DESIGN AND DEVELOPMENT OF A SPATIAL IMMERSIVE TRACK CYCLING SIMULATOR

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Abstract

Virtual Reality (VR) is a technology that makes use of computer graphics, algorithms and special hardware to simulate the real world in real time. There are four main elements required to make a VR system a success, namely virtual world, immersion, sensory feedback and interactivity. The virtual world created must be as real as possible. Users should have a sense of immersion in the virtual world. Position tracking is usually incorporated into a VR system for visual, sound and force feedback on the users and the virtual objects in the VR world must be interact-able with the users. VR has proven to be effective in training and widely used in many areas, for example medical surgery, dental treatment, psychology treatment for phobia, engineering design, maintenance and repair, sports and many more. By implementing VR technology in training, users are able to reduce the training cost and time. VR training is also safer for users, as harsh environments can be simulated despite the environment and/or human factors. On the other hand, the physical facilities and infrastructures of the track cycling are very costly. In track cycling, the game field, known as a velodrome, requires a large space of area. It requires a huge budget and professional manpower to maintain these facilities. Therefore, the proposed spatial immersive track cycling simulator is invented to overcome these issues. The aim of this study is to simulate the velodrome track cycling in VR environment and synchronize with a 6 degree-of-freedom motion platform. The simulator is aimed to be low cost and minimal space requirement compared to actual velodrome. A trainee who undergoes VR track cycling simulator training wears a head-mounted-display

(HMD) to visualize the VR environment. An actual bike will be mounted on the 6-DOF motion platform, which the platform will synchronize with the VR environment to simulate the track condition for the training purposes. An encoder is placed at the bicycle wheel to feedback the moving speed and synchronize the visualize feedback to the HMD.

Keywords: Virtual reality, track cycling, simulation, 6-DOF platform, training

Introduction

Virtual environment

Fully immersive visualization facilities are still a relatively novel technology, but they are in fact the key subject of many research and industrial projects. Head mounted displays (HMDs) are commonly used in immersive virtual environment systems. HMDs are designed to present two separate views of the virtual environment to the user. One view is for the user's right eye and the other view is for the left eye. These two stereo views are fused by the viewer's perceptual system in the same way as right and left eye views of natural scenes. HMD system must also compute the synthetic views, track the viewer's location and viewing orientation in the virtual world to create the correct right and left eye views. The latest technologies allow the development of better and cost effective spatially immersive visualization systems. Helen et al. (2012) listed the basic input technologies, tracking technologies, grounded display technologies, wireless display technologies, stereoscopic technologies and other output technologies used to present virtual environment in 25 academic papers relating to sports virtual reality Helen et al. (2012).

Stewart Platform

Stewart Platform is a kind of parallel manipulator which is able to move in six degree of freedom (DOF) (Stewart, 1965) [2]. It consists of a fixed base platform and a moving platform, connected by six prismatic actuators which are the mechanisms which control the motion of the moving platform. Typically, the joints between the prismatic actuators and the moving platform are spherical joints while the joints between the prismatic actuators and the base platform are universal joints. A parallel manipulator is more accurate than a serial manipulator, due to the fact that it is a closed kinematic chain. Its weight to strength ratio is greater than that of the serial manipulator as well [3]. The Stewart Platform is being widely deployed in various fields such as industrial applications, reconfigurable parallel robots, space applications, medical science and miscellaneous applications. A motorcycle simulator using the Stewart Platform is known as the MORIS simulator. It is a virtual realistic simulator which is able to take steering input and provide audio, instrumental and visual feedback. The MORIS simulator is a tool for motorcycle designer as the designer have to meet the exact specification to make sure that the design can be performance effectively. This simulator allowed them to test their new prototype before they actually build them. Therefore, they are able to cut down the cost for designing a motorcycle [4]. Mohamad (2010) reported on the Stewart Platform in his studies on vehicle simulator as well [5]. The motion of the bicycle in virtual environment can be simulated using the Stewart Platform mechanism. It enables the user to feel the motion sensation in the virtual world. However, this might cause dizziness in certain individuals. Forward kinematics can be used to predict kinematics and also dynamic behavior. However, the forward kinematics of the Stewart Platform is extremely complicated because of its structure and its mechanical stiffness (El-Badawy & Youssef, 2013). Many researchers have presented single polynomial of direct kinematics, which might be time consuming and cause heavy computational loads [6].

Virtual Reality

Virtual Reality (VR) technologies are widely used in research and industrial projects nowadays, with the improvement in high speed computing, high resolution graphics and the user experience devices [7]. VR technology is a technology that makes use of computer graphics, algorithms and special hardware to simulate the real world in real time. A VR system creates a virtual environment which enables human to interact with virtual objects. VR has been widely applied in medicine, engineering, manufacturing plant, education, science, military, architecture, sport science, etc. The applications included teaching and learning aid in theory classes as well as practical hands on training. Virtual reality enhances the graphical presentation of knowledge delivery, which increases students' learning efficiency [8]. To increase the immersive feeling of the user in virtual environment, co-location stereoscopic visualization system can be applied. The term co-location refers to the presence of a display and input in the same location at the same time. Co-location VR system allows easy interaction between the user and the virtual object. In addition, such a system can help eliminate the need to model the whole working environment. There are four main elements required to make a VR system a success, namely virtual world, immersion, sensory feedback and interactivity. The virtual world created must be as real as possible, and users should have a sense of immersion in the virtual world. Position tracking is usually incorporated into a VR system for visual, sound and force feedback on the users and the virtual objects in the VR world must be interact-able with the users. VR scenarios coupled with real time presence and interaction enhance sports performance. VR sports simulations reveal the formation of useful mental strategies and improve athletes' performance in the actual sport. VR sports simulations can physically immerse a group of individuals into a competition virtual environment as well. VR technology impacts both physical and visual immersion through the use of vestibular and force feedback. This feedback not only creates realism by compensating for muscular movements or indicating contact with objects, but also keeps the virtual world from colliding with the real world, possibly causing an injury. VR as training aid in sports is not new. Many sports such as golf, skiing, cycling, and athletics have been using VR technology as an aid to measure athletes' performance and analyze their technique. VR has proven to be effective in training and widely used in many areas, for example medical surgery, dental treatment, psychology treatment for phobia, engineering design, maintenance and repair, sports and many more. By implementing VR technology in training, users are able to reduce the training cost and time. VR training is also safer for users, as harsh environments can be simulated despite environmental and human factors.

Track cycling

In track cycling, facilities and infrastructure are very costly. For example, and indoor velodrome facility built in Aigle, Switzerland cost 11 million dollars US and the 200-meter board track, fully homologated and Union Cycliste Internationale (UCI) certified track cost around 400 thousand dollars, which includes the track, electronic timing, lighting, sound system, computerized scoreboard, access tunnel and UCI certification. The remaining 10.6 million dollars was the land, building, and architect's fees. Velodrome Rakyat located in Ipoh was the first velodrome built in Malaysia. It cost around RM44 million at the time it was built. The cost of building a proper Velodrome is huge. Once a Velodrome is built, maintenance and cleaning work must be carried out from time to time. In Malaysia, the government used to send the national track cyclists to train abroad. The cost incurred for sending a team to overseas is another huge amount of money. While VR systems keep improving, VR track cycling simulator can provide a real-time visualization on Velodrome track, giving the rider the same sensational as riding on the real bicycle. No matter the time or the weather, a virtual bike training system lets the athletes get out and ride. Athletes can reap the benefits of a full workout paired with the excitement of riding a virtual bike trainer along a real Velodrome as the system tracks the training data. Track cycling can be very dangerous if someone in the field thinks that he has enough experience to race aggressively. Accidents may happen anytime when a person cycling on a Velodrome track, especially for the beginner. This is because the track cycling is much different than normal road cycling in term of the slope of the track, track path, bicycle type, and bicycle brake system. In order for top athletes and sport organizations to focus on improving physical performance without suffering injuries, immersive virtual reality combined with real time motion analysis is becoming a primary training tool. Gait analysis and training can be used for sport related research and therapy. The VR technology is invaluable for injury prevention and rehabilitation, research and human gait analysis. These systems are ideal for creating and implementing new training programs in premiere sports centers. Virtual reality scenarios coupled with real time presence and interaction offers great potential for enhancing sports performance in track cycling. VR simulations can be tailored for any track cycling event. Those simulations reveal the information of useful mental strategies and improve one's performance in the actual sport. Such VR track cycling simulations may use the virtual reality concepts to physically immerse an individual into a simulated competition as well.

Related previous research

Several related research works have been conducted. Alejandro et al. [10] studied the data of existing platforms, mechanisms, hardware and software for the development of a 6 DOF platform, focused on flight simulator application. They concluded that to achieve the necessary requirements of flight simulator, 6 servo motors are required with servo drives installed. Servo motors are used in industrial applications where elevated dynamics, torque control, speed precision and positioning precision requirements are critical in another project is "The development of a virtual cycling simulator" by Yuk-Ming et al. [11]. The simulator they developed shows information such as speed and distance travelled on screen to evaluate rider skill. They have implemented the resistance force to simulate road friction and the effect of riding up hill. To achieve this effect, an actuation unit is mounted at the

back wheel of the bicycle. The actuation unit consists of a damper and a servomotor. The simulator can be displayed with stereoscopic effect and with sound effect playing at the background. Kim et al. [12] developed a VR bicycle simulator as well, specifically for rehabilitation training of postural balance. They have conducted a series of experiments on the VR bicycle simulator in three conditions (without visual feedback, with visual feedback of weight shift and with visual feedback of the center of pressure). Their experiments suggested that the visual feedback of weight shift is most effective for increasing the effect of the balance training. Chen et al. [13] had proposed an interactive bike simulator of 2 DOF platform. The platform is controlled by adjusting the cable tied to the platform and is presented in VR. They proposed numerical methods to calculate the bike motion equations and road conditions in virtual bike riding. Yap et al. [14] designed a 6 DOF system for virtual bicycle simulator prototype. The kinematics equation of the 6 DOF system has been formulated with accuracy tested. The authors commented there are still many further improvements required. They successfully created a design feasibility programming to verify the design of a 6 DOF platform before actually building one. The authors suggested the addition of a display of the virtual environment to complete an immersive virtual bicycle simulator.
The objectives of this study are:

- To simulate Velodrome track cycling in a virtual environment
- To synchronize the 6 degree of freedom (DOF) mechanism with the VR environment

Section II of this paper concerns the methodology of the integration of the hardware, control system and the virtual environment design of the spatial immersive track cycling simulator. Next, in section III, results and discussions on the questionnaire survey are provided based on the 50 university students who had tried the simulator. Conclusions and future work are discussed in section IV.

Methodology

The mechanism that drives this simulator is divided into three parts, namely hardware, control system and virtual environment. Figure 1 shows the spatial immersive track cycling simulator elements. The hardware consists of a modified bicycle, a 6 DOF platform and an Oculus HMD. The bicycle is modified to be able to mount on the 6 DOF platform with back wheel freely rotate when force is applied on to the pedals. The 6 DOF platform is controlled by 6 servomotors. The Oculus HMD is connected to a computer to display a virtual environment using VR technology. The control system consists of a Wiimote and an Ardruino board. The Wiimote was mounted on the back wheel of the bicycle as a sensor to track the angular speed of the back wheel while the Ardruino board is used to send signal to the 6 servomotors to control the 6 DOF platform. The virtual environment is designed and presented using Unity 3D. A virtual bicycle is designed to imitate the actual bicycle mounted on the 6 DOF platform. The angular speed of the Wiimote is converted to the moving speed of the virtual bicycle, while the orientation of the virtual bicycle is calculated to control the 6 DOF platform accordingly.

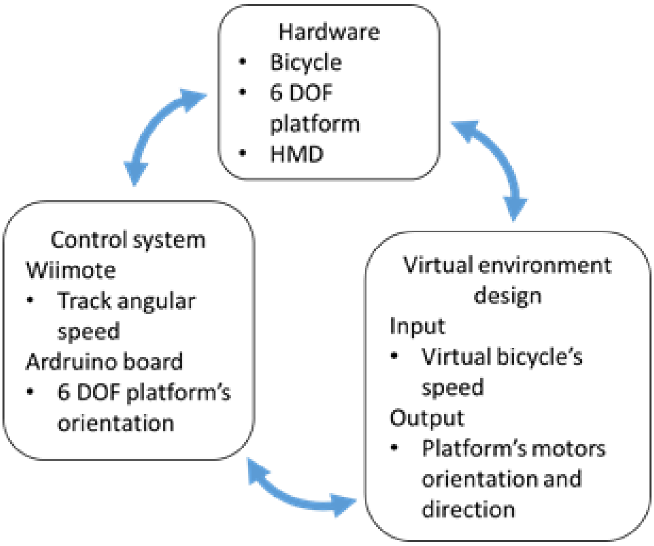

Figure 1: Spatial immersive track cycling simulator elements

6 DOF platform's design and Ardruino control system

The orientation of the virtual bicycle is tracked in the virtual environment. The roll, yaw and pitch orientation of the virtual bicycle represent the roll, yaw and pitch orientation of the 6 DOF platform. To control the platform's orientation, the 6 servomotors have to be rotated to the designated step and direction. The communication between the virtual environment and the Ardruino board is wired using an USB cable. The orientation of the virtual bicycle is identified in roll axis and pitch axis, table 1 shows the rotation direction of the 6 motors to achieve positive or negative value of roll angle and pitch angle of the bicycle. Figure 2 shows the 6 DOF platform arrangement.

Table 1: Bicycle orientation vs 6 motors orientation

Bicycle orientation		6 DOF platform motor orientation					
		Motor 1	Motor 2	Motor 3	Motor 4	Motor 5	Motor 6
Roll	+ve	CCW	CW	CCW	CCW	CW	CCW
	-ve	CW	CCW	CW	CW	CCW	CW
Pitch	+ve	CW	CCW	CCW	CW	CW	CCW
	-ve	CCW	CW	CW	CCW	CCW	CW

CW: Clockwise
CCW: Counter-clockwise

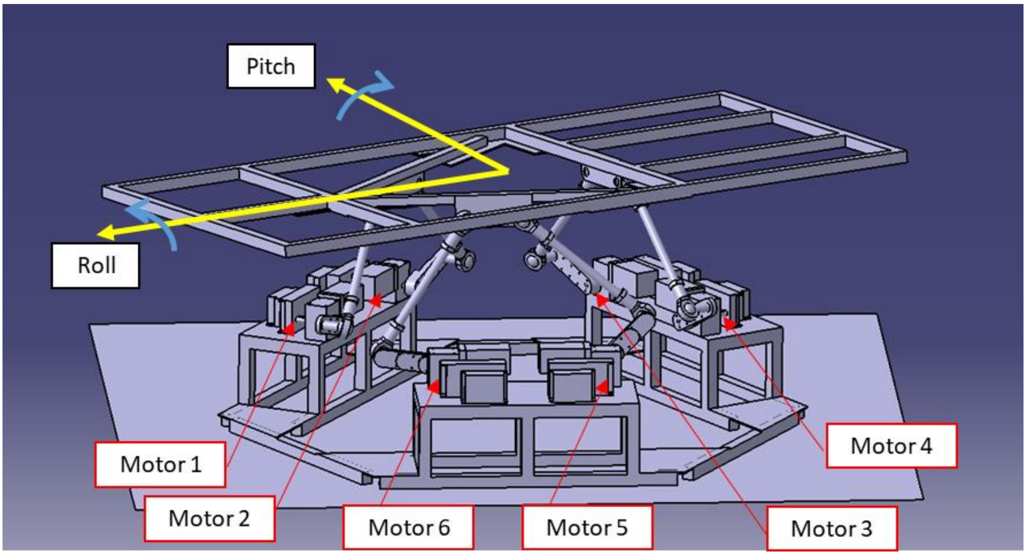

Figure 2: 6 DOF platform arrangement

Wiimote setup and virtual bicycle speed calculation

A Wiimote is attached at the back wheel of the bicycle and is used to track the speed of the actual bicycle and send the data to the virtual environment for controlling the virtual bicycle. Figure 3 shows the setup of Wiimote in spatial immersive track cycling system. The Wiimote API calculates the angular speed of the Wiimote (roll, yaw and pitch) in degree per second. To convert the angular speed from degree per second to radian per second, the data need to be multiplied by 0.01745. The yaw angular speed of the Wiimote represents the angular speed of the bicycle wheel. The velocity of the bicycle is the product of the Wiimote's angular speed in yaw and the radius of the back wheel. In this research, the radius of the back wheel is 0.66 m. Figure 4 provides an explanation of the virtual bicycle velocity calculation and roll, pitch angle of the virtual bicycle.

$V = □ * r$

Where,

V is the velocity of the bicycle (m/s)

□ is the Wiimote's yaw speed (rad/s)

r is the radius of the bicycle (m)

Figure 3: Placement of Wiimote

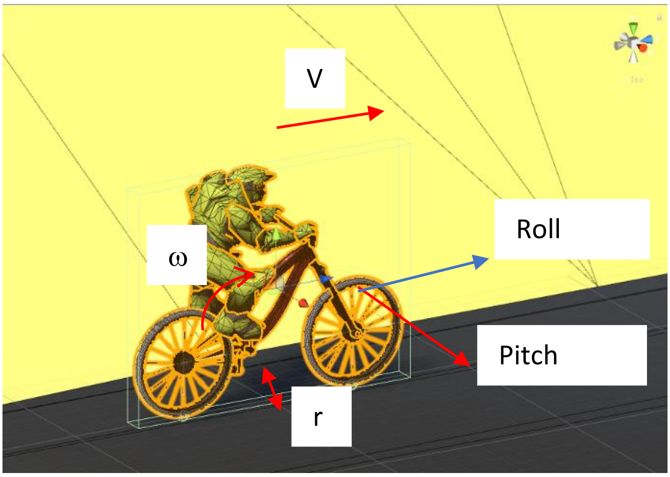

Figure 4: Virtual bicycle velocity and orientation view

Virtual environment of the track cycling simulator design

Based on Cycle Sports Facilities Design Guide from Sport England, the standard dimension of various Velodrome track is given. According to Webb [9], the tracks are constructed according to the metric distance of cycling events:

- 250m track is 4 laps = 1km
- 333.333m track is 3 laps = 1km
- 500m track is 2 laps = 1km

Table 2 below shows the length and width of the track.

Table 2: Velodrome track dimension

Track (m)	Length (m)	Width (m)
250	116	78
333.333	138	97
400	181	104

There are also smaller Velodrome tracks for indoor events and the dimensions of the track are as below:

- 166.666m (6 laps = 1km)
- 200m (5 laps = 1km)

The highest banking angle of the 250 m track is up to 45° while for the 333.333 m track, the highest banking angle is 28°. The 333.333m track has a higher radius of curvature of 48.5m. The detailed dimensions for the 333.333m Velodrome track are as in table 3.

Table 3: The 333.333m Velodrome track dimension

Parameter	Dimension
Concourse circumference	436m
Track circumference	333.333m
Track perimeter	373.5m
Track width	7m
Highest angle	28º
Lowest angle	5.5º
Length	138m
Width	97m

The track with size of 3 laps = 1km, 333.333m Velodrome track is recommended as a good solution to the need for general cycling activities from beginner to elite level. It provides a central arena area to accommodate a wide variety of sports. Figure 5 shows a standard 333.333m Velodrome track dimension.

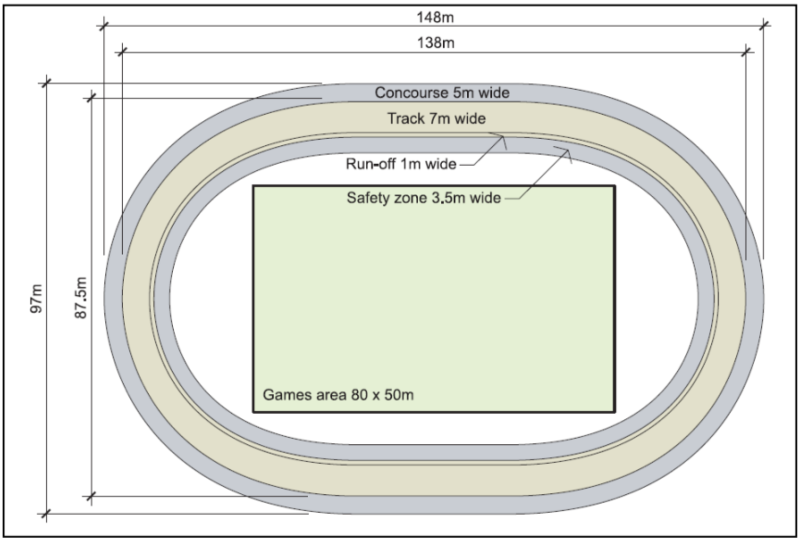

Figure 5: The 333.333m Velodrome Track Dimension

A virtual Velodrome stadium based on the dimensions above was built using CAD software and imported to Unity environment. When viewed in Oculus HMD, the image is split into left and right images (stereographic view). The virtual environment is designed and rendered according to the real Velodrome sample to allow the user to have a realistic feel in the virtual environment. Figure 6 shows a screenshot of the Velodrome model in Unity software.

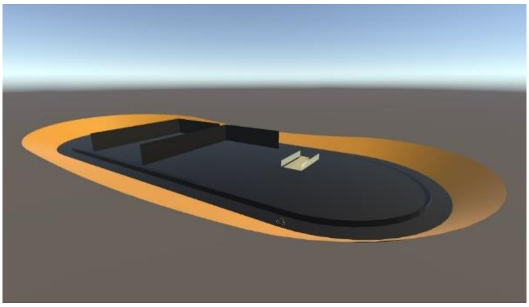

Figure 6: Velodrome model in Unity software

Prototype of the spatial immersive track cycling simulator

A prototype of the spatial immersive track cycling simulator is built. A 6 DOF platform is built with an Ardruino board as the controller to control 6 servomotors. The 6 servomotors are connected to 6 independent linkage connected to a flat metal surface. The platform moves and rotates when the servomotors rotate. A bicycle complying with UCI standards is mounted on the platform. The bicycle is modified with the back wheel freely rotates when force is applied on the pedals. A Wiimote is attached at the back wheel to check its angular speed. Figure 7 shows the setup of the hardware. Figure 8 shows a student wearing the HMD and trying the spatial immersive track cycling simulator.

Figure 7: Hardware setup

Figure 8: User testing the spatial immersive track cycling simulator

Results and discussion

50 students from Faculty of Engineering, University of Malaya were selected to try the developed spatial immersive track cycling simulator. They were then asked to complete a questionnaire survey regarding the spatial immersive track cycling simulator. The questionnaire can be summarized as below:

i. The easiness of VR track cycling simulator
ii. User interface realistic level
iii. The usefulness of the VR track cycling simulator
iv. The usefulness of the VR simulation applications
v. Adoption of the VR track cycling simulation as training tool
vi. Recommendations from users

The results of the questionnaire analysis are discussed below.

38/50 of the students preferred to display the simulation in HMD as compared to normal projector. In their opinion, HMD can provide an immersive feeling in the simulation. 90% of the students preferred to use VR simulator for training purpose as compared to static bicycle trainer. This is because the view in the VR simulator is interactive and the users had more fun in VR simulator.

30% of the students did not like the VR simulator because of the lack of a data analysis display. 25% thought that the simulator is not realistic enough, while 11 students felt that the interactive teaching aid need to be improved. 12% of the students thought that auditory feedback is lacking in current simulator and 11% complained about the jittering and lagging of VR scene in the simulator.

6 students claimed that the system is not user friendly while the rest thought the system is good. 8 students feedback that the orientation of the virtual bicycle does not tally with the simulator, while 24 thought that it does tally while the rest thought it is acceptable. 20% of the students feel that the simulator speed is not tally to the actual pedal moving speed, while 38% of the student thought that the speed is correct and the rest 42% thought that it is acceptable. 45 students saw the virtual environment as real scale while the other 5 students thought that the design and dimensions are not according to a real-life scale.

94% of the students reported that this VR track cycling simulator could improve real track cycling skills. 46 students suggested that track cyclists should try VR track cycling simulator before exposed to the real training, while four students did not agree. 78% of the students think that the training cost can be reduced by having this VR track cycling simulator while the rest think this VR track cycling is costly and cannot reduce the training cost. 41 of 50 students thought that the playback function is necessary for them to review their performance and strive to improve in future training. All of the students suggested adding an instant computer aided instruction and full cycling technique guidance in the simulation to provide them instant correction on bicycle handle orientation, cycling speed, proper cycling posture and technique.

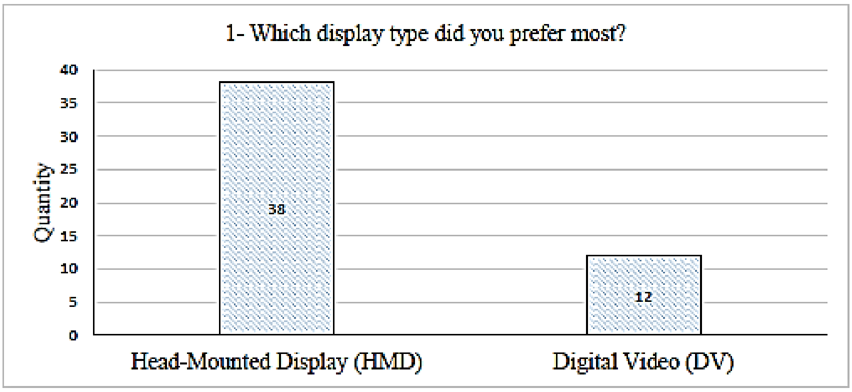

Figure 9: Chart analysis on student's display preference when using simulator

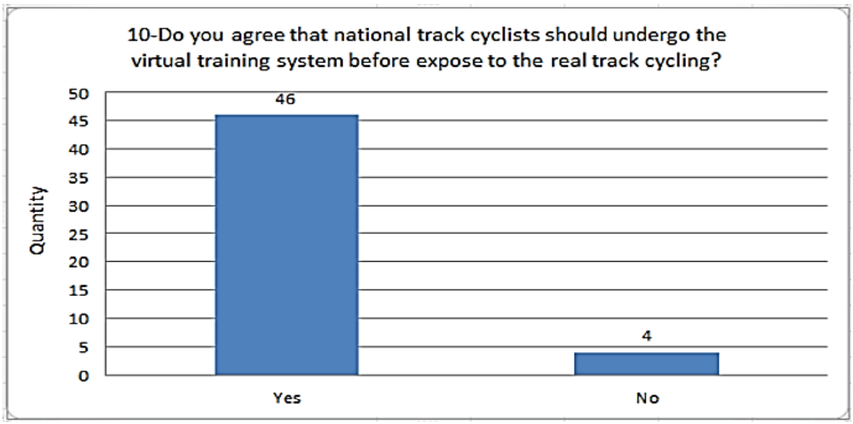

Figure 10: Data analysis on student's opinion on VR training adoption

Conclusion and future work

The development of the spatial immersive track cycling simulator will help in training cyclist athletes. It will definitely save the cost and space for training facilities. However, the effectiveness of this simulator in raising the performance of the athletes is uncertain. Hence, a review of the simulator with professions in track cycling is suggested for future work. Based on the questionnaire results, a majority of the students have accepted the current prototype of spatial immersive track cycling simulator as training tool. To further improve the system, the performance of the user in the simulator can be shown on the screen follows with suggestion for improvement. Video playback to show the user performance at the end of the training session would add merit to the simulator.

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