A Seminar Report on

EXERCYCLE USING VR SYSTEM FOR MOTION SICKNESS EVALUATION

Submitted By

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CERTIFICATE

This is to certify that the seminar report on **EXERCYCLE USING VR SYSTEM FOR MOTION SICKNESS EVALUATION** that is being submitted by **MUKKA DHEEKSHITHA (17251A05B0)** in partial fulfilment for the award of B.Tech in Computer Science & Engineering to the Jawaharlal Nehru Technological University is a record of bonafide work carried out by her in our guidance and supervision.

The work done in the seminar have not been submitted to any other University or Institution for the award of any degree or diploma.

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ABSTRACT

Physical activity is an important determinant of both physical and psychological health. Physical inactivity is the fourth leading cause of death globally and leads to an increased risk of developing death-threatening diseases, such as cardiovascular disease and type 2 diabetes. As a result, the use of equipment and methods that may motivate people to exercise more would be highly beneficial to the individual, as well as to society due to the potential reduction in health care expenses. However, Virtual Reality devices are currently flooding the technology market. VR technology's most mainstream focus is the gaming and entertainment industries. With commercial VR equipment (Head-Mounted Displays - HMDs) becoming available to the public at affordable prices, VR technology has the potential to be integrated into various everyday applications. One field that has significantly benefited from the availability of VR technology is Exergaming. Exergaming refers to video games that include some form of physical exercise and rely on technology that can track body movement. Among various available exergames, cycling exergames have attracted a lot of attention due to facilitating the use of stationary exercise bikes by providing audiovisual applications that increase the motivation levels of the users. The ability to promote physical activity is a highly advantageous characteristic of exergames. This system is a physical exercise system consisting of a smart-exercise-bike and a virtual reality platform that allows the users to engage into physical exercise while immersed within a virtual environment.

INDEX TERMS Chronic diseases, Head-Mounted Displays, Exergaming, Smart-exercise-bike, Virtual Reality devices

DOMAIN NAME Virtual Reality

Table of Contents

1. INTRODUCTION AND OVERVIEW

Physical exercise is very important for both physical and psychological health. Exercise is being engaged in any physical activity which can increase your heart rate beyond normal resting level. Some of the physical activities would be swimming, dancing, yoga, jogging etc., Being physically active will have many health benefits. It also makes you live longer. Research tells that if you are physically inactive, then it leads to increased risk of death-threatening diseases like cardiovascular disease, obesity, increased blood pressure, cholesterol and type 2 diabetes. Physical inactivity is the 4th leading cause of death. 75-150 minutes of exercise per week is recommended for leading a healthy lifestyle. 40-65% of the people that start a physical exercise are expected to drop out within 3-6 months. Most of the people don't prefer physical exercises. There are many reasons for that. Like, many don’t enjoy exercises, they don’t know how to exercise, many quit soon, they are tired or they don’t have time to allot it to do exercises. But there are many disadvantages of not being active. As a result, we can use equipment and methods that can motivate people to exercise more.

Virtual reality devices are currently flooding the technology market. Its mainstream focus is the gaming and entertainment industry. It also has applications in manufacturing, architecture, medicine, military etc., One field that has significantly benefited from VR technology is Exergaming. Exergaming is a kind of video games that include some form of physical exercise and rely on technology that can track body movement. Among various available exergames, cycling exergames have attracted because of the use of stationary exercise bikes and audiovisual applications that increase the motivation levels of the users. We use HMD’s so that they can be very well integrated with various other applications. With VR, it is also important to understand how the quality of VR can directly affect user experience. It is said that HMD’s often create discomfort and even nausea. This condition is known as simulator sickness which is a subcategory of motion sickness. This arises due to sensory conflict between what users see and what they feel. Some of the symptoms of simulator sickness are nausea, vomiting, dizziness, sweating, headaches etc., This model is a physical system which consists of a smart-exercise-bike and a virtual reality platform that allows users to engage into physical exercise while immersed into a virtual environment. The proposed model system allows you to control a virtual bike by pedaling a stationary exercise bike which transmits the pedaling signals to a computer. The users would see the bike moving around the virtual world by HMD.

2. BACKGROUND KNOWLEDGE

Interactive video game exercise has been shown to be effective in enhancing exercise adherence, as well as various health status markers. The availability and low cost of stationary exercise bikes and computers makes cycling exergames an ideal platform for indoors training at the user's homes. Cycling exergames have been shown to increase the motivation of their users to engage into physical exercise.

Göbel et al. presented a set of simple video games controlled by a stationary bike, aiming at improving the long-term motivation of users to engage into physical exercise. Hoda et al. examined the acceptance rates of users when given the opportunity to use a cycling exergame system. Both their quantitative and qualitative results showed that exergames are more entertaining and more encouraging to people with basic activity levels.

In another work, Silva and El Saddik examined the use of a smart-phone as an input controller for a cycling exergame, as well as other types of exergames, showing that smart-phones can be suitable controllers for such games. Their approach offers support for the design of configurable and flexible exertion interfaces that can be integrated with pre-existing games without the need for any modification. Müller et al. designed a cycling game controller and developed a 3D first person cycling game designed to provoke emotions with game elements in different game settings, like timed race, parkours traversal, and virtual world exploration. Their study showed that crafted computer exergame elements are able to provoke emotions in the users, thus by following specific design patterns the games can facilitate and boost their user's engagement with them.

With the recent availability of VR technology, cycling exergames can benefit from the introduction of VR by providing a more immerse and real-life experience that could potentially further increase the motivation of their users for engaging with them.

Apart from research works, commercial cycling exergame products have recently appeared in the market, utilizing both VR and more traditional gaming approaches.

3. EXISTING SYSTEM

Exercise is being engaged in any physical activity which can increase your heart rate beyond normal resting level. Exercise is any bodily activity that enhances or maintains physical fitness and overall health and wellness. Some of the physical activities would be swimming, dancing, yoga, jogging etc., Being physically active will have many health benefits both physically and mentally. It also makes you live longer. Most of the people don't prefer physical exercises. There are many reasons for that. Like, many don’t enjoy exercises, they don’t know how to exercise, many quit soon, they are tired, or they don’t have time to allot it to do exercises.

Exercise is key to good health. But we tend to limit ourselves to one or two types of activity. "People do what they enjoy, or what feels the most effective, so some aspects of exercise and fitness are ignored," says Rachel Wilson, a physical therapist at Harvard-affiliated Brigham and Women's Hospital. But it is necessary to do aerobics, stretching, strengthening, and balance exercises.

Physical exercises are generally grouped into three types, depending on the overall effect they have on the human body:

- Aerobic exercise is any physical activity that uses large muscle groups and causes the body to use more oxygen than it would while resting. The goal of aerobic exercise is to increase cardiovascular endurance. Examples of aerobic exercise include running, cycling, swimming, brisk walking, skipping rope, rowing, hiking, dancing, playing tennis, continuous training, and long distance running.
- Anaerobic exercise, which includes strength and resistance training, can firm, strengthen, and increase muscle mass, as well as improve bone density, balance, and coordination. Examples of strength exercises are push-ups, pull-ups, lunges, squats, bench presses. Anaerobic exercise also includes weight training, functional training, eccentric training, interval training, sprinting, and high-intensity interval training which increase short-term muscle strength.
- Flexibility exercises stretch and lengthen muscles. Activities such as stretching help to improve joint flexibility and keep muscles limber. The goal is to improve the range of motion which can reduce the chance of injury.

Physical exercise can also include training that focuses on accuracy, agility, power, and speed.

Types of exercise can also be classified as dynamic or static. 'Dynamic' exercises such as steady running, tend to produce a lowering of the diastolic blood pressure during exercise, due to the improved blood flow. Conversely, static exercise (such as weightlifting) can cause the systolic pressure to rise significantly, albeit transiently, during the performance of the exercise.

4. DISADVANTAGES

Most of the people don't prefer physical exercises. There are many reasons for that. Like, many don’t enjoy exercises, they don’t know how to exercise, many quit soon, they are tired, or they don’t have time to allot it to do exercises. Physical inactivity is the 4th leading cause of death.

Research tells that if you are physically inactive, then it leads to

1. increased risk of death-threatening diseases like cardiovascular disease, obesity, increased blood pressure, cholesterol and type 2 diabetes.
2. increased feelings of anxiety and depression.
3. increasing the risk of certain cancers.

Physically active overweight or obese people significantly reduced their risk for disease with regular physical activity.

Studies show that physically active people are less likely to develop coronary heart disease than those who are inactive. This is even after researchers accounted for smoking, alcohol use, and diet.

Many deaths occur each year due to a lack of regular physical activity. Here are some facts:

- More people tend to have an inactive lifestyle as they get older.
- Women are more likely to have inactive lifestyles than men.
- Non-Hispanic white adults are more likely to get physical activity.
- Hispanic and African American adults are less likely to get physical activity.

5. PROPOSED SYSTEM

Virtual reality devices are currently flooding the technology market. Its mainstream focus is the gaming and entertainment industry. It also has applications in manufacturing, architecture, medicine, military etc., One field that has significantly benefited from VR technology is Exergaming. So, exergaming is kind of video games that include some form of physical exercise and rely on technology that can track body movement. Among various available exergames, cycling exergames have attracted because of the use of stationary exercise bikes and audiovisual applications that increase the motivation levels of the users. We use HMD's so that they can be very well integrated with various other applications. With VR, it is also important to understand how the quality of VR can directly affect user experience. It is said that HMD's often create discomfort and even nausea. This condition is known as simulator sickness which is a subcategory of motion sickness. Simulator sickness arises due to sensory conflict between what users see and what they feel. Some of the symptoms of simulator sickness are nausea, vomiting, dizziness, sweating, headaches etc.,

So here, this model is a physical system which consists of a smart-exercise-bike and a virtual reality platform that allows users to engage into physical exercise while immersed into a virtual environment. The smart-exercise-bike system is designed as a generic kit that can be attached to any stationary exercise bike in order to provide "smart" capabilities and is able to operate either as a generic gaming controller, or in combination with dedicated applications, such as the VR cycling application discussed in this work.

The proposed model system allows you to control a virtual bike by pedaling a stationary exercise bike which transmits the pedaling signals to a computer. The users would see the bike moving around the virtual world by wearing an HMD.

6. ARCHITECTURE

The proposed smart-exercise-bike VR system consists of three components:

(a) the bike module,

(b) the bike server application, and

(c) the VR application.

The bike module is used in order to transmit the input from the exercise bike to the computer, where the bike server converts the received data to the required actions for use in the VR application. The bike module, accompanied with the server application, is designed as a “plug and play” kit that can be attached to generic exercise bikes and convert them to gaming controllers, thus transforming generic computer games to cycling exergames. Furthermore, dedicated applications, such as the VR application, can be developed in order to better exploit the system’s capabilities and provide enhanced cycling exergaming experiences.

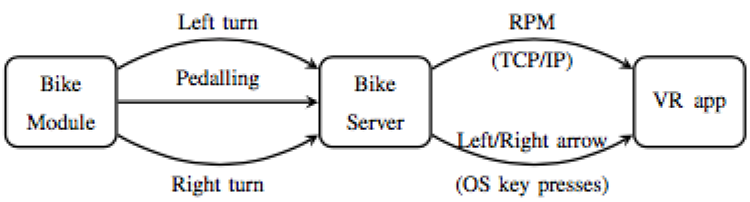

Fig. 1: Outline of the proposed Smart-Exercise-Bike system

6.1 The Smart-Exercise-Bike Module

The bike module is used in order to transmit input from exercise bikes to the computer, where the bike server converts the received data to the required actions for use in VR application. Bike module accompanied with server application is designed as a plug and play kit that can be attached to any exercise bike and convert them to gaming controllers. We need a real stationary bike as base for smart-exercise-bike and to this end, a custom microcontroller-based circuit is designed and attached to the bike to detect the bike movement and transmit the information to the computer.

In order to create a truly immersive virtual reality cycling application, a real stationary exercise bike was used as the base of the smart-exercise-bike system. To this end, a custom micro-controller-based circuit was designed and attached to the bike in order to detect the rotation of the exercise bike's pedals, provide buttons for steering, and transmit this information to an attached computer in real-time. The bike module was designed as a generic peripheral that can be attached to any exercise bike and connect to any USB enabled computer that can support the accompanying software. A commercially available microcontroller board was used as the basis of the bike module and a custom designed circuit board was used in order to connect all the electronic components to the board.

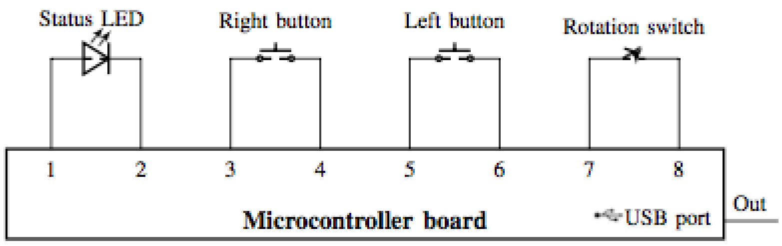

Fig. 2: Basic outline of the bike module

To detect the rotation of the bike's pedals, a magnetic switch was used, with one part of the switch attached to the bike's body and one on the pedal. At the end of a full rotation of the pedals, the proximity of the magnetic switch's parts causes the circuit to close and the microcontroller then detects the event and transmits a signal to the computer via the USB connection. Support for steering was implemented via two buttons, on the left and the right side of the bike's handles respectively. Upon pressing the button, the microcontroller would transmit to the computer the signal to turn left or right via the USB connection. Continuous pressing of the steering controls was also supported in order to allow for smoother and more natural steering control. An LED was also attached to the board in order to indicate whether user input is registered by the board by blinking when a control signal is received. The board is directly powered by the USB connection used for communication with the computer.

6.2 The Smart-Exercise-Bike Server

The signals transmitted to the computer by the bike module are handled by a server application that converts them to an appropriate form for use in various applications. When the server application receives a steering signal, it sends a corresponding key press signal to the operating system. For steering left, the server issues a "left arrow" key press, while a "right arrow" key press is issued accordingly for steering right. For single steering signals, the key press signals are issued as "press and release" signals, while for continuous pressing of the steering button, the key press signals are issued as "press and hold" and a "release" signal is issued when the steering button is released. Mapping the input from the bike module to the operating system's key presses allows for straightforward integration with any application that supports control using the arrow keys. Furthermore, key mappings can easily change to allow support for various applications.

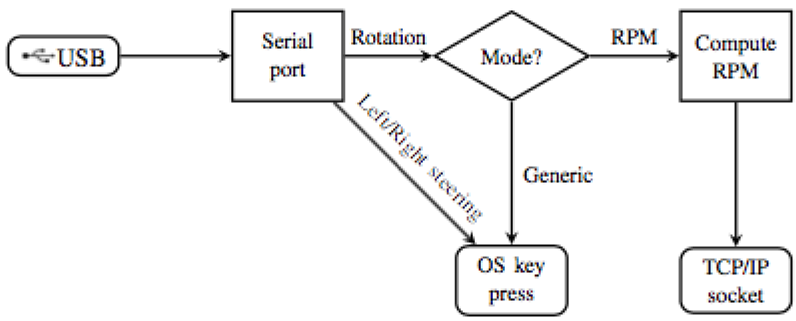

Fig. 3: Outline of bike server application

For the pedaling signals, the server application supports two modes of operation:

(a) The generic mode handles each rotation signal as a key press of the "forward arrow" key, similar to the steering control.

(b) In the RPM (rotations per minute) mode, used in the examined VR application, the server receives the rotation signals and calculates the number of rotations per minute.

Applications can then connect to the server via a local TCP/IP socket and receive the RPM speed in real time. This approach allows multiple applications to connect to the bike server and receive pedaling information, thus providing great flexibility in developing applications for the smart-exercise-bike system.

6.3 The Virtual Reality Environment

A simple free roaming environment was developed, consisting of a track that extends within an open area with trees, hills, houses, and large rocks. Objects expected to be present in such an environment (e.g., signposts, benches, streetlights) were also present in order to increase the diversity, the complexity, and the realness of the virtual environment. Furthermore, ambient sounds consistent with the scenery were also played within the game environment. While free roaming, it was also important to limit the playable area to the track. This was achieved by creating a boundary around the track, made up of fences, large rocks and boulders. The track is designed as a closed loop without any dead ends. As a result, the user can roam through the virtual environment for an unlimited distance and time.

(a) (b) (c)

Fig. 4: Screenshots from the virtual environment. (a) Aerial view of the map. (b) First person view. (c) The questionnaire.

The speed of the virtual bike is decided by adjusting the rotation speed transmitted from the bike server according to the size of the virtual bike's wheels, thus resulting in more realistic motion. Steering is achieved by setting a minimum turning angle which is gradually increased up to a maximum angle while a steering button is pressed. Releasing the steering button results in the virtual steering handlebar returning to its neutral position (0 turning angle).

7. EXPERIMENTAL EVALUATION

7.1 Experiment Setup and Equipment

The participants of this study were asked to use the smart- exercise-bike system while using a commercially available HMD in order to roam through the developed virtual reality environment. The utilized HMD is a virtual reality headset that uses two OLED panels, one for each eye, each having a resolution of 1080 x 1200 pixels and a 90 Hz refresh rate, providing a total resolution of 2160 x 1200 pixels and global refresh. The HMD was connected to a computer equipped with a 4.2 GHz 4-core CPU, 64 GB of RAM, and a high-end graphics card with 12 GB of memory. While using the smart-exercise-bike system, a wireless 4- lead electrocardiography (ECG) sensor was attached to the participants in order to obtain an ECG signal with a sampling frequency of 512 Hz. ECG is the process of recording the electrical activity of the heart in relation to time. ECG signals have been extensively used for affecting recognition and more recently for perceptual video quality evaluation. Furthermore, a Galvanic Skin Response sensor (GSR - Sweating) was also used by attaching two electrodes to the middle and index finger of the right hand of the participant. The sampling rate of the GSR sensor was approximately 20 Hz. GSR provides a measure of the resistance of the skin, which decreases when perspiration increases, an event that usually occurs when a human experiences emotion such as stress or surprise.

Both signal sensors were attached to a laptop computer (2.3 GHz 2-core CPU, 4 GB RAM) that was used for signal recording and for plotting the two signals on the screen in real- time.

7.2 Experimental scenarios

During the experiment, the participants roam through the virtual environment under various visual quality settings. The supervising researcher set-ups the experiment by typing the participants name and selecting the duration of the baseline quality setting (30 *sec*) and of each stimulus (60 *sec*). At each quality setting test, the users would first pedal around the virtual environment at the baseline high quality setting (HH) for 30 sec in order to allow time for any effects of the previous test setting to disappear. Then, they had 60 sec to pedal around the virtual environment at the test quality setting and then they had to fill a questionnaire that was presented to them within the virtual environment as shown in Fig 4c.

During the experiment, each participant had to rate two times each of 6 different quality settings of the virtual reality environment. The variables that were adjusted in order to create the different quality levels were texture resolution and frame rate. For the baseline high quality setting, texture resolution was set to 1024 x 1024 pixels and the frame rate to 60 fps (HH). Test settings included half (512 x 512) and a quarter (256 x 256) of the texture resolution at 60 fps (MH and LH respectively), high texture resolution (1024 x 1024) at half (30 fps) and at a quarter (15 fps) of the set high frame rate (HM and HL respectively), and random low-resolution textures (256 x 256) at 60 fps (RH). For the random low-resolution textures setting (RH), the textures within the environment were set to the highest resolution and random textures would change to low resolution while the user roamed through the environment.

ID	Quality Setting		Texture resolution	Frame rate
	Texture quality	Frame rate	(Width × Height)	(fps)
HH	High	High	1024 × 1024	60
MH	Medium	High	512 × 512	60
LH	Low	High	256 × 256	60
RH	Random low quality textures	High	Random textures at 256 × 256	60
HM	High	Medium	1024 × 1024	30
HL	High	Low	1024 × 1024	15

TABLE I: Examined Quality Settings

As a result, various random objects within the virtual environment would appear with lower quality, allowing us to examine whether the users would be able to notice them, thus affecting the overall quality ratings.

7.3 Experimental procedure

Afterwards, the electrodes for the ECG and GSR sensors were attached to their bodies. After validating the quality of the captured ECG and GSR signals through visual inspection of the plotted signals on the monitoring screen, the HMD was positioned on the head of the participants and adjusted according to the head size. Three random test scenarios were then run in order to familiarize the participants with the test procedure.

The visual quality of the virtual environment was evaluated using *Absolute Category Ratings* (ACR), as defined by ITU-T Rec. P.910.

The quality settings shown in Table I were used as test stimuli and participants were asked to rate them using a five-level scale: (1) Bad, (2) Poor, (3) Fair, (4) Good, and (5) Excellent. In order to examine the consistency and the reliability of the results, each test stimulus was presented twice to the participants in random order, ensuring that the same stimulus would never appear twice in a row. Furthermore, to avoid any presentation order effects, the order of the test stimuli shown to each participant was randomized.

Apart from the quality rating, after each stimulus the participants were also asked to evaluate any symptom of simulator sickness that they might have felt. The *Simulator Sickness Questionnaire* (SSQ) was used in order to evaluate the levels of simulator sickness reported by the participants. The SSQ is based on the older *Pensacola Motion Sickness Questionnaire* (MSQ) which contained 28 symptoms associated with or premonitory motion sickness. From the 28 symptoms of the MSQ, the SSQ utilizes only 16 which are more suitable for simulator sickness. These symptoms are: 1) general discomfort, 2) fatigue, 3) headache, 4) eye strain, 5) difficulty focusing, 6) increased salivation, 7) sweating, 8) nausea, 9) difficulty concentrating, 10) fullness of head, 11) blurred vision, 12) dizziness (eyes open), 13) dizziness (eyes closed), 14) vertigo, 15) stomach awareness, 16) burping, and are clustered into three distinct categories, i.e. *nausea* (N), *oculomotor* (O), and *disorientation* (D). The severity of each of these symptoms was reported by the participants using a 4-point scale (0, 1, 2, 3), with symptom severity regarded as 0: None, 1: Slight, 2: Moderate, and 3: Severe. Weighting of the scores was then applied in order to compute the score for each category (N, O, D), as well as the simulator sickness *Total Score* (TS).

ECG and GSR recordings were captured from each participant for the whole duration of the experiment. Unix timestamps with millisecond accuracy were used in order to synchronize the ECG and GSR recordings, as well as the test scenarios experienced by the users. After the end of the experimental phase of the study, the captured timestamps were used in order to divide the ECG and GSR recordings into segments referring to each stimulus, in order to examine possible relations between the visual quality or the simulator sickness to the physiological responses.

7.4 Participants

18 subjects participated in this QoE and simulator sickness evaluation experiment. From these 18, 16 were male and 2 were female, with their age varying between 17 and 36 years ($\mu = 26$, $\sigma = 5.65$). The subjects were undergraduate, postgraduate, and PhD students recruited from the University of the West of Scotland and all had normal or corrected eyesight, without any problem with their vision and depth perception.

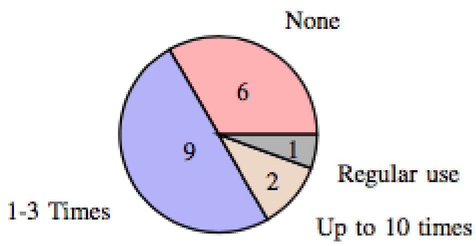

Fig. 5: Participants' experience with virtual reality equipment

The subject’s visual acuity was tested using Snellen charts, while Ishihara charts were used for the examination of colour vision. Fig. 5 provides information about their prior experience with virtual reality applications, showing that 66.66% of the participants had prior experience with virtual reality technology, while 50% had prior experience with the HMD used in this study. Furthermore, 17 out of 18 participants had ridden a regular bike before and 16 out of 18 had used an exercise bike. Prior experience with either regular or exercise bikes was a requirement for participation in the study. Regarding the levels of physical exercise, 61.11% of the participants reported engaging into physical exercise at least 1-2 times per week, while the rest reported typical daily walking as their only physical exercise.

8. RESULTS AND DISCUSSION

8.1 QoE

Mean Opinion Scores (MOS) and the respective 95% confidence intervals (CIs) were computed using the participants' quality ratings in order to determine how the participants perceived the visual quality of the virtual environment. It is evident that the wMOS ratings acquired for each quality setting are all very close to a MOS of 3 (MOS 2 [2.60, 3.47]), indicating that the users perceived all quality settings to be of "Fair" visual quality in general. As expected, texture resolution was the most significant indicator of the perceived quality. The quality setting using the low-resolution textures and high frame rate (LH) received the lowest MOS (2.60) in this study, with the quality setting using the medium resolution textures and high frame rate (MH) receiving a MOS of 2.88, and the one using the high-resolution textures and high frame rate (HH) achieving a MOS of 3.19. All the quality settings using high resolution textures received higher MOS than the quality settings with medium and low-resolution textures.

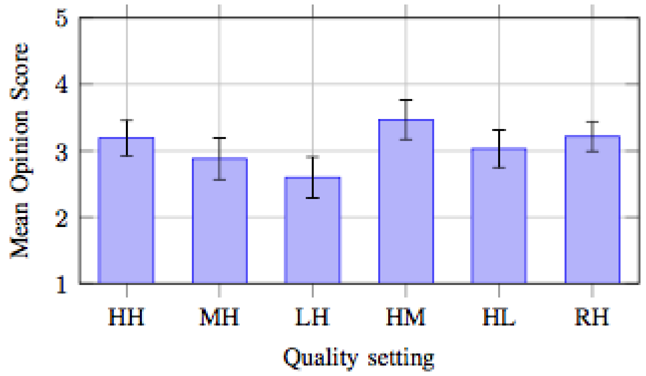

Fig. 6: MOS and 95% CIs obtained for each quality setting

The quality setting that used high quality textures with random textures being of lower resolution (RH) achieved an almost similar MOS to the high-quality setting HH (3.22 vs 3.19), indicating that the participants did not notice the low-quality objects within the virtual environment. It seems that due to the moving speed of the virtual bike and the focus of the user into following the road and not crashing into the fences on the sides, resulted in the users paying less attention to individual objects within the environment.

The quality setting with high resolution textures and low frame rate HL received a 3.03 MOS, higher than the one achieved for the low and medium resolution settings with high frame rate (2.88 for MH and 2.60 for LH), but lower than the one achieved for the quality setting with high resolution textures and high frame rate HH (3.19). The most notable outcome of the results analysis was that the quality setting with high texture resolution and medium frame rate (HM) received the highest MOS (3.47) among all the examined quality settings.

To evaluate this unexpected finding, the acquired quality ratings for HH were compared to the quality ratings for HM using a 1-way analysis of variance (ANOVA). Results showed that there is no statistically significant difference between the quality ratings for HH and HM ($p = 0.214$). A non-parametric Wilcoxon Rank Sum Test was also performed between the HH and HM quality ratings, with the null hypothesis that the two distributions are the same, and hence have the same median, but the null hypothesis was not rejected ($p = 0.181$). This finding is further reinforced but the evident overlap between the MOS ratings for the two settings when confidence intervals are taken into consideration (3.19 ± 0.26 for HH vs 3.47 ± 0.30 for HM). Consequently, a statistically significant difference between the quality ratings for HH and HM cannot be established, indicating that the users were not able to differentiate between the two quality settings. Similarly, to the RH setting, it seems that the moving speed of the virtual bike and the focus of the user into following the road and not crashing into the fences, prevented the users from noticing the reduced frame rate, especially in the HH vs HM case (60 fps vs 30 fps). In the HL case (15 fps), the reduction in frame rate was more noticeable, thus the lower MOS, but still not sufficient to severely affect the perception of quality.

A within-subjects analysis of variance (ANOVA) was conducted in order to provide a statistical evaluation of the impact of the texture resolution, the frame rate, and the quality setting (Texture Resolution & Frame rate) on the participants' quality ratings. The ANOVA results on Table II indicate that texture resolution, frame rate, as well as their combination have a statistically significant contribution ($p < 0.013$) to the participants' quality ratings.

TABLE II: Within-subjects ANOVA on quality ratings

Factor	Sum Sq	df	Mean Sq	F	p
Texture resolution	12.42	3	4.14	5.57	0.0012
Frame rate	6.84	2	3.42	4.46	0.0127
Quality setting	15.69	5	3.14	4.28	0.0010

Sum Sq: Sum of squares, *df*: Degrees of freedom, *Mean Sq*: Mean squared error

TABLE II: Within-subjects ANOVA on quality ratings

8.2 Simulator Sickness Measurement

The average scores for nausea (N), oculomotor (O), disorientation (D), and the Total Score (TS) acquired from the participants for each quality setting are shown in Fig. 7.

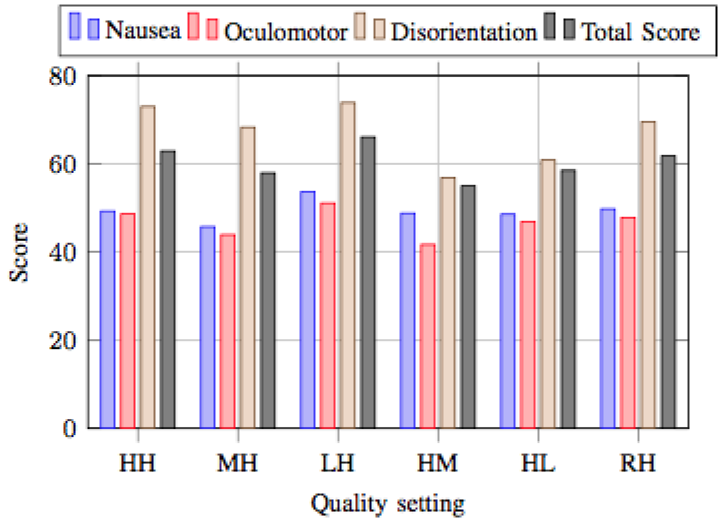

Fig. 7: Average simulator sickness scores for all the quality settings tested

From this figure, it is evident that all quality settings led to an average TS of more than or equal to 55 (µTS 55), with the low-resolution quality setting (LH) resulting in the highest average TS (66.14), and the high resolution with medium frame rate setting (HM) resulting in the lowest average TS (55). While the average TS for all participants and quality settings was between 55 and 66.14, the maximum and average TS observed for each individual participant for all the quality settings exhibit high variability, as shown in Fig. 8.

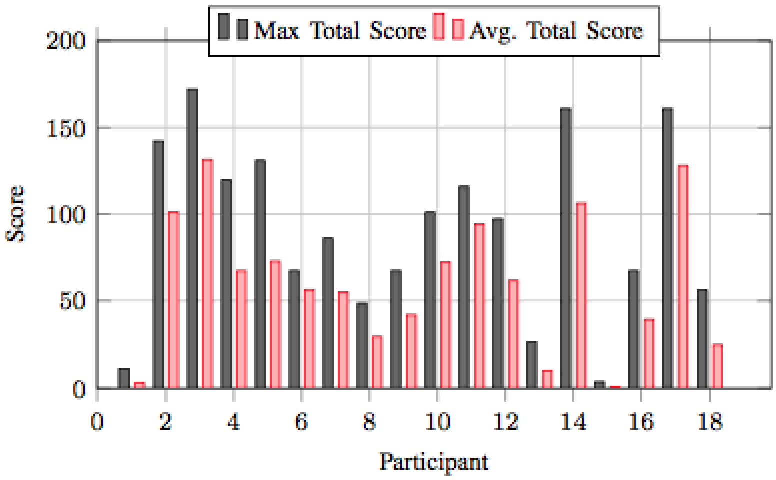

Fig. 8: Maximum and average simulator sickness Total Score for each participant during the experiment

The lowest TS was observed for participants #15 (MaxTS#15 = 3.74, AvgT S#15 = 0.62) and #1 (MaxTS#1 = 11.22, AvgTS#1 = 3.12). Participant #15 was the only participant to report regular use of virtual reality equipment, whereas participant #1 reported having used virtual reality equipment 1-3 times. Both of them had prior experience with the HMD used in this study.

A within-subjects analysis of variance (ANOVA) was conducted in order to provide a statistical evaluation of the impact of prior experience with virtual reality equipment, gender, texture resolution, frame rate, and the quality setting (Resolution & Frame rate) on the participants' simulator sickness Total Scores (TS). The ANOVA results on Table III suggest that prior experience with virtual reality equipment had a statistically significant impact on simulator sickness TS ($p = 1.6 \cdot 10$ 11).

Factor	Sum Sq	df	Mean Sq	F	p
VR experience	94627.08	3	31542.36	20.31	1.60E-11
Gender	11339.32	1	11339.32	5.81	0.0169†
Texture resolution	1642.44	3	547.48	0.27	0.8463
Frame rate	1578.44	2	789.22	0.39	0.6759
Quality setting	2755.78	5	551.16	0.27	0.9287

†Biased due to only 2 out of 18 participants being female

TABLE III: Within-subjects ANOVA on simulator sickness Total Score (TS)

Indeed, as shown on Table IV, average simulator sickness scores are the highest for subjects with no prior experience with VR, decrease for people that have used VR equipment 1-3 times, and are the lowest for subjects that reported having used VR equipment up to 10 times or more. Although gender was also shown to have a statistically significant impact ($p = 0.0169$), with female participants showing higher TS on average than male participants, this finding cannot be considered as reliable due to only 2 out of 18 participants being female. Moreover, results also indicated that resolution, frame rate, and quality setting did not have a statistically significant impact on simulator sickness TS ($p > 0.67$).

VR experience	N	O	D	TS
None	74.70	66.16	96.73	87.92
1-3 Times	40.54	43.51	55.68	52.33
Up to 10 / Regular	34.18	24.42	53.75	39.89

TABLE IV: Average simulator sickness scores in relation to the subjects' prior VR experience

From Fig. 7 it is evident that the scores of disorientation (D) were always the highest among all examined settings, as also observed by Singla et al. in a study about QoE and simulator sickness of omnidirectional videos in two commercially available HMDs, including the one used in this study. It is worth mentioning that in that study, the maximum average TS reported was less than 35, significantly less than the minimum average TS of 55 reported in this study. We attribute this difference to two main reasons: Firstly, the use of high resolution (FullHD and 4K) real video content with which the users are more familiar compared to the computer generated artificial virtual world used in this study, and secondly the fact that unlike being static observers of a video, in the examined application the users are engaged in constant body movement (bike pedaling) while at the same time they are exposed to more sudden changes in their viewing angle depending on their pedaling speed, steering, and course within the virtual world.

All the examined quality settings included constant motion which exposed the users to constant sensory conflict due to the induced perception of self-motion caused by the optical flow patterns generated in the virtual environment. Sensory conflict is one of the main theories about the causes of simulator sickness, thus explaining the increased N, O, D, and TS scores in this study.

Out of the 18 participants of this study, 3 had to stop early due to severe symptoms of simulator sickness. All of them reported before the experiment that they had never used any virtual reality equipment. Participant #7 successfully completed 11 out of the 12 tests before quitting the experiment. During the session, his average simulator sickness Total Score (TS) was 55.08, with the maximum TS being 86.02. Participant #9 completed 5 tests, having an average TS of 41.89, with the maximum TS being 67.32, and participant #14 completed 7 tests, with a 106.32 average TS and a 160.82 maximum TS.

8.3 Physiological Signals Evaluation

The segments of the ECG and GSR recordings that corresponded to each test setting were extracted using the available timestamps, leading to a 60 sec ECG and GSR recording for each quality setting. Recordings for two participants were not retrievable and thus were not used for the analysis. Filtering was applied to reduce the levels of noise and it consisted of a median filter with a time window of 500ms, followed by a mean filter with a time window of 1000ms. Lowpass filtering and smoothing are common pre-processing operations in GSR signal analysis, employed to remove artefacts stemming from movement, as well as electrical artefacts.

After applying the filters, the number of peaks in each GSR segment was computed by detecting the local maxima with a minimum distance of 20 samples (≈1000ms). Furthermore, the momentary heart rate (HR), corresponding to each sample of the ECG recording, was computed and five commonly used HR parameters, were extracted from each ECG segment: the mean HR, minimum HR, maximum HR, median HR, and the standard deviation of the HR.

Factor	Sum Sq	df	Mean Sq	F	p
GSR peaks	130.44	5	26.09	1.28	0.2756
Mean HR	159.47	5	31.89	0.25	0.9387
Min HR	146.97	5	29.39	0.19	0.9649
Max HR	316.62	5	63.32	0.42	0.8314
Median HR	173.03	5	34.61	0.27	0.9273
St.Dev. HR	8.52	5	1.70	0.45	0.8124

TABLE V: Within-subjects ANOVA between physiological parameters and quality ratings

An analysis of variance (ANOVA) was conducted in order to evaluate the impact of the quality settings on the aforementioned physiological parameters. The ANOVA results showed that the quality setting did not have a significant impact on the number of peaks in the GSR signal ($p = 0.2756$), neither on the examined HR parameters ($p > 0.8124$), as shown in Table V.

A correlation analysis between the physiological parameters and the simulator sickness scores showed that there is only weak or very weak correlation between the two, as depicted in Table VI.

Parameter	TS	N	O	D
GSR peaks	-0.01	0.01	0.02	-0.05
Mean HR	-0.12	-0.17	-0.04	-0.15
Min HR	-0.09	-0.13	-0.00	-0.13
Max HR	-0.09	-0.13	-0.03	-0.12
Median HR	-0.13	-0.17	-0.04	-0.16
St.Dev. HR	0.06	0.07	0.01	0.09

TABLE VI: Pearson's Correlation Coefficient between physiological parameters and simulator sickness scores

Sweating and increased heart rate are common symptoms associated with simulator sickness [20]. Nevertheless, the weak correlation found with the GSR and the heart rate parameters can be attributed to the specific activity performed in this experiment, i.e., pedaling on a bicycle. The sweating of both hands holding the bicycle's handlebars affected the GSR readings, whose electrodes were attached on the middle and index finger of the right hand of the participants. During strenuous activity, sweating will rise to dissipate the body heat generated, making it difficult to detect fluctuations in the GSR signal associated with emotional responses [34]. Similarly, the heart rate of the participants was also affected by the physical exercise conducted, thus explaining the weak correlation with simulator sickness scores. In terms of GSR and heart rate, the effects of simulator sickness did not produce responses of higher intensity compared to the physical exercise that the participants were engaged in, thus no connection could be established under the setting of the current experiment.

9. ADVANTAGES

- Exergaming promotes the ability to do physical activities. Due to the high level of engagement and enjoyment that they can offer, they hold a potential to motivate, engage and improve performance of people.
- Exergaming promotes exercise among kids and motivates them to exercise more frequently.
- Exergaming can help improve coordination and body movements.
- It helps to decrease stress levels, as it provides a way to have fun and relieve stress.
- Studies have shown that exergaming can boost energy expenditure and also positive social effects.
- People get an aerobic workout while playing, and exergaming has cardiovascular benefits.
- Exergaming promotes sensory motor learning and has positive effects on cognitive performance for children.
- Although exergaming can be played alone in the privacy of your living room, it can also be a social way to keep fit. Online exergaming communities offer a place where exergamers can meet and compete.

  It can also be a family activity, facilitating family bonding, because exergaming has options for all ability levels and ages. Playing against other people promotes competition and therefore offers more of an incentive to exercise. Virtual trainers are available, so gamers can go through fitness programs where their progress is saved and reviewed.

CONCLUSION

In this report, we have evaluated a smart-exercise-bike virtual reality system based on a commercially available HMD and a custom designed smart-bike controller. The proposed system, both as a generic exergaming controller as well as a virtual reality exergaming system, constitutes a realistic and engaging solution for motivating users to engage in more physical exercise, thus providing health benefits to the users. In the case of the virtual reality application, the analysis of user feedback showed that texture quality and frame rate have a statistically significant impact on the perceived visual quality but not on the simulator sickness scores. Nevertheless, the moving speed of the virtual bike and the focus of the users into following the road and not crashing, prevented them from noticing any quality degradation when the frame rate was reduced from 60 fps to 30 fps. The quality setting was also shown to have no impact on the physiological responses of the participants in terms of the ECG and GSR modalities, while very weak correlation was observed between the physiological parameters and simulator sickness scores. Engaging in strenuous activity, like pedaling, causes an increase in sweating and in cardiac activity, thus interfering with physiological responses in the GSR and ECG signals that could be related to simulator sickness.

Increased simulator sickness scores were observed, compared to other works where the same HMD was used for viewing omnidirectional videos. This difference can be attributed to the use of computer-generated graphics, as opposed to high resolution real video with which the users are more familiar, as well as to the constant and sometimes sudden motion that happens when riding the virtual bike, which results in increased sensory conflict. While the examined quality settings did not affect simulator sickness scores, the levels of prior experience with virtual reality technology were shown to have a statistically significant impact on simulator sickness Total Scores, with users more used to virtual reality technology being less affected by simulator sickness. Consequently, a slow familiarization period could be allocated in order to allow users to become accustomed to the virtual reality system before engaging with it for long periods of time.

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