Reducing sickness and enhancing virtual reality simulation on mobile devices by tracking the body rotation

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KEYWORDS

Virtual Reality; Human-Computer interactions; Motion Sensors; Mobile; Motion Sickness.

ABSTRACT

Smartphones are well fit to be used as head mounted displays for virtual reality, because they already embed the sensors necessary to track the head rotation. The purpose of this study is to find out how much we can improve the user experience by adding three more degrees of freedom to track the user chest rotation, in particular with respect to the perceived motion sickness. With this addition the user can rotate the body independently from the head, meaning that he or she can look in a direction different from the one he or she is facing. The interface is complemented with a technique to match the rotation of the user body and head with his or her virtual avatar.

The proposed physical interface is tested on two custom simulations. The first is a virtual museum where the user can walk and look around. The user can control the direction where the avatar is looking with the head, and the direction he or she is facing using the body. The second simulation is a game that uses the chest rotation as a core gameplay mechanic, allowing to control a flying skateboard by moving the body, with the goal of traveling around a circuit to establish the best time.

INTRODUCTION

Virtual reality (VR) is an interesting topic whose applications are already widespread spread but yet to explore in their entirety. Nowadays virtual reality is used in entertainments, robotics, health care, education, training and more. In particular, simulation can benefit from the capability of immerse the user in an environment where he or she can experience artificially generated worlds. Many different devices have been developed during the past century to recreate virtual reality experiences, but it is only in the recent past that this technology became available to the masses. Devices such as Oculus Rift [1] and HTC Vive [2] are the current standard for end users virtual reality experiences, but they are very expensive and cumbersome, requiring an entire room to be properly utilized. With the introduction of Google Cardboard [3], VR technology became available to anyone that owns a mobile phone, but currently it is mostly used for passive experiences like watching 3D and 360°videos.

In this proposal, we aim at creating a VR application that leverages the high portability and low costs of mobile hardware, but that also gives to the user an active experience, with new possibilities to interact together with a higher sense of immersion. The objective of this paper is to find out how much we can enhance the level of immersion in virtual reality on mobile hardware by adding a single extra sensor placed on the chest of the user that tracks his or her body rotation. Secondly, by having better responses to the movements in virtual reality we also aim to reduce motion sickness, which is a problem that affects any VR experience and one of the major causes of why VR struggle to become a mainstream technology. It is caused when the brain perceives that something that the body senses are perceiving is strange and noncoherent and so it raises its defenses. The most common hypothesis for the cause of motion sickness is that it functions as a defense mechanism against neurotoxins [4].

The novelty of this work concerns two aspects of the virtual reality technology available for simulations: firstly, it accurately maps the chest rotation into a virtual world with an inexpensive and widely available sensor. Secondly, the absence of optical tracking device increases portability and reduces the space required to be used.

RELATED WORKS

The reproduction of human body movements into the virtual world is a difficult task, and in this section we compare the similarities and differences of our solution with other proposed in literature. One of the first modern embodiment solution can be seen in [5], where the authors present a series of harness mechanism to reproduce a set of movements in VR for training purposes, but the technology used is cumbersome and outdated for today world. In [6] the authors presents an application that uses gestures recognition for immersive virtual reality. Although their system is able to recognize a wider range of movements, it was implemented with

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the Microsoft Kinect, a technology no more available. In [7] the author presents a method to integrate a full body tracker with a more accurate and higher quality head tracking system. His solution allows virtually any possible movement in VR but it is implemented with extremely costly hardware and he does not present a case study. In [8] the authors use optical tracking to simulate "a wide range of upper body motions using motion and positional data from only the head and hand motion data". Being an indirect measurements, the chest tracking is less accurate than our solution. An interesting usage of wearable sensors to enhance VR is presented in [9], where the authors use the sensors as feedback for anti-stress therapy. However, the way the wearable sensors are used is completely different from our solution. An application to training basic fire-fighting skills, using a modified fire extinguisher is presented in [10]. A modern solution that uses mobile hardware for virtual reality is described in [11], where the author develops a mobile game for google cardboard where the player can move and aim by just moving the head or with a controller, a similar analysis with the case studies presented here, but where we also compare a third control solution, the one with the chest motion sensor. The problem of finding the optimal placement in an anchor-based tracking system for virtual reality simulation is presented in [12]. Lastly, none of the cited papers keep track of the motion sickness experienced by the user in their analysis.

THE PROPOSED SETUP

We start presenting our proposal by describing both the hardware and software setup.

Hardware setup

The main simulation is implemented through a mobile application that runs on an Android smartphone with high performance, combined with a VR Headset in order to use the device as an HMD (Head Mounted Display). The sensor used to track the chest rotation is implemented with a micro-controller connected to an inertial measurement unit (IMU). In our prototype we used an Arduino Leonardo [13] programmable microcontroller board, supported by an additional board, the Arduino 9 Axes Motion shield, used to get the actual rotation in the physical three-dimensional spaces. The shield mounts the BNO055 [14] motion sensor from Bosch Sensortec, integrating an accelerometer, a gyroscope and a magnetometer, each one with 3 axes making 9 axes in total. The sensor has also embedded a sensor fusion algorithm that can compute internally the three dimensional rotation with high accuracy. The Arduino is then connected to the smartphone with a micro-USB and an USB OTG (On The Go) adapter, to use the smartphone in host mode. The Arduino is fixed to the chest of the user with a custom harness mechanism that keep the microcontroller firmly in place. In order to keep the cost of the prototype as low as possible, as well as in a possible future product line-up, the chest-mount has been made compatible with standard

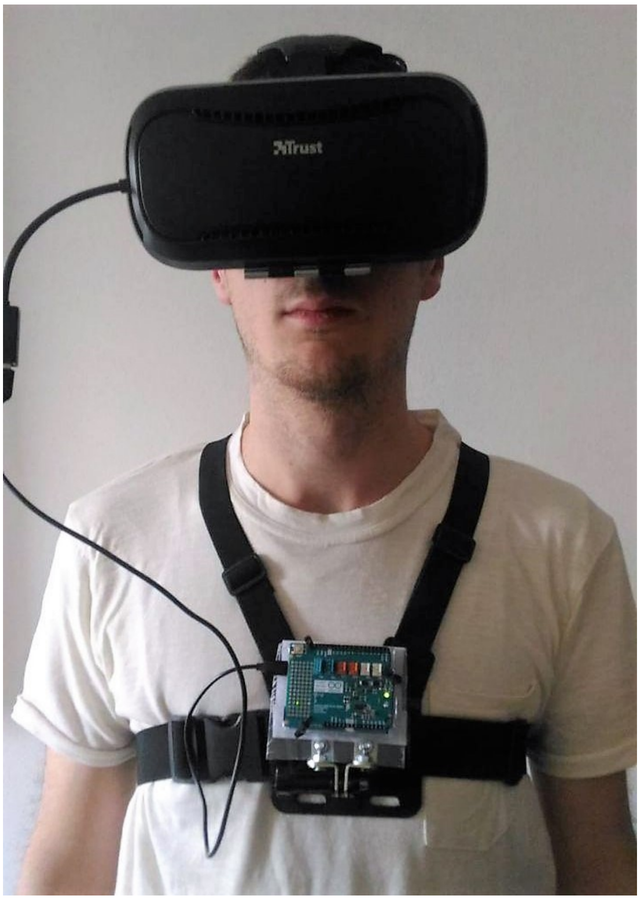

Fig. 1. Complete setup with the microcontroller connected to the smartphone (positioned inside the head mount).

wearable interfaces used to support sport camera such as the GoPro. The complete setup is shown in Fig. 1.

To give the user additional inputs methods we also used an external bluetooth gamepad paired with the mobile device. In this way the controller can be held by the user in his or her hands while using the application, without the risk of creating knots with the cables connecting the custom made sensor with the mobile phone.

Software setup

The mobile application was developed with Unreal Engine 4.20.3 [15], and NVIDIA CodeWorks for Android [16], required by Unreal Engine to build the game for the Android platform. For the sensor software, Arduino provides a library [17] to read the quaternions, which locate the direction of the board in the physical space, from the embedded sensor on the shield. The firmware on the Arduino gets the quaternions from the sensor shield and write them back on the serial port. The communication between the Arduino and the game engine on Android occurs with USB, and the pipeline to handle the data stream was handcrafted since there were no plugin available that support this data transfer. A public available library was used to read the serial data on Android [18].

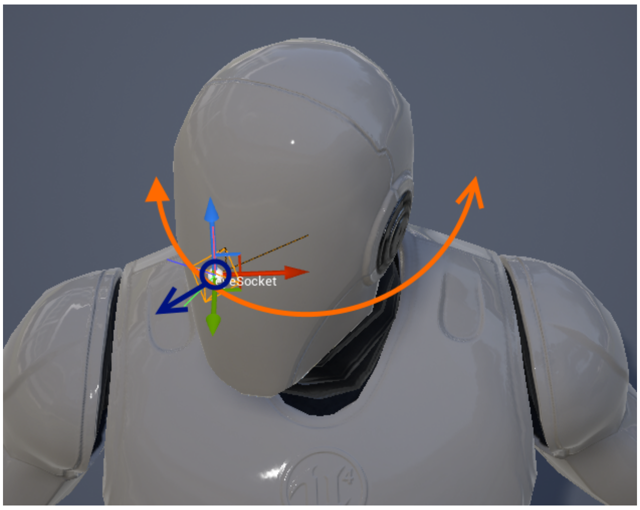

Fig. 2. When rotating the head, the camera moves along the orange arrow, directed as the blue arrow which is always perpendicular to the orange one.

Application development

The considered application uses a mixed first person / third person setup. In particular, the user sees the world in first person, but he or she has also an avatar whose chest and feet can be seen when looking down. The mesh used as a body is the Unreal Mannequin, already rigged. The mannequin was then animated using the data available from the head rotation and the chest rotation.

For the head, the rotation data was automatically used to rotate the camera object by UE4, but we also used it to rotate the head of the user's avatar and bind the camera position to the avatar eyes. This way, the camera rotates and move following a circle like real human vision, instead of just rotating in place, as shown in Fig 2.

For the body, the difference in rotation from a neutral position is initially computed, and later used to rotate the avatar chest bones. The neutral position is registered when the user presses the corresponding button on the controller: this step acts as a calibration of the devices, and must be done with the user standing still in a neutral position. The three rotation axes can be used combined to rotate the chest in the three dimensions, or we can use the vertical axis to rotate the whole avatar. This way we have decoupled the direction where the user is looking with the one where the user is facing.

CASE STUDIES

We developed two case studies to test the application on real users, to see whether this extra motion sensor can improve the simulation experience. To allow comparing our proposal with conventional interaction techniques, the case studies were developed by creating three different patterns for performing the required set of actions: by moving the chest and the head, using a controller, or by simply rotating the head. The comparison of the user experiences with these three different setup can show whether the chest motion control addition enhanced the simulation, or if simpler controls patterns would have been equivalent for the end user.

Fig. 3. One of the room of the Art Gallery.

Art Gallery

The purpose of this case study is to find out if the ability to rotate the head independently from the body is useful in a calm and familiar environment (see Fig. 3). In the *Art Gallery* scenario, the user has to walk around from the entrance to the exit of an exhibition building, visiting all the rooms and observing his or her surrounding. The architecture is simple: the roof has been removed to create a sense of warmth and realism with a simple directional light coming from above to illuminate the environment.

The user always uses a gamepad together with the other sensor devices: the controller matches the one used in classical video games, with two small analog joysticks moved by the thumbs (thumbsticks), plus other buttons and directional switches. In all the tested configuration, the user moves his or her avatar with one of the two thumbsticks; when using only the controller he or she also rotates with the other thumbstick. When using the head instead, the direction of moving is bound to the direction where the user is looking at and the joystick decides only if he or she is moving forward or backward. Finally, when using the developed motion sensor, the user can look around rotating the head and rotate the avatar rotating the chest.

Hoverboard

In this case study we developed a game where the chest rotation is used as a core gameplay mechanic. The game consists in driving on a circuit to establish the best time on three laps. The vehicle used is a hoverboard, a sort of floating skateboard but with the user facing forward as illustrated in Fig. 4. The user can control the hoverboard by accelerating, braking, steering or strafing. To keep it playable, the physics used in the game is simplified and handcrafted but still is mostly derived from the real world.

Again, the hoverboard can be controller in three different ways. When using the controller, all the inputs are given with the buttons and thumbsticks of the gamepad. When using the body, the idea is to control the hoverboard by balancing the body, just as in real life. So the user bends his or her chest forward to accelerate, backward to brake, rotate or bend left and

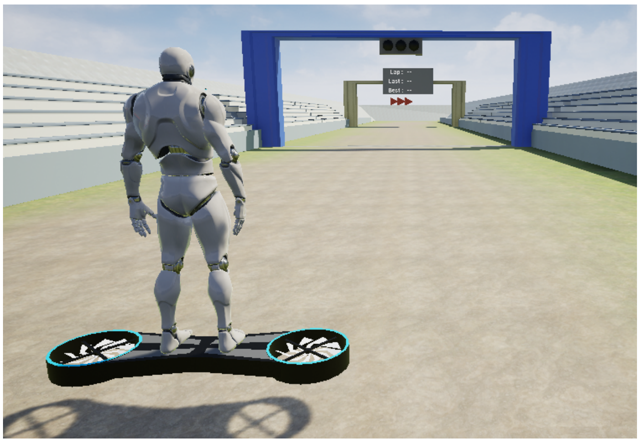

Fig. 4. View of the avatar on the Hoverboard from behind (not actual gameplay image).

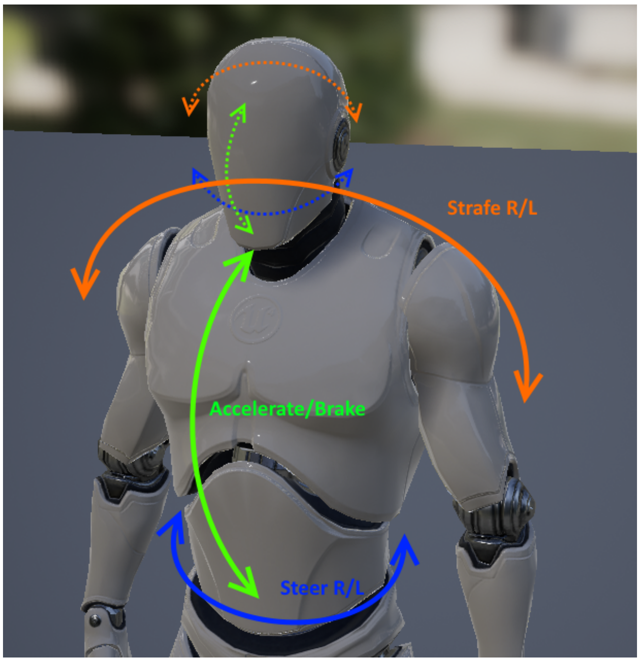

Fig. 5. Hoverboard body motion controls. The dashed arrows indicate the movements for the head controls.

right to steer and strafe left and right. When using just the head, the user does all the previous described chest movements by simply rotating the head. A visual representation to better understand the commands is given in Fig. 5.

RESULTS

For each case study, we tested on as many subjects as possible the three game modes described before: classic controller, head motion controls, and body motion controls. We collected upfront some information about the subjects like sex, age, whether or not they are used to play videogames and if they already experienced VR in the past.

The order of the three modes tried was different for each subject to avoid any bias in the results. After the simulation was played with one specific controller, we asked the user what was his or her level of motion sickness experienced while playing in a scale from one (no sickness) to five (very high sickness). If the user has experienced some form of motion sickness, we let them rest for some time to prevent nausea from piling up quickly. After all the modes were tested, we asked which mode the user preferred.

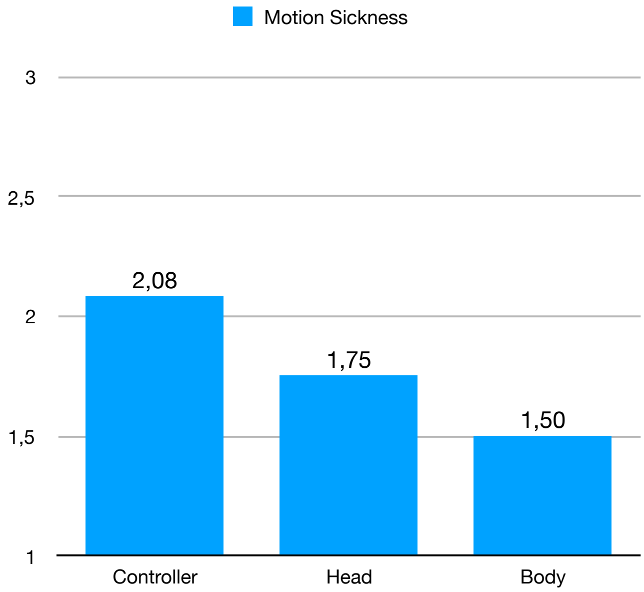

Fig. 6. Levels of motion sickness experienced in the “Art Gallery” case study.

Art Gallery

For this case study, we tested the application on 12 people. 5 of these were used to play video games, and 3 already tried virtual reality. Out of these 12 subjects, 9 preferred to use the body motion controls, 2 the head motion controls, and only one liked to play with the controller. Playing with the body controls caused the lowest amount of motion sickness, followed by the head controls and classic controller (see Fig. 6).

The problem that emerges when using only the head to both rotate the vision and the avatar, is that if done while also moving it causes an unnatural change of direction that confuses the player and his or her perceptions. While using only the controller, the user must stand still with the body oriented in one fixed direction, and the sense of immersion at 360°is completely lost.

Hoverboard

This second case study was tested on 16 people. 8 of these were used to play video games, and 9 already tried virtual reality. Out of these 16 players, 9 preferred the head controls, 4 of them the body controls, and 3 the classical controller. Head was also the mode that caused less motion sickness, followed by controller and body. Since there were some differences in the collected data between gamers and non-gamers, the data was split between the two categories as seen in Fig. 7 and 8. In both cases the results were not what we expected, and the feedback from the testers highlighted the following problems and characteristics: classic controller mode has low sense of immersion, but for gamers who are used to play with it, it allows more accurate

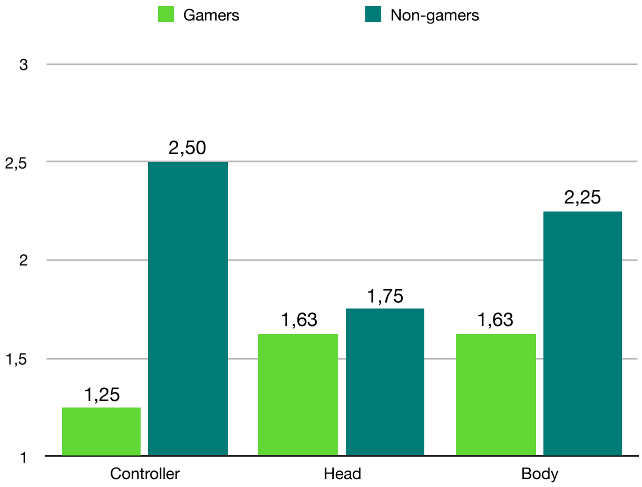

Fig. 7. Levels of motion sickness experienced in the "Hoverboard" case study, divided by gamers and non-gamers.

	Controller		Head		Body	
	$\overline{x}$	σ	$\overline{x}$	σ	$\overline{x}$	σ
G.	1.25	0.463	1.625	0.916	1.625	1.061
NG.	2.5	1.309	1.75	0.886	2.25	1.165

TABLE I: Differences in motion sickness perceived for Gamers and Non-Gamers, with average and standard deviation for each mode.

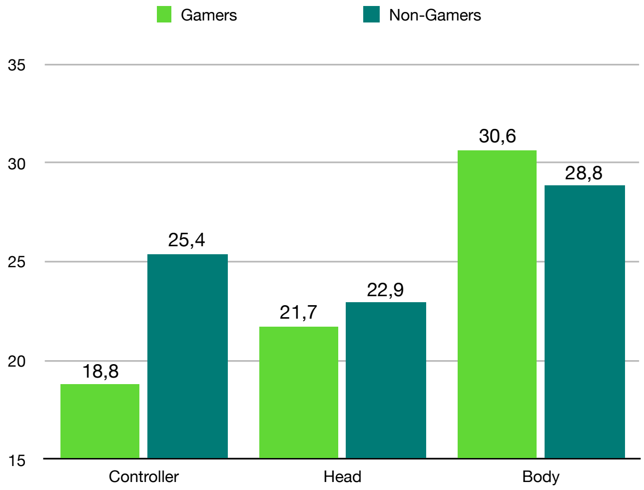

Fig. 8. Best laps (in seconds) done while playing in the "Hoverboard" case study, divided by gamers and non-gamers. The bars start at 15 seconds because it is more or less the best time a player can do.

controls. However, this mode was the least preferred because of the lack of novelty. Head motion controls was the favorite mode of the majority, it was intuitive to play both for gamers and non-gamers. Gamers who preferred this mode did it because of the immersiveness, novelty, and fun introduced, while non-gamers did it because it was actually the easiest way to play for them. Body motion controls was the most complex mode to get used to, as confirmed by the higher lap times. The preferences in this mode were due to personal tastes and how easily the user get into virtual reality. In fact, all the people who preferred this mode have already experienced VR in the past.

It is quite obvious that gamers, being more acquainted with the classic controller, have better lap times than non gamers, while there is no sensible difference in time for body and head motion controls (Fig. 8). What is more interesting, is that gamers also perceive less motion sickness than non-gamers while playing with the controller (Fig. 7). Executing an unpaired t-test with the data from Table I, at 95% level of confidence, we can conclude that there is indeed a significant statistical difference in the motion sickness perceived between gamers and non-gamers (two tailed p-value equals to 0.023).

CONCLUSIONS

In a virtual tour where the user only has to walk and look around, the body motion sensor increases the sense of immersion and reduce the motion sickness, when compared with traditional controller or simplified motion controls, where only the headset sensors are used. The body sensor allows to move in one direction and look at another, based on where the user's chest and head are facing. As a consequence, the user can observe his or her surrounding in motion and in a natural way. In a more complex scenario, the results were different: motion controls are fun, but to use body movements as the core gameplay mechanic of a game makes it more difficult and causes a higher motion sickness. The majority of the users preferred the more intuitive interface that uses only the motion of the head, since in this way they have better sense of control over their avatar.

Future works will build on the test applications presented in this paper to create more complex simulation experiences. In particular, to better focus on physical parameters concerning the study of motion sickness, a set of objective measures such as heartbeat, sweating, blood pressure, ecc. could be collected during and after the test, to obtain a more advanced evaluation. The success of the virtual tour experience in the "Art Gallery" application may be used in real application, such as museums, churches or any other place of interest. These locations often have some rooms not available to the general public. Or maybe those objects or locations were damaged by time and it would be nice to see how things were in their original form, reproduced in virtual reality.

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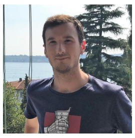

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