Validate the Users' Comfortable Level in the Virtual Reality Walkthrough Environment for Minimizing Motion Sickness

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***Abstract*—Motion sickness is a common scenario for users when they are exposed to a virtual reality (VR) environment. It is due to the conflict that occurs in the brain that tells the user that they are moving in the environment, but the fact is that the user's body is sitting still causing them to get symptoms of motion sickness like nausea and dizziness. Therefore, motion sickness has become one of the main reasons why users still do not prefer to use VR to enhance their productivity. Motion sickness can be overcome by increasing the user's comfort level of walkthrough in the VR environment. Meanwhile, a popular VR simulation which is widely used in many industries is a walkthrough in a VR environment at a certain speed. This paper is focused on presenting the result of walkthroughs in a VR environment using movement speed and based on frame rates performance and adopting the unified theory of acceptance and use of technology (UTAUT) model construct variables namely performance expectancy (PE) and effort expectancy (EE) to measure the user's comfort level. A mobile VR, 'VR Terrain' application software was developed based on the proposed framework. The application software was tested by 30 users by moving around in a VR environment with 4 different movement speeds that were implemented into four colored gates using a head-mounted display (HMD). A descriptive and coefficient analysis was used to analyze all the data. The blue gate revealed the most comfortable, outperforming all other three gates. Overall, the most suitable speed to use for VR walkthrough is 4.0 km/h. The experiment result may be used to create a parameter for the VR developers to reduce the VR motion sickness effect in the future.**

Keywords*—*Virtual reality; motion sickness; head-mounted display; head lean movement; mobile VR; walkthrough technique; UTAUT; frame rate

I. Introduction

A. Background Study

Virtual Reality (VR) is the technology that provides almost real and believable experiences in a synthetic or virtual way [1]. Recent research says VR objects typically act similarly to their real-world counterparts. The user can interact with these things in line with the actual physics principles [2]. Users that use hardware devices like goggles, headphones, and special gloves encounter virtual worlds created and served by software [3]. Experiencing VR technology requires a system with designed computer software that can implement the technology and a head-mounted display (HMD) that allows users to see the VR environment [4]. The first HMD was invented and developed by Sutherland in 1965, which was introduced as the ultimate display [5] and became available to the public commercially as the revival of VR with HMD at a low price [6].

However, there are common issues that occur involving the use of VR technology. Users are reported to often experience motion sickness when experiencing VR [7][8]. Motion sickness is generally detected after the symptoms appear. This indicates that the sickness has begun, and this effect is already uncomfortable for the user [9]. When it comes to motion sickness or VR related, many report that women are more susceptible than men. One of the classic examples is seasickness with a ratio of approximately 5:3 by Lawther and Griffin, (1988) [10]. Several factors of motion sickness in VR are associated with the HMD such as motion, field of view (FOV), latency, duration of use, and the VR environment [11][12][13][14][15]. These uncomfortable effects will inhibit future experiences of VR.

In this paper, researchers attempted to minimize VR motion sickness by measuring the comfortable level of experience in mobile VR through movement speed of walkthrough. The users must perform a walkthrough by moving around in the VR environment using the four levels of speeds that were implemented in the developed Android application software, 'VR Terrain'. The test evaluation was carried out by adopting some parts of Unified Theory of Acceptance and Use of Technology (UTAUT) [16]. For evaluation, the theory's construct variables namely performance expectancy (PE) and effort Expectancy (EE) were involved, as well as observing the frame rate value of the used device.

B. Paper Contribution

The contributions of the paper are the following:

- The description and the implementation of the VR walkthrough movement speed parameter.
- An Android application software to measure the users' comfortable level experience of VR walkthrough.
- Results of UTAUT and frame rate values for users' comfortable level experience of VR walkthrough.

II. Related Work

A. Motion Sickness of Virtual Reality

One major theoretical issue that has dominated the field for many years concerns the motion sickness effect in VR. It is also known as cybersickness in terms of symptoms as they are similar. The only difference between the terms is that motion sickness is caused in the real world while cybersickness is caused by the virtual one [17]. With developers striving for higher constancy in VR, the content's specifics are becoming more complicated. Thus, this paper also highlights several factors and effects of VR motion sickness.

1) Factor of VR motion sickness: VR motion sickness is caused when the brain receives sensory input that does not match the movements of the body. Even though VR technology is becoming more advanced, users still experience motion sickness. This paper focuses on the factors that cause motion sickness among VR users, specifically involving the use of head-mounted display (HMD). There are five main factors that contribute to VR motion sickness: motion and speed, field of view, latency, duration of use, and environment. Rapid and intense movements [18][10][19], a narrow field of view [12][20][21], high latency [22][23][24], prolonged use [25][26][27], and overly stimulating environments [28][29][30] can trigger motion sickness in VR users. By understanding these factors and taking steps to mitigate them, it is possible to reduce the risk of VR motion sickness and improve the VR experience for users.

2) Effect of motion sickness: On the other hand, VR motion sickness occurs when a person experiences discomfort or disorientation while using VR technology, due to a mismatch between what they see and feel in the VR environment and what their body is physically experiencing [31]. The effects of VR motion sickness can include nausea [32][33][31], dizziness [34][35][29], headache [8][36][37], fatigue [38][39][40], and eye strain [41][12][37]. These effects can vary from person to person and negatively impact a person's overall enjoyment and use of VR technology. Understanding the effects of VR motion sickness is important for developers and designers of VR technology, as it can help them create more comfortable and effective VR environments for users. The goal of this research is to minimize the effects of VR motion sickness.

B. Head Lean Movement Techique for VR Walkthrough

The head lean movement technique allows for hands-free navigation in VR by relying solely on head movement and six degrees of freedom (6-DoF) tracking [42]. The user simply leans their head to move forward, making it easy to use. The smartphone's gyroscope measures the head movement. Studies have shown that this technique can be effective, but there may be a pause gap between inputs due to the user's tendency to look forward and downward while navigating [43]. Studies have also measured the effects of this technique on factors such as sickness, presence, usability, and comfort when experiencing VR. Previous research has employed this method with a variety of VR headsets, including the Oculus Rift, Samsung Gear VR, and even the HTC Vive, on both mobile and desktop platforms. Table I below shows the head lean technique for VR.

TABLE I. Head Lean Technique for VR

Head Lean Technique			
No	***VR Device***	***VR Platform***	***Author***
1	Oculus Rift DK2	Desktop	[44]
2	Samsung Gear VR	Mobile	[42]
3	Samsung Gear VR	Mobile	[45]
4	HTC Vive	Desktop	[43]

C. Unified Theory of Acceptance and Use of Technology

A concept called the Unified Theory of Acceptance and Use of Technology (UTAUT) integrates eight separate hypotheses to explain why people adopt and use technology [16]. It can account for 50% of the variations in technology usage and 70% of the variations in willingness to use technology [46]. UTAUT was initially developed for usage in business environments, but it can be used in other contexts as well. The Technology Acceptance Model (TAM), the Theory of Planned Behavior (TPB), and Social Cognitive Theory (SCT) are among the models on perception, acceptance, and preparedness to employ technology that are combined in this study. Performance Expectancy (PE), Effort Expectancy (EE), Social Influence (SI), and Facilitating Conditions (FC) are the four variables used by UTAUT to validate users' capacity and willingness to adopt new technology.

1) Performance expectancy: Performance expectancy (PE) is the degree to which a person expects that using technology will help them execute their jobs more effectively [16]. Age and gender also determine the impact of PE [47]. The first fundamental factor used to determine UTAUT for consumers is the degree to which consumers benefit from using technology [48].

2) Effort Expectancy: Technology's early acceptance behavior is influenced by how easily it may be used [49]. Effort Expectancy (EE) stands for "the degree of system usability" [16]. For older people, online technologies could be challenging. Age, gender, and experience are also determining the impact of EE [47]. Regardless of the consumers' technological competency, the EE can be used to determine whether they anticipate experiencing difficulties when utilizing the system.

3) Social Influence: Social Influence (SE) refers to how much a person values other people's opinions about whether they should use new technology [16]. Subjective norms in technology adoption indicate social influence [50]. Age, gender, experience, and voluntariness of use are determining the impact of SI [47]. The intention to use technology is impacted by having active social contacts [51].

4) Facilitating Conditions: Facilitating conditions (FC) refer to the extent to which consumers believe they have the resources and technologies to support their use of modern technology [16]. Besides, awareness and motivation are what encourage people to overcome technological obstacles. According to UTAUT, FC is the internal attribute of a target customer [16][47]. Only age and experience determine the impact of FC [47]. The enabling condition influences effort expectancy or ease of use and can predict the use of technology.

D. Frame Rates for Mobile VR

For mobile VR, keeping a high frame rate is very crucial. Smartphones, which are less powerful than desktop PCs or gaming consoles, power mobile VR systems. Because mobile devices have limited capabilities, it might be challenging to attain a high frame rate with mobile VR systems [52][53]. Mobile VR systems must also work under the constraints of the and motion tracking sensors, which can further cut down on the resources available for producing and showing VR content [54]. Notwithstanding these difficulties, high frame rate mobile VR has made tremendous advancements.

The Oculus Quest 2 and Samsung Gear VR are two examples of the most recent mobile VR systems that have made considerable advancements in offering a high-quality VR experience with a high frame rate [55][51]. For instance, the Oculus Quest 2 can display VR material at 72 FPS, which is quite near to the optimal frame rate of 90 FPS.

III. Development and Implementation

A. Application Software Development

For this paper, suitable hardware and software have been chosen to avoid any difficulties during the development of this virtual rehabilitation application. Hence, it was important to have the level of expertise in selecting the hardware and the software to ensure any problems that arise during this development process can be solved.

The VR Terrain application software was designed in the Unity editor version 2018. This editor enables developers to create apps, games, or 2D and 3D experiments on a variety of platforms, including PC, Mac, Linux, iOS, Android, Windows, and web. Prior to importing the models, a configuration setting must be done to enable the VR environment settings and the Android build support. Thus, three software packages needed to be imported and installed to produce a working Android mobile application with Unity 3D software. Therefore, an Android Software Development Kit (SDK), Java Development Kit (JDK) and Google VR SDK were added to the Unity editor. The first two software packages convert the application built into an '.apk' file. This file can only be compatible with Android Operational System (OS) smartphone devices. On the other hand, the Google VR SDK software package enables the development of applications for VR HMD or glasses.

Next, the 3D models had been selected and downloaded from the Unity store which can be accessed through the Unity 3D website, were then imported into the editor. Then, the models were modified, scaled, and moved to form a terrain that later was turned into a VR environment. A function called 'Character Controller' by Unity was created. This function applies as the camera that will give user an ability to see the VR environment in first-person view and rotate their head to change the viewing angle, allowing presence of immersion for VR user. After .apk file was created when the development had been completed, it will be installed in the smartphone. Users can view the VR environment through the lenses in the HMD.

The head lean movement technique was applied to enable the user to humanly move from one place to another in the VE. The user needed to lean their head to the front and downward to simulate the walking movement. The head rotation plays an important part as it was set to a certain degree using a script. The script had also been added and applied a condition, which changed the movement speed of the character controller. The speed changed when there was a collusion between the character controller and the gates.

There are four gates designed with four color variations which are green, blue, purple, and red. In order for user to change the movement speed when performing the walkthrough in the VR environment, the gates were set as collusion objects, which means when the user makes contact with one of the gates, the movement speed will take effect and make the user virtually move at a specific level of speed. There are four levels of speeds set in VR Terrain application software which are 3, 4, 5 and 6 kilometer per hour (km/h) and individually connected the gates. When the user penetrates the green gate, they will move at a speed of 3 km/h. When the user penetrated the blue gate, they will move at speed of 4 km/h. When the user penetrates the purple gate, they will move at the speed of 5 km/h. When the user penetrates the red gate, they will move at the speed of 6 km/h.

Finally, the speed in kilometers per hour (km/h) and the frame rate information display were added into the application. This information was displayed on the top corner of the screen in the application to keep tracking their current uses of the walkthrough speed movement in the VR environment. This information was used in evaluation phase to strengthen the results and provide a valid outcome. Fig. 1 shows the screenshot of the application view in the smartphone.

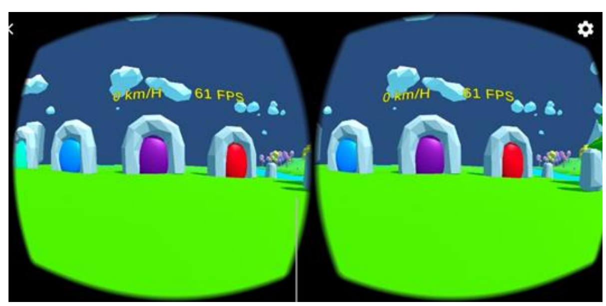

Fig. 1. Application screenshot from mobile.

B. Implementation

Prior to the test, the users will be instructed to fill in the required consent form to prove that the users agreed to be subjects in the test session and the data obtained from the test was used and studied. Each subject was later given a consent form signing that they voluntarily agreed to allow their individual data to be collected and analyzed after the session ended. Note that this testing procedure was using the same smartphone to ensure quality of the research is guaranteed and to avoid data confusion.

The users were asked to wear HMD with the smartphone attached to the front. The VR Terrain application software was previously installed and launched before the device was attached to the headset. After the HMD had been properly attached, the users were instructed to move through one of the four colored gates and moved around the terrain before moving through another colored gate one at a time before ending the session. The users were also instructed to lean their head down forward to a minimal degree as it is the way they can move in the VR environment. The users were also able to change direction by turning their head left or right. The session ended after the users had moved through all the gates and moved around the terrain. After taking a rest for five minutes, the users were asked to complete an online self-survey regarding their session before returning home. Fig. 2 shows the flowchart of the testing procedure.

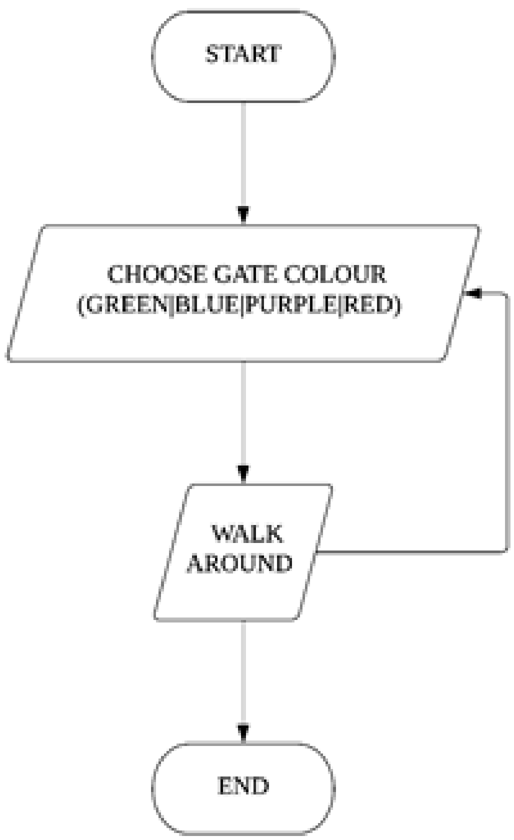

Fig. 2. VR terrain testing procedure flowchart.

C. Evaluation

In this paper UTUAT was used to validate the users' comfortable level walkthrough of VR Terrain application. Only two key constructs have been considered which are PE and EE. These two constructs were selected to validate the comfort level of the user when performing walkthrough in the VR environment using VR Terrain application. In addition, the frame rates of the VR Terrain were observed during the test was running.

1) UTAUT evaluation: Performance Expectancy (PE) and Effort Expectancy (EE) are two of the four components from the Unified Theory of Acceptance and Use of Technology included in this paper where each of the items brought out three items that were used to determine the users' comfort level of VR walkthrough for the reducing motion sickness in VR environment application software, VR Terrain application. For the evaluation of users' comfort level walkthrough of VR Terrain application, there are six variables used which are three variables each for PE and EE. The variables are different from one to another. These variables are as shown in Table II.

In the questionnaire, four colored gates (green, blue, purple, and red) are represented with six variables of PE and EE (PE1, PE2, PE3, EE1, EE2, and EE3), making the questionnaire to have a total of twenty-four items of UTAUT model variables assessment that the users are required to complete.

The data was collected and carried out to perform quantitative analysis using SPPS software. The analysis focused on finding PE and EE significant value (p-value) of the four colored gates. The least significant value was taken into account and declared as the most significant findings. Thus, the most comfortable movement speed to use in VR walkthrough was revealed. Table II below has also been adapted in the online questionnaire.

TABLE II. UTAUT RESEARCH VARIABLE

Variable	*Item*
Performance Expectancy (PE)	PE1: I find this movement speed of VR walkthrough useful for my study/future job.
	PE2: I find using this movement speed of VR walkthrough enables me to accomplish my task pleasantly.
	PE3: I find using this movement speed of VR walkthrough increases my chances of achieving things that are important to me.
Effort Expectancy (EE)	EE1: I find my interaction with this movement speed of VR walkthrough is clear and understandable.
	EE2: I find learning how to use VR walkthrough with this movement speed is easy for me.
	EE3: I find it is easy for me to become skillful at using with this movement speed of VR walkthrough.

2) Frame rates evaluation: The frame rates are measured in frames per second (FPS) as a measurement unit and dependent on the processing power of the device. Therefore, the same device has been used to test the VR Terrain application software as the display. This FPS was also validated to see whether it remained constant or underwent any change during the testing session.

IV. RESULT

A. Respondent Profiles

In this paper, the users' demographic profile (n = 30) was classified using frequency distribution. The profile of respondents consists of three descriptions of users that cover the respondents' age, gender, and experience with VR. Table III shows the profile of the respondents using the frequencies and percentages analysis.

TABLE III. RESPONDENT PROFILES

No	Respondent Profiles	Frequency (N)	Percentage (%)
1	**Age**		
	21	4.0	13.3
	22	19.0	63.3
	23	3.0	10.0
	24	4.0	13.3
2	**Gender**		
	Male	14.0	46.7
	Female	16.0	5.3.3
3	**Experience with VR**		
	Yes	24.0	80.0
	No	6.0	20.0

The demographic analysis provides a general view of the users, which is beneficial in understanding the respondents' background. Based on the result, the majority of the age of the respondents recorded was 22 years old (63.0%), followed by 21 years old (13.3%), and 24 years old (13.3%) participated for the prototype testing. Likewise, most of the respondents were females (53.3%) while males recorded with 46.7%.

Apart from this, the result shows that most of the respondents (80.0%), had experienced VR while only 20.0% of the respondents had not experienced VR before testing the VR Terrain application.

B. Performance and Effort Expectancy Descriptive Analysis

TABLE IV. PERFORMANCE EXPECTANCY DESCRIPTIVE ANALYSIS

No	Item	Frequency (N)	Min	Mean	Max	Std. Dev.
	Green Gate					
1	PE1	30.0	1.00	3.07	5.00	1.60
2	PE2	30.0	1.00	3.00	5.00	1.58
3	PE3	30.0	1.00	3.23	5.00	1.59
	Blue Gate					
4	PE1	30.0	1.00	3.27	5.00	1.51
5	PE2	30.0	1.00	3.37	5.00	1.56
6	PE3	30.0	1.00	3.33	5.00	1.53
	Purple Gate					
7	PE1	30.0	1.00	3.73	5.00	1.28
8	PE2	30.0	1.00	3.50	5.00	1.41
9	P3	30.0	1.00	3.50	5.00	1.36
	Red Gate					
10	PE1	30.0	1.00	2.93	5.00	1.51
11	PE2	30.0	1.00	2.90	5.00	1.47
12	PE3	30.0	1.00	3.03	5.00	1.47

TABLE V. EFFORT EXPECTANCY DESCRIPTIVE ANALYSIS

No	Item	Frequency (N)	Min	Mean	Max	Std. Dev.
	Green Gate					
1	PE1	30.0	1.00	3.30	5.00	1.58
2	PE2	30.0	1.00	3.20	5.00	1.58
3	PE3	30.0	1.00	3.10	5.00	1.60
	Blue Gate					
4	PE1	30.0	1.00	3.33	5.00	1.56
5	PE2	30.0	1.00	3.27	5.00	1.52
6	PE3	30.0	1.00	3.23	5.00	1.48
	Purple Gate					
7	PE1	30.0	1.00	3.57	5.00	1.38
8	PE2	30.0	1.00	3.37	5.00	1.47
9	P3	30.0	1.00	3.40	5.00	1.38
	Red Gate					
10	PE1	30.0	1.00	3.07	5.00	1.57
11	PE2	30.0	1.00	3.07	5.00	1.53
12	PE3	30.0	1.00	2.97	5.00	1.54

In Table IV, the mean score of performance expectancy ranges between 2.90 to 3.73, and the standard deviation ranges between 1.28 and 1.63. Meanwhile, Table V shows the mean score of effort expectancy which ranges between 2.97 to 3.57, and the standard deviation ranges between 1.38 and 1.60.

Both standard deviation scores are relatively small (less than 3). Thus the degree of performance expectancy and effort expectancy variations is within the normal distribution as proposed by Burn and Bush, (2010) [56].

C. Performance and Effort Expectancy Analysis Coefficient Result

TABLE VI. COEFFIECIENT RESULTS OF PERFORMANCE EXPECTANCY

Model Performance Expectancy (PE)		Unstandardized Coefficients		Standardized Coefficients	t	Sig.(p)
		B	Std. Error	Beta (β)		
1	(constant)	0.707	0.372		1.903	0.069
	PE_G	0.041	0.118	0.063	0.350	0.729
	PE_B	0.316	0.112	0.482	2.819	0.009
	PE_P	0.222	0.118	0.285	1.876	0.072
	PE_R	0.195	0.099	0.281	1.972	0.060
Dependent Variable: CL						

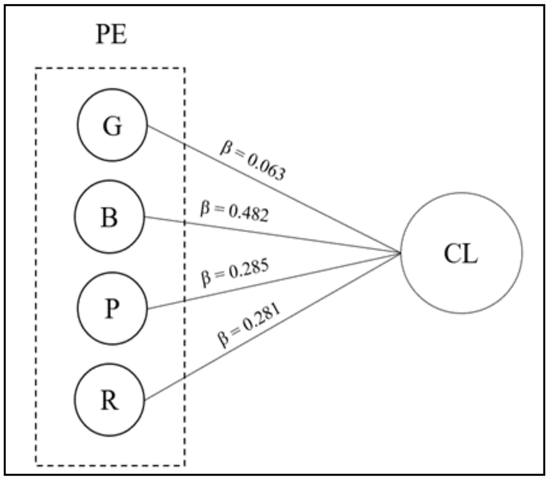

Fig. 3. Performance expectancy (PE) beta (β) result summary.

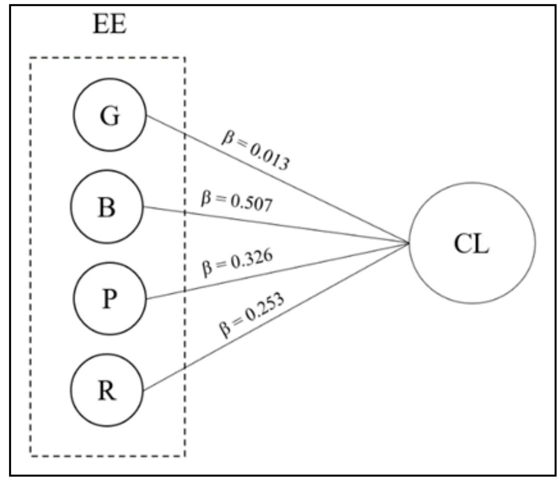

Fig. 4. Effort expectancy (EE) beta (β) result summary.

Table VI shows the result coefficients table for performance expectancy (PE) on comfort level (CL). From the result, it shows that the highest beta value of performance expectancy (PE) is blue gate (0.482), followed by purple gate (0.285), red gate (0.281) and green gate (0.063).

The result concludes that the strongest comfort level for walkthrough in VR environment using VR Terrain application in terms of performance expectancy is Blue Gate (β = 0.482, *p* = 0.009). From the finding, walkthrough from Blue Gate (B) has helped the users to accomplish their task pleasantly. Moreover, the movement speed of Blue Gate has increased the user learning in VR environment.

In contrast, Green Gate (G) is not significantly achieving the comfort level for walkthrough (β = 0.063), as it did not reach the significant level ($p = 0.729 > 0.05$). Similarly Purple Gate and Red Gate received the same beta value (β = 0.285, 0.281), which are also not significant (*p* = 0.072, 0.060) to achieve comfort level in walkthrough. Fig. 3 above shows the summary of Performance Expectancy Beta results.

TABLE VII. COEFFIECIENT RESULTS OF EFFORT EXPECTANCY

Model Effort Expectancy (EE)		Unstandardized Coefficients		Standardized Coefficients	t	Sig.(p)
		B	Std. Error	Beta (β)		
1	(constant)	0.742	0.341		2.173	0.039
	EE_G	0.009	0.131	0.013	0.066	0.948
	EE_B	0.341	0.121	0.507	2.827	0.009
	EE_P	0.237	0.107	0.326	2.204	0.037
	EE_R	0.170	0.091	0.253	1.863	0.074
Dependent Variable: CL						

Table VII shows the result coefficients table for effort expectancy (EE) on comfort level (CL). From the result, it shows that the highest beta value of effort expectancy (EE) is blue gate (0.507), followed by purple gate (0.326), red gate (0.253) and green gate (0.013).

The result concludes that the strongest comfort level for walkthrough in VR environment using VR Terrain application in terms of performance expectancy is Blue Gate (β = 0.507, *p* = 0.009). From the finding, walkthrough from Blue Gate (B) has helped the users to accomplish their task pleasantly. Moreover, the movement speed of Blue Gate has increased the user learning in VR environment.

In contrast, Green Gate (G) is not significantly achieving the comfort level for walkthrough (β = 0.013), as it did not reach the significant level ($p = 0.948 > 0.05$). Similarly Purple Gate and Red Gate received the same beta value (β = 0.326, 0.253), which are also not significant (*p* = 0.037, 0.074) to achieve comfort level in walkthrough. Fig. 4 above shows the summary of Effort Expectancy Beta results.

D. Result of Frame Rate Observations

The frame rate of a VR experience is a critical factor in determining the overall quality of the experience. A low frame rate can cause motion sickness and detract from the immersion of the experience, while a high frame rate can provide a smoother and more realistic experience. For this reason, the frame rate is one of the most important metrics to be measured and validated during VR Terrain application software testing. From the observation during the test, the collected frame rate data was analyzed to assess the performance of the VR Terrain software application.

TABLE VIII. RESULT OF FRAME RATE OBSERVATIONS

VR Walkthrough Movement Speed (km/h)	Frames Per Second (FPS)		
	59	60	61
	Frequency (N)		
3	0	0	30
4	0	0	30
5	2	25	3
6	2	27	0

According to Table VIII, there are four different movement speeds: 3, 4, 5, and 6 km/h. All 30 users performed the VR walkthrough at all four movement speeds, and the frame rate was recorded through the observation for each user at each speed. The data shows that for 3 and 4 km/h, all users experienced 61 FPS, with no one experiencing 59 FPS or 60 FPS. This indicates that the frame rate was consistently high for these speeds and that the VR experience was smooth and immersive.

For 5 km/h movement speed, however, the data tells a different story. Two users experienced 59 FPS, which is below the generally accepted standard for smooth VR experiences. 25 users experienced 60 FPS, which is generally considered to be the minimum frame rate for a smooth VR experience. Three users experienced 61 FPS, which is higher than the generally accepted standard, indicating that the VR experience was exceptionally smooth and immersive for these users.

Finally, for 6km/h movement speed, the data again shows some variability in the frame rate. Two users experienced 59 FPS, which is below the generally accepted standard for smooth VR experiences. 28 users experienced 60 FPS, which is generally considered to be the minimum frame rate for a smooth VR experience. No users experienced 61 FPS, indicating that the VR experience was not exceptionally smooth or immersive for any users at this speed.

Likewise, for 3km/h and 4km/h, the average frame rate was 61fps, as all users experienced this frame rate. For 5km/h, the average frame rate was 60fps, as 25 users experienced this frame rate, and it is generally considered to be the minimum standard for a smooth VR experience. For 6km/h, the average frame rate was 60fps, as 28 users experienced this frame rate.

In conclusion, the frame rate of a VR experience is a critical factor in determining the overall quality of the experience. In the context of a VR walkthrough, the frame rate has become even more important, as users are moving through a VR environment and a low frame rate can cause motion sickness and detract from the immersion of the experience. Based on the data collected, the average frame rate was consistently high for 3km/h and 4km/h, indicating a smooth and immersive VR experience in mobile device. However, for 5km/h and 6km/h, the frame rate was more variable, with some users experiencing frame rates below the generally accepted standard for a smooth VR experience (Kopczynski, 2021; Menakhin, 2016; Fuchs, 2017). Overall, this data highlights the importance of maintaining a high frame rate in VR walkthroughs to ensure a smooth and immersive experience for all users.

E. Result Summary

Overall, the blue gate (B) received the most positive result compared to the purple gate (P), red gate (R), and green gate (G). Likewise, the most comfortable walkthrough in VR recorded in terms of performance expectancy and effort expectancy was with the blue gate (B). Therefore, the result of PE and EE to support CL proposed that, 4 km/h is the most suitable movement speed to use for walkthrough in VR environment. Additionally, the VR walkthrough using VR Terrain application is smooth with the average frame rate of 61 FPS which is acceptable for VR experience for mobile device.

V. FUTURE WORK AND CONCLUSION

A. Future Work

The VR walkthrough application software can and should be further enhanced, so that the system is better, more efficient, and more effective. The suggestions for providing a better result are as stated below:

1) Enhanced interfaces: Future researchers can provide more information for users to see in the display such as the time engagement and the distance travelled for users to understand more about their current situation. Besides, the researchers can also use higher quality 3D object and create more realistic VR environment such as city environment, houses, and walking tracks to enhance the VR experience for the user.

2) Cross-sectional study: Currently, the research and development of VR environment using the walkthrough technique for minimizing motion sickness is only limited to technological science study. This research and development can be further studied across many regions especially in medical and human science since it involves motion sickness, which is the biological condition for humans. This indirectly contributes to more insight and increases the diversity of knowledge of VR.

3) Expanding platform: There are still some limitations to this technology that can be addressed in future versions of mobile-based VR Terrain. Therefore, future work is suggested to expand the testing of VR Terrain software application in desktop-based VR device such as using HTC Vive Pro or in a standalone VR device such as Oculus Quest 2. Desktop-based VR devices offer more advanced hardware and capabilities compared to mobile-based VR experiences. With more powerful hardware, these VR experiences can offer higher quality graphics, more complex interactions, and greater immersion. In addition, stand-alone VR devices offer the convenience of mobile-based VR without the need for an external device like a smartphone.

B. Conclusion

The developed VR Terrain application software was used for VR walkthrough to measure the users' comfort level VR walkthrough experience and was validated by adopting UTAUT model construct variables which are performance expectancy (PE) and the effort expectancy (EE) as well as the frame rate observations. The result of comfort level shows all users found that VR Terrain application was useful and convenient to use. Overall, VR Terrain application was considered satisfying for the user to use for measuring comfort level of walkthrough in VE. The UTAUT analysis and FPS rate shows 4 km/h is the most comfortable to use for walkthrough in VE, in which the result indicates that 4.0 km/h movement speed can be used in walkthrough in VR environment to minimize the effect of VR motion sickness. Therefore, it can be said that the users' comfort level walkthrough measurement of VR Terrain application is useful for VR developer to use as a reference in minimizing the VR motion sickness effect.

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REFERENCES

[1] Furht, B. (2008). Immersive virtual reality. Encyclopedia of Multimedia. Springer, Boston, MA.

[2] Popov, V. V., Kudryavtseva, E. V., Katiyar, N. K., Shishkin, A., Stepanov, S. I., & Goel, S. (2022). Industry 4.0 and Digitalisation in Healthcare. Materials 2022, 15, 2140.

[3] Mokhtar, M. N. A. B. D., Ismail, I., Hamzah, W. M. A. F. W., Shamsuddin, S. N. W., & Arsad, M. A. M. (2022, July). Real-Time Dream House Decorator in the Virtual Reality Environment. In Sustainable Finance, Digitalization and the Role of Technology: Proceedings of The International Conference on Business and Technology (ICBT 2021) (pp. 525-537). Cham: Springer International Publishing.

[4] Zolkefly, N. N., Ismail, I., Safei, S., Shamsuddin, S. N. W., & Arsad, M. A. M. (2018). Head gesture recognition and interaction techniques in virtual reality: a review. International Journal of Engineering & Technology, 7(4.31), 437-440.

[5] Fluke, C. J., & Barnes, D. G. (2016). The ultimate display. arXiv preprintarXiv:1601.03459.

[6] Wang, J., & Lindeman, R. (2015). Coordinated hybrid virtual environments: Seamless interaction contexts for effective virtual reality. Computers & Graphics, 48, 71-83

[7] Jerald, J. (2015). The VR book: Human-centered design for virtual reality. Morgan & Claypool.

[8] Keshavarz, B., Hecht, H., & Lawson, B. D. (2014). Visually Induced Motion Sickness: Causes, Characteristics, and Countermeasures.

[9] Liao, C. Y., Tai, S. K., Chen, R. C., & Hendry, H. (2020). Using EEG and deep learning to predict motion sickness under wearing a virtual reality device. Ieee Access, 8, 126784-126796.

[10] Lawther, A., & Griffin, M. J. (1988). A survey of the occurrence of motion sickness amongst passengers at sea. Aviation, space, and environmental medicine, 59(5), 399-406.

[11] Riener, R., Harders, M., Riener, R., & Harders, M. (2012). Virtual reality for rehabilitation. Virtual Reality in Medicine, 161-180.

[12] Chang, E., Kim, H. T., & Yoo, B. (2020). Virtual reality sickness: a review of causes and measurements. International Journal of Human–Computer Interaction, 36(17), 1658-1682.

[13] Brunnström, K., Dima, E., Qureshi, T., Johanson, M., Andersson, M., & Sjöström, M. (2020). Latency impact on quality of experience in a virtual reality simulator for remote control of machines. Signal Processing: Image Communication, 89, 116005.

[14] Qu, J., Wang, W., Yuan, S., Li, F., & Cai, R. (2018, July). Analysis of Simulator Sickness and Performance in Virtual Training. In Journal of Physics: Conference Series (Vol. 1060, No. 1, p. 012030). IOP Publishing.

[15] Park, S., Mun, S., Ha, J., & Kim, L. (2021). Non-contact measurement of motion sickness using pupillary rhythms from an infrared camera. Sensors, 21(14), 4642.

[16] Venkatesh, V., Morris, M. G., Davis, G. B., & Davis, F. D. (2003). User acceptance of information technology: Toward a unified view. MIS quarterly, 425-478.

[17] Martirosov, S., & Kopecek, P. (2017). Virtual reality and its influence on training and education-literature review. Annals of DAAAM & Proceedings, 28.

[18] Iijima, A., Kiryu, T., Ukai, K., & Bando, T. (2007). Vergence eye movements elicited by non-disparity factors in 2D realistic movies. In Proceedings of The First International Symposium on Visually Induced Motion Sickness, Fatigue, and Photosensitive Epileptic Seizures (VIMS 2007) (pp. 59-66).

[19] Rahimi, K., Banigan, C., & Ragan, E. D. (2018). Scene transitions and teleportation in virtual reality and the implications for spatial awareness and sickness. IEEE transactions on visualization and computer graphics, 26(6), 2273-2287.

[20] Wu, F., & Rosenberg, E. S. (2019, March). Combining dynamic field of view modification with physical obstacle avoidance. In 2019 IEEE Conference on Virtual Reality and 3D User Interfaces (VR) (pp. 1882-1883). IEEE.

[21] Keshavarz, B., Hecht, H., & Zschutschke, L. (2011). Intra-visual conflict in visually induced motion sickness. Displays, 32(4), 181-188.

[22] Kundu, R. K., Rahman, A., & Paul, S. (2021). A study on sensor system latency in vr motion sickness. Journal of Sensor and Actuator Networks, 10(3), 53.

[23] Halarnkar, P., Shah, S., Shah, H., Shah, H., & Shah, A. (2012). A review on virtual reality. International Journal of Computer Science Issues (IJCSI), 9(6), 325.

[24] Torres Vega, M., Liaskos, C., Abadal, S., Papapetrou, E., Jain, A., Mouhouche, B., ... & Famaey, J. (2020). Immersive interconnected virtual and augmented reality: a 5G and IoT perspective. Journal of Network and Systems Management, 28, 796-826.

[25] Wang, Z., Foo, K., Yan, S., Gonzalez, V. A., & Giacaman, N. (2022). Refresh Rate and Graphical Benchmarks for Mobile VR Application Development. Journal of Mobile Multimedia, 1561-1598.

[26] Cao, Z., Jerald, J., & Kopper, R. (2018, March). Visually-induced motion sickness reduction via static and dynamic rest frames. In 2018 IEEE conference on virtual reality and 3D user interfaces (VR) (pp. 105-112). IEEE.

[27] Cheung, B., & Nakashima, A. (2006). A review on the effects of frequency of oscillation on motion sickness.

[28] Chattha, U. A., Janjua, U. I., Anwar, F., Madni, T. M., Cheema, M. F., & Janjua, S. I. (2020). Motion sickness in virtual reality: An empirical evaluation. IEEE Access, 8, 130486-130499.

[29] Berti, S., & Keshavarz, B. (2020). Neuropsychological approaches to visually-induced vection: an overview and evaluation of neuroimaging and neurophysiological studies. Multisensory Research, 34(2), 153-186.

[30] Saredakis, D., Szpak, A., Birckhead, B., Keage, H. A., Rizzo, A., & Loetscher, T. (2020). Factors associated with virtual reality sickness in head-mounted displays: a systematic review and meta-analysis. Frontiers in human neuroscience, 14, 96.

[31] Keshavarz, B., & Golding, J. F. (2022). Motion sickness: current concepts and management. Current opinion in neurology, 35(1), 107-112.

[32] Wickham, R. J. (2020). Revisiting the physiology of nausea and vomiting—challenging the paradigm. Supportive Care in Cancer, 28, 13-21.

[33] Zhong, W., Shahbaz, O., Teskey, G., Beever, A., Kachour, N., Venketaraman, V., & Darmani, N. A. (2021). Mechanisms of nausea and vomiting: current knowledge and recent advances in intracellular emetic signaling systems. International journal of molecular sciences, 22(11), 5797.

[34] Cha, Y. H., Golding, J. F., Keshavarz, B., Furman, J., Kim, J. S., Lopez-Escamez, J. A., ... & Lawson, B. D. (2021). Motion sickness diagnostic

criteria: consensus document of the classification committee of the Bárány society. Journal of Vestibular Research, 31(5), 327-344.

[35] Hromatka, Bethann S., Joyce Y. Tung, Amy K. Kiefer, Chuong B. Do, David A. Hinds, and Nicholas Eriksson. "Genetic variants associated with motion sickness point to roles for inner ear development, neurological processes and glucose homeostasis." Human molecular genetics 24, no. 9 (2015): 2700-2708.

[36] Marcus, D. A., Furman, J. M., & Balaban, C. D. (2005). Motion sickness in migraine sufferers. Expert opinion on Pharmacotherapy, 6(15), 2691-2697.

[37] Hettinger, L. J., & Riccio, G. E. (1992). Visually induced motion sickness in virtual environments. Presence: Teleoperators & Virtual Environments, 1(3), 306-310.

[38] Tychsen, L., & Foeller, P. (2020). Effects of immersive virtual reality headset viewing on young children: visuomotor function, postural stability, and motion sickness. American journal of ophthalmology, 209, 151-159.

[39] Zhang, C. (2020, September). Investigation on motion sickness in virtual reality environment from the perspective of user experience. In 2020 IEEE 3rd International Conference on Information Systems and Venkatesh, V., Thong, J. Y., & Xu, X. (2012). Consumer acceptance and use of information technology: extending the unified theory of acceptance and use of technology. MIS quarterly, 157-178.Computer Aided Education (ICISCAE) (pp. 393-396). IEEE.

[40] Chattha, U. A., & Shah, M. A. (2018, September). Survey on causes of motion sickness in virtual reality. In 2018 24th International Conference on Automation and Computing (ICAC) (pp. 1-5). IEEE.

[41] Chen, J., Yoon, I., & Bethel, E. (2005). Interactive, Internet Delivery of Scientific Visualization viaStructured, Prerendered Multiresolution Imagery (No. LBNL-57528). Lawrence Berkeley National Lab.(LBNL), Berkeley, CA (United States).

[42] Tregillus, S., Al Zayer, M., & Folmer, E. (2017, May). Handsfree omnidirectional VR navigation using head tilt. In Proceedings of the 2017 CHI Conference on Human Factors in Computing Systems (pp. 4063-4068).

[43] Buttussi, F., & Chittaro, L. (2019). Locomotion in place in virtual reality: A comparative evaluation of joystick, teleport, and leaning. IEEE transactions on visualization and computer graphics, 27(1), 125-136.

[44] Kitson, A., Hashemian, A. M., Stepanova, E. R., Kruijff, E., & Riecke, B. E. (2017, March). Lean into it: exploring leaning-based motion cueing interfaces for virtual reality movement. In 2017 IEEE Virtual Reality (VR) (pp. 215-216). IEEE.

[45] Anggoro, P. D. W. (2018). Kajian Interaksi Pengguna untuk Navigasi Aplikasi Prambanan VR berbasis Virtual Reality. Jurnal Teknologi Informasi dan Ilmu Komputer (JTIIK), 5(2), 239-246.

[46] Nazmi, N. A. M., Rizhan, W., & Rahim, N. Developing and Evaluating AR for Food Ordering System based on Technological Acceptance Evaluation Approach: A Case Study of Restaurant's Menu Item Selection.

[47] Venkatesh, V., Morris, M. G., & Ackerman, P. L. (2000). A longitudinal field investigation of gender differences in individual technology adoption decision-making processes. Organizational behavior and human decision processes, 83(1), 33-60.

[48] Venkatesh, V., Thong, J. Y., & Xu, X. (2012). Consumer acceptance and use of information technology: extending the unified theory of acceptance and use of technology. MIS quarterly, 157-178.

[49] Cimperman, M., Brenčič, M. M., & Trkman, P. (2016). Analyzing older users' home telehealth services acceptance behavior—applying an Extended UTAUT model. International journal of medical informatics, 90, 22-31.

[50] Davis, F. D. (1989). Perceived usefulness, perceived ease of use, and user acceptance of information technology. MIS Q. 13 (3), 319–340 (1989).

[51] Rice, R. E., & Aydin, C. (1991). Attitudes toward new organizational technology: Network proximity as a mechanism for social information processing. Administrative science quarterly, 219-244.

[52] Raaen, K., & Kjellmo, I. (2015). Measuring latency in virtual reality systems. In Entertainment Computing-ICEC 2015: 14th International Conference, ICEC 2015, Trondheim, Norway, September 29-Ocotober 2, 2015, Proceedings 14 (pp. 457-462). Springer International Publishing.

[53] Ho, K. T., King, C. T., Das, B., & Chang, Y. J. (2018, March). Characterizing display QoS based on frame dropping for power management of interactive applications on smartphones. In 2018 Design, Automation & Test in Europe Conference & Exhibition (DATE) (pp. 873-876). IEEE.

[54] Hwang, C., Pushp, S., Koh, C., Yoon, J., Liu, Y., Choi, S., & Song, J. (2017, October). Raven: Perception-aware optimization of power consumption for mobile games. In Proceedings of the 23rd Annual International Conference on Mobile Computing and Networking (pp. 422-434).

[55] Hillmann, C., & Hillmann, C. (2019). Comparing the gear vr, oculus go, and oculus quest. Unreal for Mobile and Standalone VR: Create Professional VR Apps Without Coding, 141-167.

[56] Burns, A. C., & Bush, R. F. (2010). Marketing Research Pearson Education.