An Oculus Rift based Exergame to Improve Awareness in Disabled People

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Abstract: In this paper we present an exergame, based on the Oculus Rift head-mounted-display, with the aim of improving spatial awareness in young people with cognitive deficits. The scope is to create a virtual environment that should be immersive, and should allow a natural human-computer interaction, without creating discomfort to the users. The exergame is simple, since the aim of the present work is not to create a photo-realistic scenario, but a familiar environment in which to play and exercise cognitive abilities. To measure and track the movements of the users' legs, in order to simulate the walking in the environment in a safe way, an additional sensor, the Playstation Move, has been embedded into the system. Finally, the system has been tested with some disabled subjects, who confirmed the usability of the exergame and a general positive feeling with such an immersive virtual reality.

1 INTRODUCTION

In this paper, we present an exergame designed for the Oculus Rift head-mounted-display (HMD), developed to improve spatial and cognitive awareness for disabled people.

Exergames, or active video games, are video games with interfaces that require active involvement and the exertion of physical force by participants. These exergames are designed to track body motion and body reactions, providing both fun and exercise for players. Numerous video game console companies have designed exergaming interfaces that have become more and more popular over the last years.

In the last years, many researchers addressed the problem of developing human-computer-interfaces, often based on Virtual Reality (VR), with the aim of obtaining immersive environments that allow a natural interaction with them. A great effort is devoted to the graphic quality of such environments, in order to achieve high levels of realism, especially when such systems are used for training purposes (Kwon et al., 2013), for surgery (Chan et al., 2013), or simply for entertainment. The natural interaction with such systems has been recently considered, see for example (Solari et al., 2013). In that paper, the authors developed a stereoscopic rendering technique that solves the misperception issues, which affect a user free to move in front of a display, thus allowing him/her to interact in a natural way with the virtual objects. Other authors analyzed the issues of misperception that affect HMDs (Sharples et al., 2008; Ukai and Howarth, 2008). In particular, a fundamental problem that must be considered when creating VR immersive environments, and that represents one of the main issues of such kind of systems, are adverse symptoms that may arise from VR use. In the real world, when a person moves, e.g he/she changes the position of their eyes or head, the projections of the 3D real world immediately shift on the retinas, and at the same time the vestibular system indicates the movement of the head. Due to hardware and software limitations, in HMD VR systems there is an unavoidable delay between a users movements and the updating of the virtual rendered scene. If this delay is excessive, the sensory information from the users visual and vestibular systems might be conflicting, and this can result in symptoms such as nausea, stomach awareness, dizziness, and headache. Finally, another important aspect to be considered is immersivity, i.e. the feeling of presence when acting in a VR environment through head-mounted-displays (Waterworth et al., 2010).

In this work, we do not address the problem of

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graphical realism, such the exergame we present has been intentionally kept very simple from the graphics point of view. On the contrary, we aim to obtain a system where the users (that are disabled people) can act in natural and comfortable way in order to maximize the healthy effects provided by the proposed exergame.

2 STATE OF THE ART

As consumer exergaming programs have evolved, numerous academics have researched the effectiveness of these types of games on rehabilitation or exercise (Tanaka et al., 2012). Most of the studies were conducted using the Wiimote and a new peripheral, the Wii Balance Board, and covered a lot of different subjects: (i) Brain function rehabilitation (Deutsch et al., 2008; Hsu et al., 2011; Joo et al., 2010); (ii) Isometric muscle strengthening (Sohnsmeyer et al., 2010); (iii) Energy expenditure (Hurkmans et al., 2010); (iv) Exercising for elderly (Wollersheim et al., 2010); (v) Balance training (Deutsch et al., 2009; Kliem and Wiemeyer, 2010).

In contrast, there have been a number of studies identifying limited effects of exergaming. For example, regarding the potential of Wii Bowling for rehabilitation in patients with upper extremity dysfunction (Hsu et al., 2011), it was found that the only significant finding was a measure of enjoyment of activity when compared to a standard exercise group. Similarly, the study that applied the Wii games to exercise and the elderly (Wollersheim et al., 2010) showed no significant increase in physical activity due to exergaming. Research in the medical field has been done for the Oculus Rift as well. A study on a patient affected by severe burn wounds on a large area of his body (Hoffman et al., 2014) has provided the first evidence that entering an immersive virtual environment using the Rift can elicit a strong illusion of presence and reduce pain during the Virtual Reality experience. Other interfaces that could be used in exercise-based games have yet to be fully explored. The use of heart rate is being examined (Parker et al., 2011) and galvanic skin response has been studied, as means to communicate emotional responses (biofeedback) to a computer. More complex biological measures, such as electrocardiogram signals or oxygen consumption devices, could certainly have applications here, but reliable devices are too expensive for home use.

3 MATERIAL AND METHODS

3.1 Hardware

The proposed exergame makes use of two external hardware devices: the *Oculus Rift* and the *PlayStation Move*.

Oculus Rift. The Oculus Rift [1] was released by Oculus VR for developers with various hardware revisions over the span of one year. The device used for this project is the Developer Kit 2 (DK2). The Oculus Rift DK2 uses an OLED panel for each eye, each having a resolution of 960×1080 pixels. These panels have a refresh rate of 90 HZ and globally refresh, rather than scanning out in lines. It uses high quality lenses to allow for a wide field of view. The separation of the lenses is adjustable by a dial on the bottom of the device, in order to accommodate a wide range of interpupillary distances. Headphones are integrated, and they provide real time spatialized binaural audio. The Oculus Rift has full 6 degree of freedom rotational and positional tracking. This tracking is precise, low-latency, and sub-millimeter accurate.

PS Move. The Sony PlayStation Move [2] is actually composed of two devices: the *Move Eye* and the *Motion Controller*, or wand. The Move Eye is an RGB camera (640×480 pixels @ 60 fps / 320×240 pixels @ 120 fps) with directive microphones, and it's utilized to detect an illuminating sphere attached to the wand in order to track the controller in a three-dimensional space, calculating the distance/depth based on the size of the sphere on each frame. For this project the Eye was not needed, thus only the wand was connected via bluetooth to the system. The Motion Controller contains a three-axis accelerometer, a three-axis gyro sensor and a geomagnetic sensor. The accelerometer and the gyro sensor are used to track rotation in overall motion and can be used for dead reckoning (in cases when the camera tracking is insufficient). To correct cumulative errors on these sensors, the geomagnetic sensor is used for calibrating the wand's orientation against the Earth's magnetic field. Consequently, the sensor fusion method makes it possible to recognize the wand's position and orientation robustly and accurately.

3.2 Software

The entire project was developed with *Unity* in C#,

[1] https://www.oculus.com
[2] https://www.playstation.com

and, in order to connect the Oculus Rift and the Move to the machine, specific plug-ins and libraries were used.

Unity. Unity [3] is a cross-platform game engine developed by Unity Technologies and used to develop video games for PC, consoles, mobile devices and websites. Recently, Unity Technologies made the complete engine available for free including all features, less source code and support.

Official Oculus Rift integration for Unity. In addition to the SDK, Oculus VR has released full support and integration for two well-known game engines: Unity and Unreal Engine. By downloading and installing the necessary plug-ins we were able to directly use a connected Oculus Rift for any Unity project without any issue.

PS Move plug-in for Unity: UniMove. *UniMove* is an open-source Unity plug-in [4], and set of C# bindings that allows the usage of PS Move controllers within a Unity game. The latest version works with OS X 10.6+, Windows and Linux. It is based on top of Thomas Perl's PS Move API [5]. The plug-in is licensed under the GNU Lesser General Public License and is still under development.

3.3 Overview of the Proposed Exergame

We propose a virtual reality game made to improve the user's awareness of road hazards and develop his/her sense of direction in an urban environment (e.g. a city). In this game the players must face a series of simple missions with increasing difficulty under the supervision of an operator. Data relative to each player's performance is stored in a database, in order to allow monitoring of the improvements of every person. The proposed exergame can be seen as a simulation of a real (and potentially dangerous) activity in a secure and harmless context. A possible application of proposed virtual reality game is to help people with intellectual disabilities to learn about the possible dangers of a city and to find the way to a known place in case they get lost. This is the reason why a number of tests was run on this type of patients.

The Move is simply tied to the player's thigh, pointing downwards. The leg movement is then tracked through the different accelerations along the

[3] https://www.unity3d.com

[4] http://www.copenhagengamecollective.org/projects/unimove

[5] http://thp.io/2010/psmove

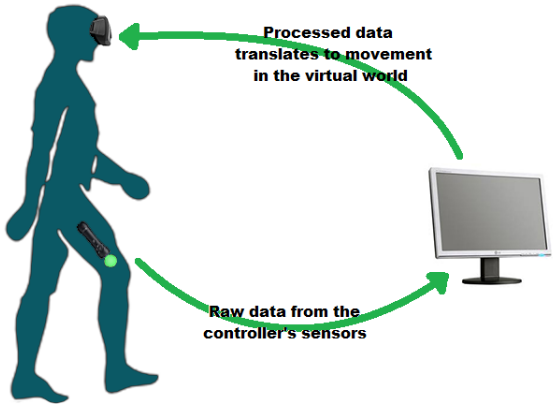

Figure 1: Outline of the entire proposed system.

XYZ axes, and sent to the main application to be processed into a realistic walking pattern (see Fig. 1). The game has been created to be as much immersive and noninvasive as possible. The possible actions in the virtual world are simplified, so that the users can focus only on the assigned tasks and the development of their abilities (danger acknowledgment, sense of direction). Our exergame lets people explore a Virtual Reality environment simply by looking around (with the Oculus Rift), and lets them move across this environment by simulating a walk (with the PS Move).

The Virtual World. The world seen though the Oculus Rift is just a simple urban environment, i.e. a small city portion with buildings, streets, sidewalks, lights and some minor details that can help in making the overall experience more realistic. The graphical interface is kept as simple as possible to avoid interfering with the game's immersivity: instructions, messages and warnings are written in a textbox at the bottom of the screen, and when a level is completed, the message is supported by a single emoticon displayed at the center of the screen, which can be happy or sad depending on the level's result (Fig. 2).

Figure 2: Two screen examples: level cleared and level failed. Note: the written text is in Italian language, since the proposed exergame is for the use with Italian disabled people.

The speakers mounted on the Oculus Rift can be used to give additional instructions and warnings, but they also generate sound effects typical of urban envi-

Table 1: Organization of the ten levels of the proposed exergame.

Level	Type	Difficulty
1	Orientation	Simple fork (go right or left)
2	Crossing	Simple crosswalk without traffic light nor vehicles
3	Orientation	T intersection, single request
4	Crossing	Crosswalk without traffic light, with some vehicles
5	Orientation	Two forks, two instructions
6	Crossing	Crosswalk with traffic light, mild traffic
7	Orientation	Two T intersections, two requests
8	Crossing	Crosswalk without traffic light, intense traffic
9	Orientation	Three intersections, three requests
10	Crossing	Crosswalk with traffic light, intense traffic

ronments, such as moving vehicles, ambulance alarms and general traffic noise. This is done to emphasize the sensation of immersivity for the player.

Gameplay. The proposed exergame offers two different challenges: *general orientation* and *pedestrian crossing*. Each challenge is then divided into different levels with increasing difficulty (see Table 1). In order to proceed to the next level, the player has to complete the previous ones, thus unlocking the new challenge. The operator can keep track of the player's progress through the monitor, and have complete control over which levels to start from, and which levels to repeat, through a menu.

Orientation Levels. The orientation levels (Fig. 3) take place in small city areas. Clear and simple instructions (go straight, turn left, turn right) are visualized on the screen and/or sent through the Oculus Rift speakers; if the player makes a mistake an error message appears, the level is not cleared and it must be repeated. For harder levels new elements are added (intersections, U-turns), and a larger set of directions is given to the player.

Crossing Levels. The crossing levels (Fig. 4) take place along a road with various moving vehicles. The presence of a crosswalk is always indicated on the screen, while a traffic light might or might not be present, depending on the level. The vehicles are managed by an artificial intelligence which takes into consideration collisions and eventual traffic lights. Harder levels can feature unexpected anomalies in the traffic, such as ambulances and police cars.

In this type of challenge, the player is asked to look around along the street in both directions before making any move, otherwise the level results in automatic failure. In a level with a traffic light the player must obviously wait for the green light first, then look

Figure 3: In the orientation levels the player has to follow the instructions (e.g. "Now turn right") and reach the goal following the right path. Note: the written text is in Italian language, since the proposed exergame is for the use with Italian disabled people.

Figure 4: In the crossing levels the player must look around in both directions, and then cross the road when the light is green.

around, and finally cross the street. In case a player sees an ambulance or hears a siren, he/she must not cross the road, even if the light is green.

Data Collection. The game has a login system to keep track of whoever is playing, and it's able to register relevant data about the players' performances.

These data are then stored and ordered into a database that keeps a profile for every player. The registered data are: (i) starting/ending date/time of each test; (ii) starting/ending time of each level; (iii) completion/failure of each level; (iv) reaction time after an instruction has been given; (v) completion time for each instruction, and whether the instruction has been performed right or wrong. The entries are stored into the database using a web service, therefore an Internet connection is required to interact properly with the system.

Game Options. Since everyone raises the legs in slightly different ways, the operator can choose from the main menu a series of options for each player, in order to adjust the simulated walk parameters. The *sensitivity* slider sets the upper threshold for the leg lifting in order to maximize the number of recognized steps. The *stride length* slider is the number of frames in which the player moves forward when a single step is recognized. The other sliders were added to adjust the complexity of some levels, and they have no impact on the user's tracking.

3.4 The Walk Tracking Algorithm

In this paper, we present a fairly robust algorithm able to detect when a player lifts a leg high enough to simulate the beginning of a step, and when he/she sets it back down (presumably lifting the other leg) to end the step. This way, a real person walking on the spot translates to a player walking across the virtual city.

Fastening the PS Move to the Leg. The idea for the tracking algorithm relies on the analysis of the leg's acceleration during a regular step, considering gravity along one of the XYZ axes: since a standing person normally starts walking with both legs perpendicular to the ground (thus parallel to gravity, assuming a flat surface), and the Move's sensor returns raw accelerations along its own relative axes, the most logical choice seemed to be fastening the move along the player's thigh, pointing upwards or downwards, in order to start the walk with one axis of the Move parallel to gravity. The thigh was chosen over the calf because the former performs a more regular movement during the gait, which can pretty much be approximated to a circular movement centered on the pelvis. For this reason, the Move's accelerations were used to compute the angle at which the leg (or, more accurately, the thigh) is lifted when a player performs a step.

Getting Acceleration Data from the Sensor. Considering the way the Move is tied to the thigh, when the player stands still one of the axes of the controller is parallel to gravity, and when the player lifts the leg the angle between the thigh and gravity can be approximated using the variation of any of the three accelerations registered by the sensor. For example, assuming that the Move is secured to the thigh as previously stated, and knowing how the three relative axes of the controller are oriented with respect to the leg, we could use accelerations along the Z and X axis to compute our desired angle, since they are affected from the rotational movement of the thigh. We chose the Z axis and found out that the property *Acceleration.Z* of the connected controller returns a normalized value: 0 when the Move points to the ground (leg down), and 1 when it points forward (leg up, thigh parallel to the ground and perpendicular to gravity). The resulting angles are then 0 degrees for a leg down ad 90 degrees for a leg completely up.

Data Processing. One crucial issue of this game is the robustness of the step recognition. The street crossing levels put the player already on the edge of the sidewalk, so any false step recognized by the tracker immediately results into an actual step into the virtual street. This can lead to unwanted failures that alter the player's record. For this reason an initial check was added, overriding any other computation: until the Z acceleration is sufficiently close to zero (leg down), the step tracking is skipped completely. This ensures that a player won't start randomly walking in the virtual world until his initial position has been confirmed as idle. The step is recognized using two parameters: the Z acceleration (*zAcc*), as mentioned above, and a boolean value named *upLeg*.

- *zAcc* is compared to two thresholds: the upper one defines whether the leg has been lifted enough to be the first part of a step, while the lower one (close to zero) defines whether the leg is low enough for the step to be considered completed.
- *upLeg*'s purpose is to deal with the obvious conflicts generated by the acceleration alone. When we estimate the position of a leg, we must take into account its previous position as well. A successful "*leg up*" implies that *zAcc* has surpassed the upper threshold from below, hence a check on *upLeg* must be done, and it must be false. Similarly, for a "*leg down*" *zAcc* has to be under the lower threshold, and *upLeg* must be true.

Without any check on the previous leg state, even standing still would generate an infinite walk, because *zAcc* would consistently be under the lower threshold, thus breaking the algorithm. In a real case scenario the leg-up condition is much more critical than the leg-down condition. While a leg down equals to 0 degrees most of the time, every person, when walking, lifts his legs by a certain amount, which is not the same for everyone (Fig. 5).

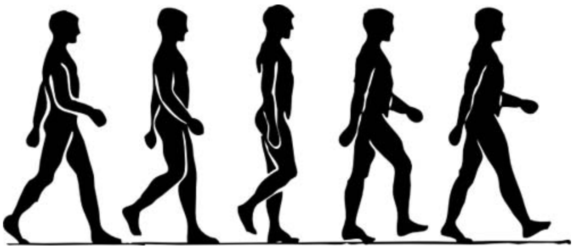

Figure 5: Walking pattern of an ordinary person.

It's easy to see that no one lifts his/her thigh up to 90 degrees when walking, and some simple tests revealed that even 45 degrees is often too much to set as the upper threshold for the step recognition. However, finding a seemingly right angle was not enough, because some players could always lift their leg even less than the testers, and if the leg-up is not recognized, the entire step gets skipped. The solution to this problem was setting the upper threshold dynamically from the game's main menu. This way, the system can be calibrated runtime for every player, and the settings can be saved into the database for future use. With these precautions we were able to ensure a smooth and robust tracking, without losing steps nor generating false ones.

Player's Movement in the Virtual World. In the virtual city, the distance covered by a single step depends on two factors: the *number of frames* in which the player moves forward, and the *amount of space* covered in each frame. The actual function for the player's movement within a frame is: *Move(drifter.facingDirection.forward* drifter.speed* Time.deltaTime)*

It is simple to understand: the *drifter* is the player, and his facing direction is computed directly from the Oculus Rift (the player always walks towards his facing direction), then there is *Time.deltaTime*, which is the timespan of a single frame, and finally there is the *walking speed*. This parameter has to be refined test after test, based on the player's height and the size of the roads, in order for the walk to seem as realistic as possible without the sensation of running (crossing the entire road in a single step). Since the speed over a single frame is de facto instantaneous, the *Move()* function causes just a minimal shift. A second parameter is then needed to create a movement that takes place over the span of many frames. This variable, named *walkFrameCount*, defines the number of frames before a player stops moving after a successful step.

The frame count variable has actually a double use: to be realistic, the simulated walk must not be jerkily at all, thus between the leg-up and the leg-down the player must absolutely continue his movement. The timespan of a virtual step depends heavily on how fast a person walks on the spot, so another custom option for each player in the main menu was added. As a counter, *walkFrameCount* must be initialized to the desired value at every successful step. While the player is moving, every frame decreases the counter until it reaches zero and then stops the shift. If another step is done before the counter reaches the end, it gets reinitialized and the shift doesn't stop. If the player performs several steps in a row, and the frame count is high enough to cover both phases of the step, the result will be a continuous movement towards the facing direction. With a good balance between *speed* and *walkFrameCount*, the player can experience a realistic shift when walking in the virtual city, and doesn't need to worry about his avatar freezing mid-step.

4 RESULTS

4.1 Subjects

The proposed exergame has been test with 6 subjects between 14 and 18 years old. They were recruited on a voluntary basis, and their legal representatives agreed on a Consent Form, in which the description of the experiments, together with explicit statements regarding ethical considerations in the recruitment and treatment of all subjects, was included. The research will conform to the ethical standards laid down in the 1964 Declaration of Helsinki that protects research subjects.

The proposed game was designed mainly to aid people with cognitive deficits, so a number of tests on a selected sample of patients has been run. More in detail, the patients were divided in two groups: one with people affected by *Down Syndrome*, and one with people affected by *Fragile X Syndrome*. Clearing all the levels with high scores wasn't the only goal of the project, a good video game must also give a great *experience* to stimulate the users to keep playing, especially with such a heterogeneous hardware interface. For this reason, there were some possible issues to deal with:

Comfort. We propose a wearable system, so in order to give the players the best experience it must be

Table 2: Data gathered during the experimental session for a sample of patients.

Player	Clearing time (mission)	Mission type	Level	Day/night	Reaction time (task)	Error	Error type
B.	30.169 s	Orientation	2	Day	1.973 s	No	-
C.	18.11 s	Orientation	4	Night	4.991 s	Yes	1
G.	31.813 s	Crossing	3	Night	8.802 s	Yes	4
L.	21.169 s	Orientation	8	Night	3.311 s	No	-
M.	15.513 s	Crossing	5	Day	9.259 s	Yes	2
N.	53.67 s	Orientation	2	Day	21.977 s	No	-

comfortable to wear, even for prolonged periods of time. The Oculus Rift is a fairly heavy headset, and a continuous usage can be tiresome for both the neck and the eyes. The PS Move on the other hand must be tied firmly to the leg, to avoid discrepancies in the accelerations' processing, but not too tightly, as it would risk hurting the patient.

Immersivity. Even with all the expedients done to ensure maximum immersivity, patients with cognitive deficits might not feel comfortable with the virtual reality environment and the interaction with the exergaming devices. If that were to happen they probably wouldn't even be stimulated to walk and explore the virtual world, thus defeating the purpose of the entire game being based on Human-Computer-Interface and Virtual Reality.

Focus. Instructions for clearing the levels can be received on-screen or through the Oculus Rift speakers. As previously mentioned, the graphical interface was kept as simple as possible to avoid obstruction of the virtual experience, but it must be at the same time clear end effective, because if a patient doesn't even notice a new instruction is available, that will greatly affect his/her reaction and completion times in the test results.

4.2 Experimental Session

Experiments were run with different combinations of game parameters. Some videos of the experiments can be found at the following links [6] [7] [8]. For example, in addition to the level type and difficulty, the operator could choose the time of the day in which the virtual city was displayed. This was added to give the players awareness about exploring a city in different light conditions. In spite of the possibility of the aforementioned technical problems, the tests went surprisingly well. The patients collaborated without any issue, and the general consensus was that they truly enjoyed the game mechanics and the possibility to explore an interactive world. From the gaming point of view this project was surely a success. The human-computer interface worked flawlessly most of the time, registering steps in the right way without disrupting the gaming experience. An example of the data gathered during the experimental session the simulation is shown in Table 2.

The tests yielded good results as well as bad ones: some patients had more difficulties clearing the harder levels, but everyone was at least able to clear the basic ones within a few tries. The time of the day didn't seem to influence the performance, and while the level difficulty surely did, the most skilled players didn't have any particular issue with the increasing number of instructions, nor with the traffic intensity. The reaction times per instruction changed a lot, even within the same player. Depending on how complex the indication was, some players performed their actions in up to 30 seconds, while the lowest reaction times ranged between 2 and 4 seconds. An *error type* field (i.e. 1: risk of being hit by a car; 3: cross walk when traffic light is yellow; 3: cross walk when traffic light is red; 4: cross walk outside zebra crossing) was added to keep track of the causes of every error, for a more accurate analysis of the players' capabilities.

5 DISCUSSION AND CONCLUSION

The tests run during the debugging phase and the experiments run on the users confirmed the potentialities of the proposed exergame:

- The virtual world was perfectly perceived by the players despite being simplified with just the essential details;
- The navigation was realistic and the tracking algorithm was robust enough: the player could feel

[6] https://youtu.be/jy67h2hug1I
[7] https://youtu.be/ujUF9JeJ1EU
[8] https://youtu.be/vQEZIVro8_8

himself walking in the city as if the roads were real;

- The system was responsive: there were no delays when looking around with the Oculus Rift, nor when walking with the Move, everything was felt real-time;
- The patients had fun and this is a crucial aspect for a video game, even without taking into account the test results: fun must be something that differentiates a game from a simple interactive application for medical purposes;

The concept of this game could be used for new and different applications in both video game and medical fields, with the use of new interfacing devices other than the Oculus Rift and the Move.

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