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Are Virtual Reality headsets efficient for remote driving?

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ABSTRACT

This study aims to analyze possible benefits of using Virtual Reality (VR) headset display instead of monitor in remote driving. It compares results of a sample of users driving in a simulated environment using VR headset then monitor display.

Virtual reality headsets become a source of inspiration in a lot of domains. But no study considers using the viewing freedom it brings to improve remote driving and avoiding crashes in rough environments. This study focuses on possible benefits of using virtual reality headset beside monitor display in remote driving. It compares driving efficiency of a sample of users driving in a simulated environment using VR headset and monitor display. In order to benefit from the flexibility it offers, we used, as a first step, a simulated environment that is easier to transform.

For our experiment we used the following hardware: a Windows 7 computer, Euro-Truck Simulator 2 [ETS2], a Logitech G27 racing wheel, a Thrustmaster T16000M joystick and an Oculus Rift headset DK2 [OCULUSDK2]. Our tests have been performed on Euro-Truck as it is one of the few software supporting VR headsets. Moreover, Euro-Truck brings a built-in tool, which allows us to create our map. This map is divided into several sections designed as exercises for users. It is designed to explicit the relevance of viewpoint freedom in critical remote driving situations. We analyzed the overall performance of the user using several criteria: time needed to execute all sections, viewpoint changes, penalties accumulated through collisions and number of falls.

The map is divided into four sections: First section consists in corridors with sharp turns, requiring the user to perform complex manoeuvring. Second section is composed of an elevated platform, requiring the user to be extremely precise in its driving. Third section goal is to reach objects, hidden in surrounding environment. Fourth is a high-speed slalom, user needs to anticipate its next turn. A sample of 44 users has done the experiment. The test is composed of two exercises of five minutes each, one with a VR headset and one with a monitor. The user can move his point of view using his head with VR headset or using a joystick without.

Most users discovered VR headset with this experiment and 49% of users were not able to finish it due to sicknesses during utilization of the Oculus Rift. This situation is well known by VR users, developers and creators. Concerning our study, 61% of users who have finished the experiment achieved a lower completion time with the Oculus Rift. The time is improved in mean by 18% and up to 49% compared with monitor display time. During these tests, we also noticed that most of the users did not use the joystick whereas every subject used his head to increase his environment perception. Up to 70% of users returned us their feeling of an easier driving with Oculus Rift, even subjects made sick by it.

These results show that users take advantage of viewpoint freedom to increase manoeuvring, and being more reactive. This shows that VR headset could be a great alternative to monitor for remote driving. Furthermore, we are working on the next step, which is making an immersive driving system on a mobile robot platform, and complete this analysis with real driving tests on this platform.

KEYWORDS

ADAS; Oculus Rift; Virtual Reality; Headset; Driving; Safety

INTRODUCTION

Vehicle automation is a great challenge for future products, but today users, especially armies, are not ready for deployment of fully automated vehicles. A gate to make them accept, is spreading of remotely guided vehicles. But, existing remotely guided products are not yet used at their maximum capacity because of driving difficulties. A lot of crashes occur due to human errors. These crashes, not including casualties, are not classified as major, but avoiding loss of robots can be an important financial benefit and an increasing way of automation acceptance. To decrease number of accidents we work on defining and setting up a driving assistance system for remote driving, or indirect driving. Indirect driving being the fact of driving without direct line of sight to exterior environment, like in a fully armoured vehicle without window driven with screen display.
This work has two axes. First axe is software solutions development for path planning and hazard detection like the preliminary work treated in [RICAUD2014]. In it, we improved by 32 times an existing pathways detection solution for rough environment, such as dirt road or snow environment. This solution was a tool used to extract road in order to detect possible hazards on it.
Second axe is hardware experiments for remote driving improvements. Researches on Oculus Rift are part of it.
In our point of view displaying information on monitor is one of the biggest problems of actual remote driving interfaces. Actually, displaying driver viewpoint on a monitor bring an important lack of information. Two problems occur:

- Viewpoint restriction due to small screens, about 14 inches (Figure 1), that can display one camera by one camera with a field of view of 60° each.
- Lack of depth perception due to 2D cameras displaying essentially black and white images that downgrade context and do not give any depth.

Whereas lab researches did more and more improvement in remote driving interfaces [FONG2003, BRADY2002], actual industrial solutions try to answer the viewpoint restriction by adding monitors (Figure 1) displaying exterior cameras images positioned around the vehicle. This solution is helpful but not sufficient. Undeniably, adding monitors helps operator to perceive his environment but it also decreases operator on-board space that is already very limited.

Figure 2: Driving an armored vehicle with an Oculus Rift. Credit to Norway Army

Figure 1: On-board monitor multiplication. Credit to Nexter Systems

We decided to work on virtual reality headset for several reasons. First, it is as cheap as monitors, so it does not add cost to current systems. Second, this technology appears to be one of tomorrow-mainstreamed products, this means fast improvements brought by competition spirit. Third, by its conception it allows a fully 360 degrees viewpoint freedom in system capable of recreating a complete 3D environment around vehicle from sensors acquisitions. Fourth, this viewpoint freedom is accessible without adding more equipment (Joystick) to be used by operators due to included tracking done with IMU and infrared camera.

By manufacturing Oculus Rift, Oculus matures virtual reality Headsets and increases interest about it. Researches from all kinds appear last years, as tracking improvements [RABET2014] or medical game developments [BLAHA2014]. On another hand, Norway Army showed recently (Figure 2) that it is looking after solution for improving armoured vehicle driving also known as transparent shielding. All these topics manifest the growing

interest for virtual reality and virtual reality headsets. Some researches concern remote driving [BUG2015], but none compares the current integrated solution, screen display, to VR headset. It convinced us to verify by our own that interest to VR headsets is justified.
As it is the most developed and easily accessible virtual reality headset, we used Oculus Rift, but we are not limited to it. A lot of other products will appear this year on the developers market: Valve-HTC Vive, Oculus-Samsung Gear, Sony Morpheus [WAREABLE2015].

This study was preliminary to large-scale researches with such technology. Its focus was to determine if viewpoint freedom brought by Oculus Rift by correlating head motion and viewpoint motion, improves performances in several tasks, especially driving in complex environment.

METHODOLOGY - Hardware & Software

In our experiment the following hardware is used (Figure 3): The virtual reality headset Oculus Rift Developer Kit 2, a 14 inches screen, a Windows 7 computer, Euro-Truck Simulator 2 video game, a Logitech G27 racing wheel and a Thrustmaster T16000M joystick.

Figure 4: Euro-Truck simulator 2, map construction. Here a view of tutorial zone 2.
Credit to Euro-Truck simulator 2.

Figure 3: User installation, with Oculus Rift (Left), with Monitor and Joystick (Right)

As explained in Introduction section, Oculus Rift was at time of experiment the most advanced virtual reality headset on market. Windows 7 computer was mandatory as Oculus Rift DK2 was not fully supported on Unix OS. Moreover, simulators game library it offers gave us a lot of possibilities. We have chosen Euro-Truck Simulator 2 for several reasons:

- It comes with a map editor (Figure 4), which means that we were able to create our own track with its obstacles and hazard.
- It is fully supporting Oculus Rift (Figure 6).

Euro Truck Simulator 2 (ETS2) offers a realistic cockpit (Figure 5) that gives visual references about head motion. These essential references are necessary to reduce sickness generated by VR systems.

Figure 5: Realistic cockpit implemented in ETS2.
Credit to Euro-Truck simulator 2.

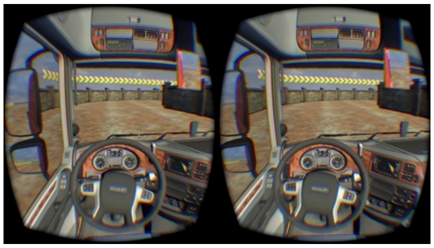

Figure 6: Image of Euro-Truck Simulator displayed on Oculus Rift Monitor inside headset.
Credit to Euro-Truck simulator 2.

Oculus Rift is a VR headset system composed by an OLED screen displaying two stereoscopic highly defined (960p) images (Figure 6) at 75Hz. Head pose is computed by capturing data from an internal IMU and an infrared camera tracking infrared LED positioned all over the headset.

METHODOLOGY - Units of Measure

Users performances have been measured following several criteria:

1) Full circuit completion time,
2) Head motion frequency and joystick handling,
3) Penalties caused by colliding environment such as walls and road signs, or platform falls. See next sections for details about environment and penalties.

1) Full circuit completion time computation consisted in adding all exercise times (explained in next section) to possible penalties. Exercise time was the time needed (in seconds) by users to complete defined tasks mandatory to evolve to next phase.

2) 3D environment allows users a fully 360° viewpoint freedom (in our case, 180° composed of window and the rest was truck's interior). We measured frequency with which users moved their head to take information from environment. A joystick allowed users to change screen viewpoint when they were experimenting screen display as well as head motion with Oculus Rift. Joystick handling was measured too. Scoring was executed by an exterior operator, which was observing experimenting user. This criteria was evaluated from 0 to 5, 0 when no viewpoint change was detected and 5 when user took a lot of information about surrounding environment.

3) Giving penalties in some cases encouraged driving precision (like collision with obstacles). In the following, precision is quantified with penalties. More details concerning their description are given in next section.

METHODOLOGY - Exercises

The circuit (map) was divided into four exercises defining a range of tasks users had to complete.

Figure 7: Image of Euro-Truck Simulator, giving preview of viewpoint freedom. Image taken during the first phase. Credit to Euro-Truck simulator 2.

The First exercise (Figure 7) aimed to show the interest of taking advantage of viewpoint freedom to achieve precise manoeuvres without knowledge of following turns. We built this exercise with several very sharp turns between 90° and 180°. Moreover, high walls were surrounding the way, forbidding user to see what was coming next. Lack of visibility should forced user to look around to gain information to turn without losing precious time. In this exercise penalties were the collisions with walls, it costs 5 seconds each to user.

As the first one, the second exercise (Figure 8 Top Left) has been designed to exhibit necessity of looking around and use viewpoint freedom to achieve precise manoeuvres. In this case users had knowledge of future environment since the entire platform was in sight. Driving was done at high altitude, about 5m from ground on a platform not wider than truck chassis. In this exercise, penalties were determined as falls. Falling from a platform provoked heavy time penalty: to go back into circuit users had to search then take a ramp that brought them back onto the platform, this operation could cost them until 30 seconds.

Third exercise (Figure 8 Top Right) called “Search and Destroy” asked user to search for particular road signs hidden in or around a dense vegetated environment. When found, these road signs had to be rolled over without touching the forbidden road signs. This exercise evidenced interest of having viewpoint freedom in case of research for information in environment where reigns low visibility. This case of application is very common when using robot. De facto, for security or militaries purposes, robots are often used to detect explosives, or retrieve information in dangerous places. In this exercise, the forbidden road signs touched counted as penalties, it costs 5 seconds each to user.

The fourth and last exercise (Figure 8 Bottom Left) was a slalom at high speed. In this one, we tried to spot head movements made by users to prepare their following turns. This exercise has objective to demonstrate that the key to high speed remote driving is the necessity to give user the ability to prepare next turn by looking at it. In this exercise, a missed or collided gate costs a 5 seconds penalty.

Figure 8: Second (top left), third (top right) and fourth (bottom left) phases.
There is an overview of the elevated platform, road signs of the “Search and Destroy” exercise - central parking road sign has to be rolled over avoiding forbidden parking road signs and slalom.

Credit to Euro-Truck simulator 2.

METHODOLOGY - Protocol

The experiment was divided into two phases of 5 minutes each. The only differences between these two phases were the display method and viewpoint control method. One phase was dedicated to Oculus Rift when the other one was dedicated to monitor and joystick test. To avoid bias caused by users learning the track, we alternated beginning display method. Once experiment began with Oculus Rift and follows with monitor whereas for the following user it was monitor to be used first and then Oculus Rift. Each phase began with a tutorial teaching user what was expected during the four exercises with easier tasks. Of course, time measurement began after tutorial.

At the end of experiment a form was given to users to know their feeling about experiment. This form contained several questions: it asked them to score their sickness from 0 to 5, what benefit brings VR Headset for them, and what they think of the tutorial.

METHODOLOGY – User sample

Users sample is 44. Sample is very heterogenic, ages are from 13 to 60 years old, women, men, boys and girls are part of it. Students, teachers, technicians and bus drivers compose it.

It is important to note that this experiment was, for most of the users, the first experiment with Oculus Rift and VR headsets. Unfortunately 49% of users were not able to complete the whole circuit because of sickness. Indeed, "Simulator Sickness" is well known by virtual reality users [HOWARTH1997]. It varies from a user to another and creates nausea and malaise. Societies such as Oculus are working on these pains and try to decrease it with hardware improvements. These improvements concern latency reduction between images, persistence lowering or head motion prediction. This paper does not tackle the problem of simulator sickness. However, it is a major subject to solve for tomorrow transportation as [SIVAK2015] demonstrated it for automated cars.

RESULTS AND ANALYSIS

As exposed in last section, our sample was of 44 users. On this sample 49% of users quitted because of sickness. These sicknesses appear only when using Oculus Rift. In the following analysis users that have ended up experiment will be called "finishers".

In the following paragraphs, we expose detailed results concerning each kind of measurements. Each exercise describes a use case for remote driving of vehicle or robot.

In spite of overall sickness, as shows on Figure 9, 61% of finishers did a better completion time on all the circuit. But this score as to be minored. Indeed, on average time, users did 4 min 44 sec to end the circuit with Oculus Rift when they did 4min 43s with monitor display.

In the first exercise, 74% of finishers did a better time when using Oculus Rift (Figure 10). Average time with Oculus Rift is 57s whereas it is 1min 5s with monitor display. This improvement of 13% appears as a real benefit for this kind of situation that can be compared to robot navigation in indoor environment or vehicle driving in narrow urban environment. "Penalties Exercise 1" Histogram (Figure 14) clearly exposes that there are more penalties with monitor than with Oculus Rift. In this exercise penalties were defined as collisions with walls. This result is notable as it indicates that users experienced less difficulty to execute sharp turns without damaging the truck. It could be explained by the Head motion histogram (Figure 18) where it appears that majority of users benefited of head movement to negotiate their curves and avoid penalties by analyzing environment before executing their manoeuvres (Figure 14 and 18).

In the second exercise, 44% of finishers did a better time when using Oculus Rift (Figure 11). Average time with Oculus Rift is 1min 49s whereas it is 1min 35s with monitor display. It seems that the low number of visual references in this exercise perturbed users, who made mistakes trying to negotiate turns. The second exercise diagrams (Figure 15) exposes that whether for monitor display or Oculus Rift, a lot of falls occurred (8/11). Lack of platform visibility seems to be the main cause of penalties. To be effective users must had to evaluate well when they had to turn and with what intensity. This evaluation was too complicated to realize with so low truck awareness, they tried to estimate the path (Figure 19) and hope to pass the platform.

In the third one, 57% of finishers did a better time when using Oculus Rift (Figure 12). Average time with Oculus is 1min 22s whereas it is 1min 24s with monitor display. This exercise was not as hard as the previous one as shown on the penalties histograms (Figure 16). Oculus Rift still is superior (3%) but considering overwhelming head motions compared to joystick use (Figure 20) it is a surprising result. We expected to see the highest time gap on this exercise. A higher complexity might have increase the gap between completion times, a point that we will study in future experiments.

In the last exercise, 53% of finishers did a better time when using Oculus Rift (Figure 13). Average time with Oculus is 36s whereas it is 39s with screen display. Again, Oculus Rift distinguishes itself by an 8% gain. This gain could be explained by the ease Oculus Rift brought to users compared to joystick (Figure 21) when they had no time to evaluate and prepare their manoeuvres, this observation is also true concerning penalties (Figure 17) where Oculus Rift driving resulted in less gate miss or gate collisions. This situation equivalent to all day driving demonstrates that comfort brought by hand free viewpoint movement improves curves estimation and path negotiation.

Concerning nausea, with a median value equal to 2 and a mean of 1.8, it seems that finishers were not so much affected by sickness. But some finishers give a value of 4 that can explain their low score in head motion measurements. Users described us that they did not move their head to do not increase their nausea. Considering the fact that some users reported us that they did not used the headset very much at the end to limit nausea, we look at head motion results to analyse if there were outliers to be considered. Results demonstrate that the finishers with a sickness score inferior or equal to 2 made an overall head motion result of 3.25 on all exercises, whereas all finishers made a result of 3.23. These close scores prove that finishers with nausea were not outliers, because only few stop moving their head to limit sickness.

Considering that exercise 2 was too complex, results on exercises 1, 3 and 4 lay out greater overall return. Completion time for exercise 1+3+4 is 2min 55s for Oculus Rift and 3min 8s for screen display (Figure 22). This 7% time improvement indicates that despite mitigated supporting results (median value equal to 2), finishers were able to score a close or better (61%, Figure 22) completion time. It is a very interesting result, because it lets us think that with hardware improvements, VR headsets could be a lot better than monitor display. So, it justifies continuing research using this technology to acquire knowledge relative to where and how to use it when it will be at its top level of manufacturing.

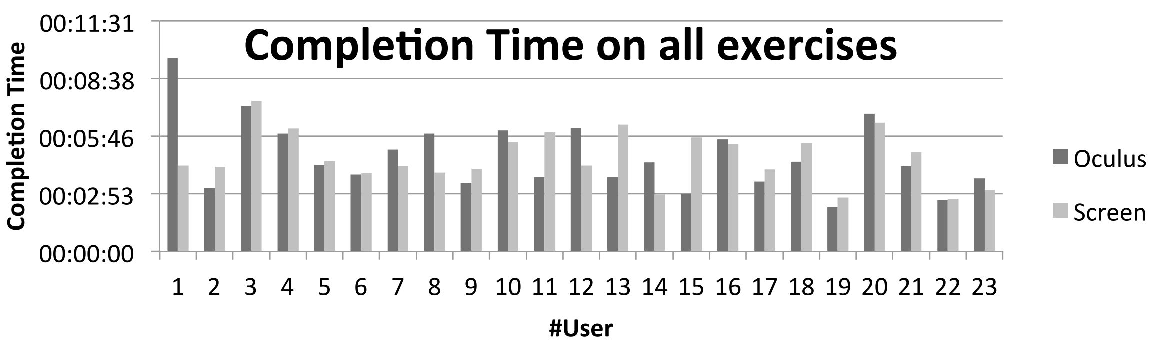

Figure 9: Completion Time for each user with Oculus Rift (Dark) and with Monitor (Clear).

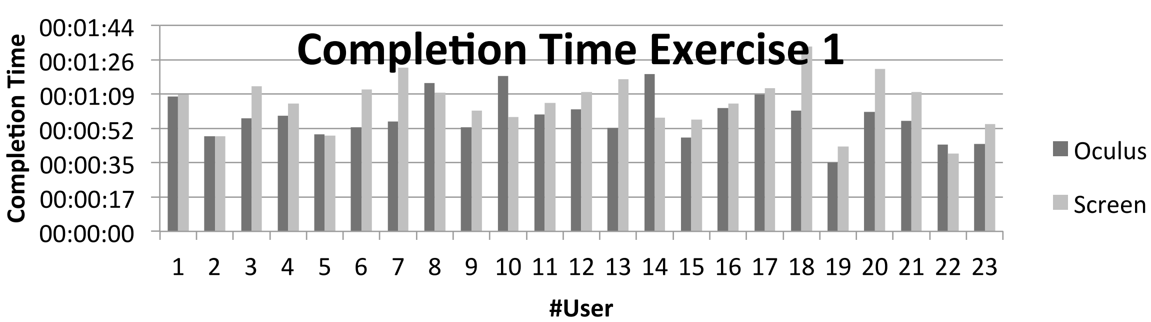

Figure 10: Completion Time for each user with Oculus Rift (Dark) and with Monitor (Clear) in exercise 1.

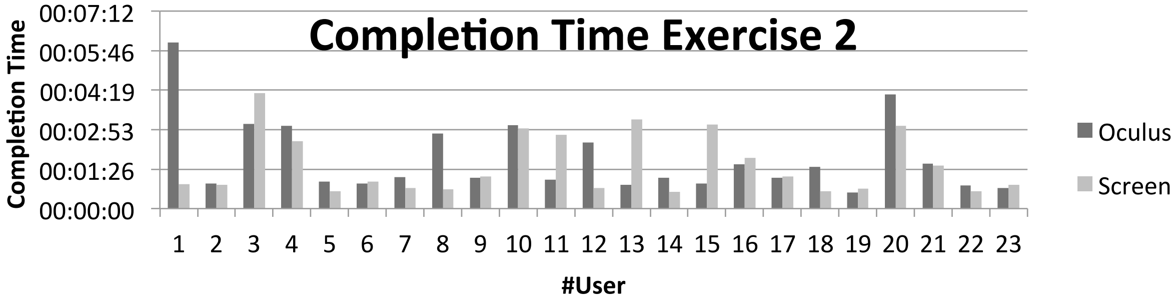

Figure 11: Completion Time for each user with Oculus Rift (Dark) and with Monitor (Clear) in exercise 2.

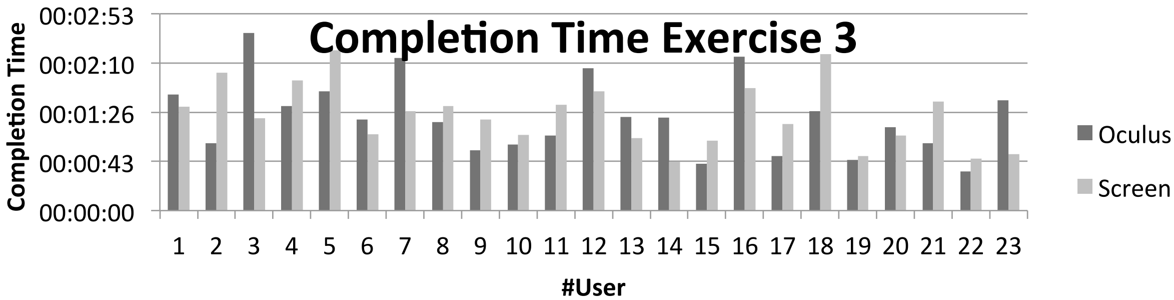

Figure 12: Completion Time for each user with Oculus Rift (Dark) and with Monitor (Clear) in exercise 3.

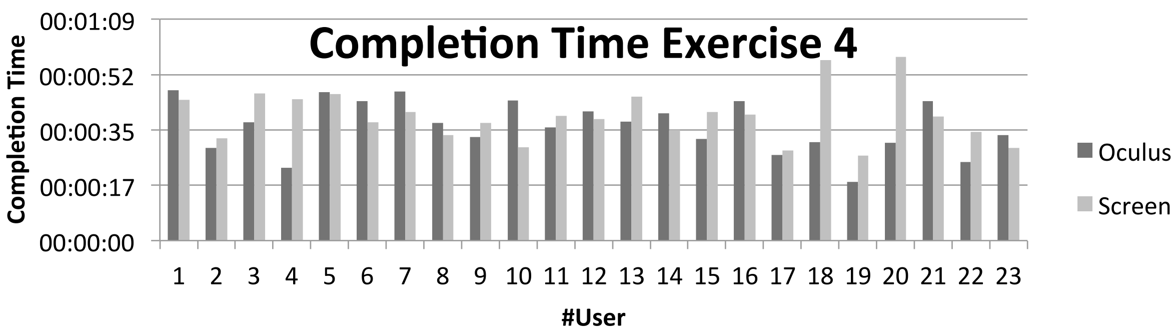

Figure 13: Completion Time for each user with Oculus Rift (Dark) and with Monitor (Clear) in exercise 4.

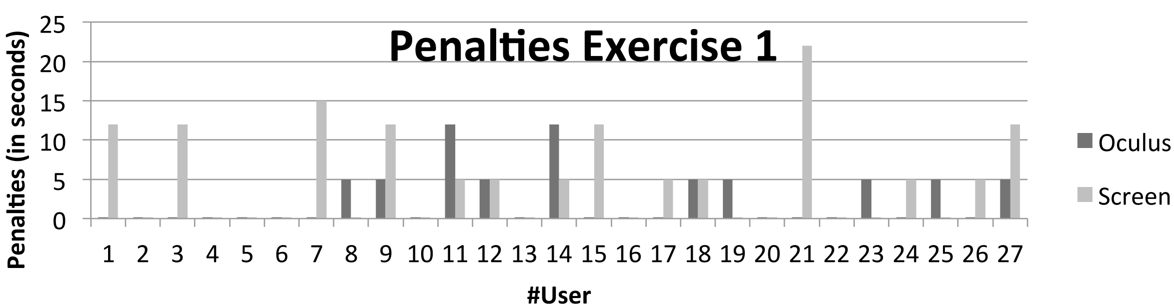

Figure 14: Penalties for each user with Oculus Rift (Dark) and with Monitor (Clear) in exercise 1.

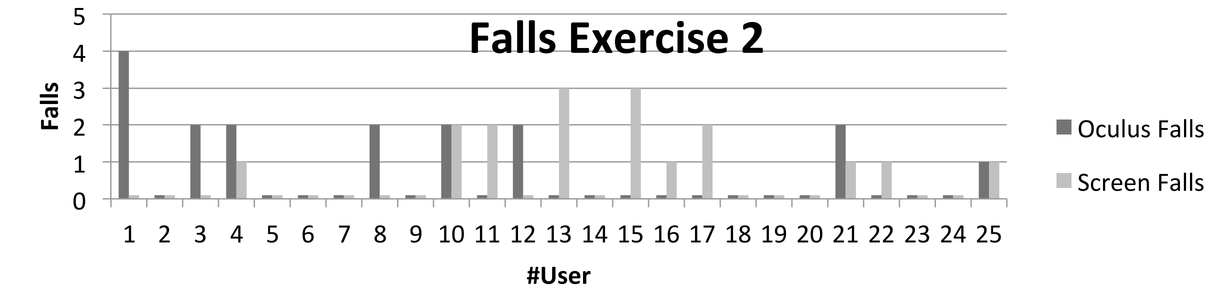

Figure 15: Penalties for each user with Oculus Rift (Dark) and with Monitor (Clear) in exercise 2.

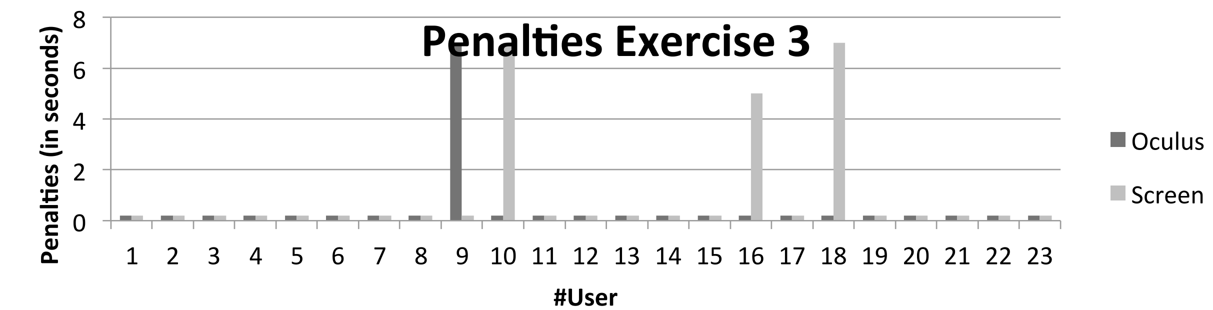

Figure 16: Penalties for each user with Oculus Rift (Dark) and with Monitor (Clear) in exercise 3.

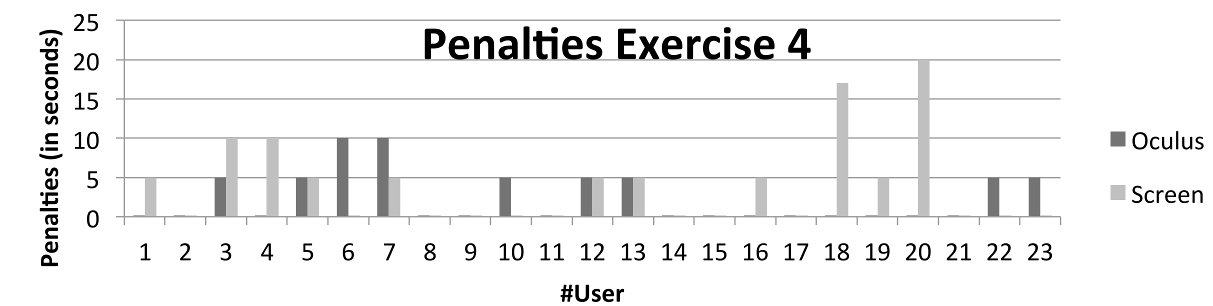

Figure 17: Penalties for each user with Oculus Rift (Dark) and with Monitor (Clear) in exercise 4.

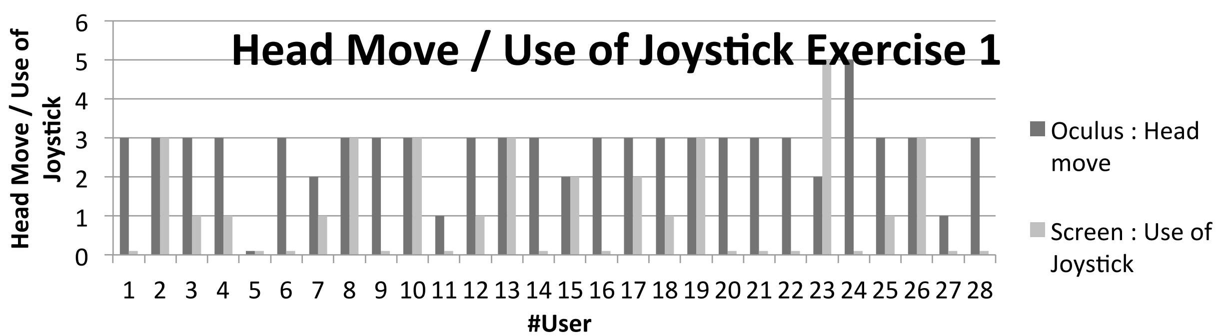

Figure 18: Head moves for each user with Oculus Rift (Dark) and with Monitor (Clear) in exercise 1.

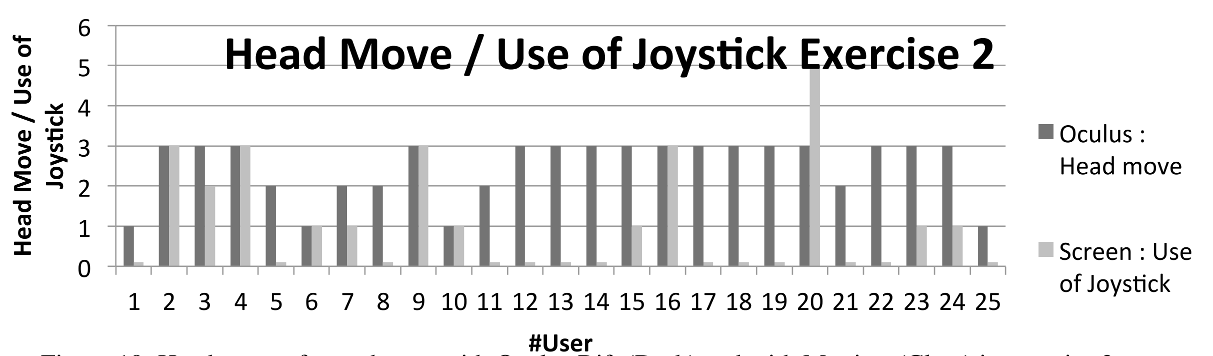

Figure 19: Head moves for each user with Oculus Rift (Dark) and with Monitor (Clear) in exercise 2.

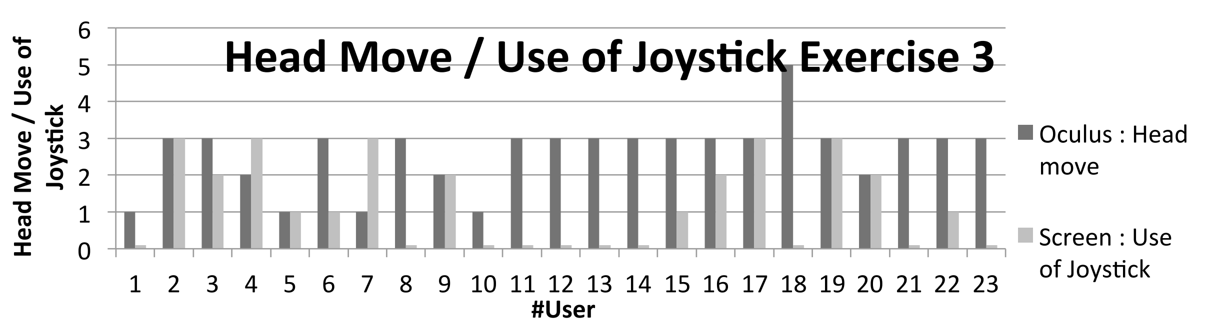

Figure 20: Head moves for each user with Oculus Rift (Dark) and with Monitor (Clear) in exercise 3.

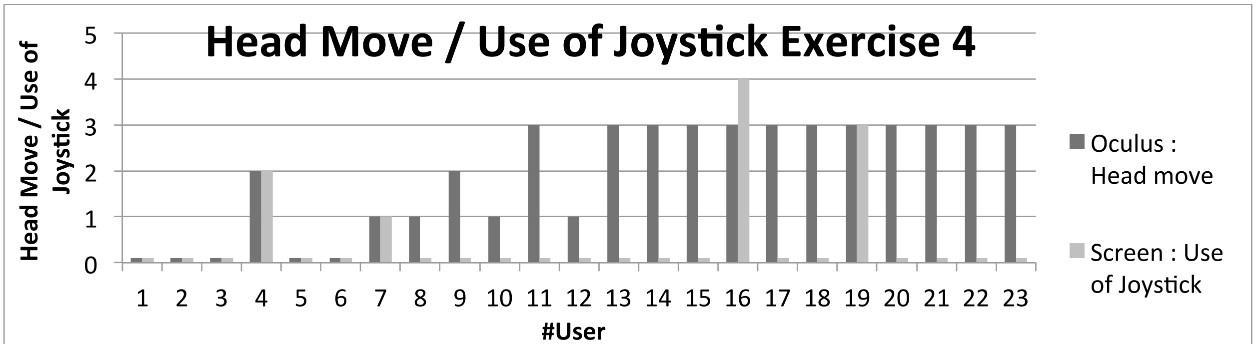

Figure 21: Head moves for each user with Oculus Rift (Dark) and with Monitor (Clear) in exercise 4.

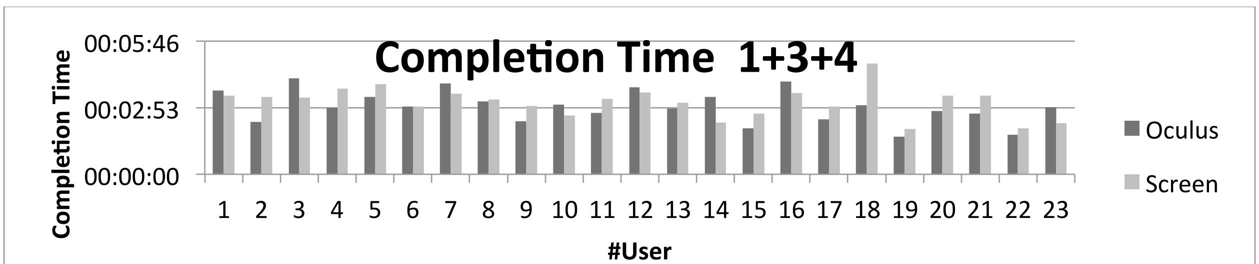

Figure 22: Completion Time for each user with Oculus Rift (Dark) and with Monitor (Clear) for exercises 1+3+4.

DISCUSSION

These results are notable for several reasons. First, concerning sickness, it indicates that about 50% of people is able to support the current version of Oculus Rift for driving simulation; which is better than expected but far from widely deployable. We expect to see great improvements brought by video game industry on this kind of display. In case they did not or if they fail, taking these results into account, VR headsets will not be exploitable in industrial product for driving or remote driving.

Second, results show better performances of Oculus Rift in regards of driving in simulated environment. It is very promising for further research we will engage about this subject. In near future we will try to highlight benefits of Oculus Rift in real remote driving situation by making experiments with robots. We are developing a robotic platform based on Wifibot Lab V4[WIFIBOT2015] to achieve it. Moreover, we work on multi-sensors environment reconstruction, and later we will merge both works to create a complete and safe system following the idea of [TERRIEN2000], with adding hazard detection, path planning and hand free viewpoint change.

The drawback of this experiment is the second exercise. Falling penalty was too punitive; in addition of slowing down user in his progression, most withdrawal due to sickness occurred during this exercise. We learned with this exercise that whereas obvious tasks are not suitable to extract information harsh ones could bias results too.

Other topics to take into account in our next experiments are the stereoscopy and the multiple monitors configuration. Oculus Rift displays stereoscopic images that give user depth information. Does it influence results compared to the monoscopic images of screen display? We cannot answer yet. In the future experiment in real environment, sensors are monoscopic cameras. In this case, Oculus Rift display will be degraded compared to simulated environment. It will be interesting to see if Oculus Rift keeps its first place.

CONCLUSIONS

These results demonstrate that users take advantage of viewpoint freedom to increase manoeuvring, being more reactive and look for information. This shows that VR headset could be a great alternative to monitor for remote driving. We are working on the next step, which is making an immersive driving system on a mobile robot platform, and complete this analysis with real driving tests on this platform.

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