accelerations of vehicle and head are significantly different according to Mann-Whitney U test and Oculus has the trend to increase simulator sickness due to Pearson correlation; these two lateral accelerations of vehicle and head have no significantly difference according to Mann-Whitney U test and Oculus has the trend to rise simulator sickness due to Pearson correlation.

For Eco2, these two longitudinal accelerations of vehicle and head are significantly different according to Mann-Whitney U test and Eco2 has the trend to avoid simulator sickness due to Pearson correlation; these two lateral accelerations of vehicle and head have significantly difference according to Mann-Whitney U test and Eco2 has the trend to avoid simulator sickness due to Pearson correlation.

For the feelings of nausea, dizziness and eyestrain, there are significant difference between Oculus and Eco2; Oculus can cause more sickness than Eco2.

For the feelings of headache, mental pressure, fear, uneasiness and immersive impression, there are no significant differences between two simulators. From the average value of each feeling, we can see that Oculus cause more sickness than Eco2.

For the visual quality, there is significant difference between Oculus and Eco2; Eco2 is much better than Oculus in visual quality.

In conclusion, Oculus HMD can cause more sickness in driving simulation than medium FOV system such as Eco2 driving simulator though this type of HMD may provide better immersive impression than medium large FOV display systems.

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