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An Empirical Research Investigating the Effectiveness of Integrating Virtual Reality: Exploration of Human Mind through an Interactive and Immersive Virtual Environment

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Abstract: Today, we live in a world where different varieties of new and advanced cutting-edge technologies emerge in a fast-paced manner. Virtual Reality (VR) is one of the most promising technologies that this period of digital devices has to offer. Nonetheless, there are only quite a few studies that venture the improvement of VR’s handheld controllers. One of the many advancements in this area is incorporating a “haptic feedback” to the controllers. The development of the haptic “touch” controllers for VR aims to make the virtual environment feel more realistic compared to the real world. However, using haptic technology in handheld controllers limits the rest of the VR experience. Even when improving the intensity of the controller’s vibration, haptics will not be sufficiently able to provide the precision visuals required for true user immersion. This study aims to integrate a motion sensor to the VR Technology and eliminate the user’s need for using a handheld controller; instead, it will utilize the functionality of the Leap Motion Controller Sensor. With that said, using the new proposed VR setup will fulfill the user’s requirements of being immersed in the Virtual Environment (VE) by offering a free motion and interaction of the Virtual objects (VO). The research was able to achieve the desired objectives by successfully integrating a motion sensor to the Oculus VR System using the Leap Motion Controller and utilizing the DOE to design and analyze how different were vitals to the overall immersive performance of the users. The indicated result of the experimented VR simulation supports multiple research about gender studies that claimed that men consistently outperform women on spatial tasks, including mental rotation, which is the ability to identify how a 3-D object would appear if rotated in space.

Keywords: Virtual Reality (VR), Virtual Environment (VE), Oculus System, Virtual Objects (VO), Leap Motion Controller (LMC), Design of Experiments (DOE)

1. Introduction

In recent years, within the field of Architecture, Engineering, and Construction (AEC) and Facility Management (FM) industries, the projects have become more complex than ever. Due to this, Lead Manufacturing Companies (LMC), such as Ford, Lockheed Martin, Boeing, and Northrop Grumman, are leaning towards creating a virtual space environment to target several areas to increase efficiency and productivity. These areas are not limited to Quality Assurance and Risk Management, Employee Training, Inventory Management, Product Design, Floor Planning, and Robotics/Mechatronics. The more advanced and sophisticated the Projects, Technologies, or Systems (PTS) will be, the more the gap widens for productivity.

Furthermore, the quality to provide these too advanced PTS is directly proportional to the prices needed for it to make and can take an extended amount of time to produce. However, the availability of skilled workers in this area has steadily declined. On top of that, manufacturers need projects delivered quicker and at less cost. Thus, this is where the application of BIM comes in. BIM is an abbreviation for Building Information Modeling. It is an exceptionally standard procedure that permits different partners and AEC (engineering, building, development) experts to team up on the arranging, structure, and developing a structure inside one 3D model (Lee et al., 2017). Notwithstanding, by applying BIM to every aspect of the project, it will reduce the mistakes in structure and development, increment the coordinated effort between the undertaking groups, and help lessen the venture time and cost (Liang et al., 2016). The data produced by BIM structures dependable choices in each phase of the PTS' life cycle – from the beginning of origin to the project's activities. BIM is both a best-practice procedure and 3D displaying programming. By utilizing it, originators can make a current building plan with coordinated data in an organization that models both the structure and the whole timetable of the task from commencement to inevitable destruction. It empowers drafters to design the same to take a shot at a solitary venture from anyplace on the planet. It gathers plenty of data about everything about a useful configuration. It encourages testing and investigation during the structure stage to locate the best response to an issue. It makes for a simpler plan, more precise coordination between colleagues and simpler structure upkeep over the whole fabricated condition, and this is only the start. Virtual Reality (VR) is a new and cutting-edge form of technology that uses 3D graphical representation and the surrounding environment to enhance and achieve a higher understanding level (Calife et al., 2009). Recently, VR has been one of the most discussed technologies that will eventually change the industry standard shortly. Figure 1 shows a detailed analysis of haptic perception devices and VR, the architectural diagram of a VR. The architecture is composed of three major parts: (1) a simulation engine, (2) visual, auditory, and perception, and (3) transducers.

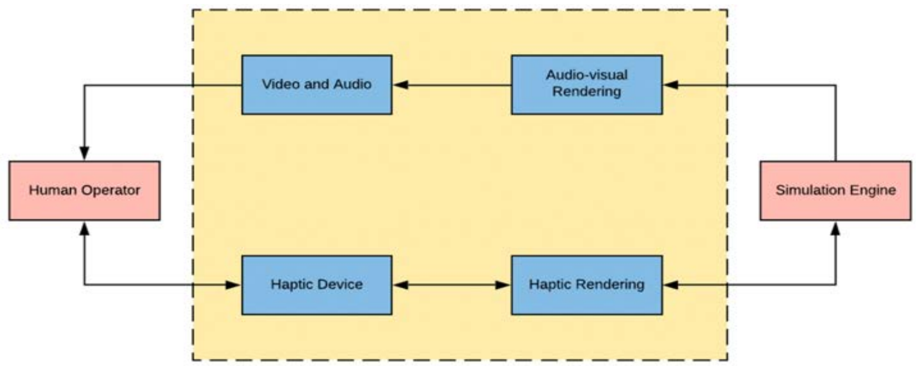

Figure 1. Virtual Reality (VR) Architecture Design

The simulation engine dynamically models the surroundings and reproduces within the virtual reality. While the visual, auditory, and perception rendering algorithms take care of interfacing with the user by generating forces, audio, and video feedback. Lastly, the transducers are responsible for producing tactile sensations from the user supported by the info provided by the simulation engine (Webb et al., 2017). VR has the capability of giving its users the experience of being immersed and interact in a virtual environment. Due to its demand and low production costs, VR is conveniently available to different consumers in the market, whether it is public or private. VR utilizes the graphics of a computer and uses it to illustrate a digital world to a more realistic world where a user is immersed and responsive to the current environment (Pallavicini, 2010). Thus, allowing users that they are part of the action. Another significant importance is that VR's situation alludes to how users can submerge themselves and feel some portion of the virtual world in a meaningful way. In this way, VR's key highlights based on the definitions above are a virtual world, immersion, sensory feedback, and interaction. With that said, the interaction between the system and user is the most critical feature of VR since it will determine the overall experience. The environment in VR plays a vital role in the whole experience of the user(s) (Garrett et al., 2017).

The more detailed and highly constructed the virtual environment is, the more significant its impact on the user's experience. Thus, it will result in a deeper connection and more immersive experience to the user. A better understanding is when people watch their favorite movies, shows, or even playing video games. The brain will stimulate a signal depending on what object the user is currently focusing on and provide appropriate feedback such as – motion and movements for that specific scenario. The brain’s two-primary cortex – parietal and prefrontal Cortex are responsible for processing and deciphering the perceived visual information and turning it into appropriate stimulants to the brain. The role of the Parietal Cortex is to signal the brain to focus and absorb the detected information based upon the environmental aspects – visual, auditory, tactile, gustatory, and vestibular. Once the user-perceived the objects in the VR Environment, the Parietal Cortex will gather the sensory receptors' information and stimulate the brain to select and enhance such behaviorally relevant information. Thus, this information is then available to other brain areas to plan and execute a physical movement. Nonetheless, there are only quite a few studies that venture the improvement of VR's handheld controllers (Hong et al., 2017). One of the many advancements in this area is incorporating a "haptic feedback" to the controllers. Haptic "touch" operators for VR are constantly improving to produce a virtual setting and become similarly realistic to real life. The haptic feedback's vibrations may be delivered to the hands coming from the operator, delivering an extra layer of adventure. However, using modern haptic technology in portable operators confines the remainder of the Virtual Reality experience. With haptics, the fingers still should be placed in a particular method to keep the controllers (Ramirez-Fernandez et al., 2017). Additionally, both improving and strengthening the magnitude of the controller's vibration, haptics will not sufficiently provide the preciseness visuals needed for a true user immersion.

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This study aims to integrate a motion sensor to the VR Technology to eliminate the user's need for using a handheld controller; instead, it will utilize the functionality of the Leap Motion Controller Sensor. Thus, using the new proposed VR setup will fulfill the user's requirements of immersiveness, interactiveness, and competitiveness virtual experience.

2. Methodology

2.1 Experimental Design Set-up

Figure 2 illustrates the DOE set-up together with the levels of each factor. The factors are the subjects, job simulation scenarios, and difficulty levels. The given figure has a designated total number of subjects – 4 Males and 4 Females. Each subject will perform four different job simulation scenarios – Auto Mechanic, Store Clerk Chef, Office Worker. Furthermore, the subject carries out three levels of difficulty in each situation – easy, medium, and hard. Thus, 12 data points were collected per subject in a single experiment, and the experimental testing was replicated twice. This experiment's response variable was the completion time of the subjects for each scenario with its designated difficulty level.

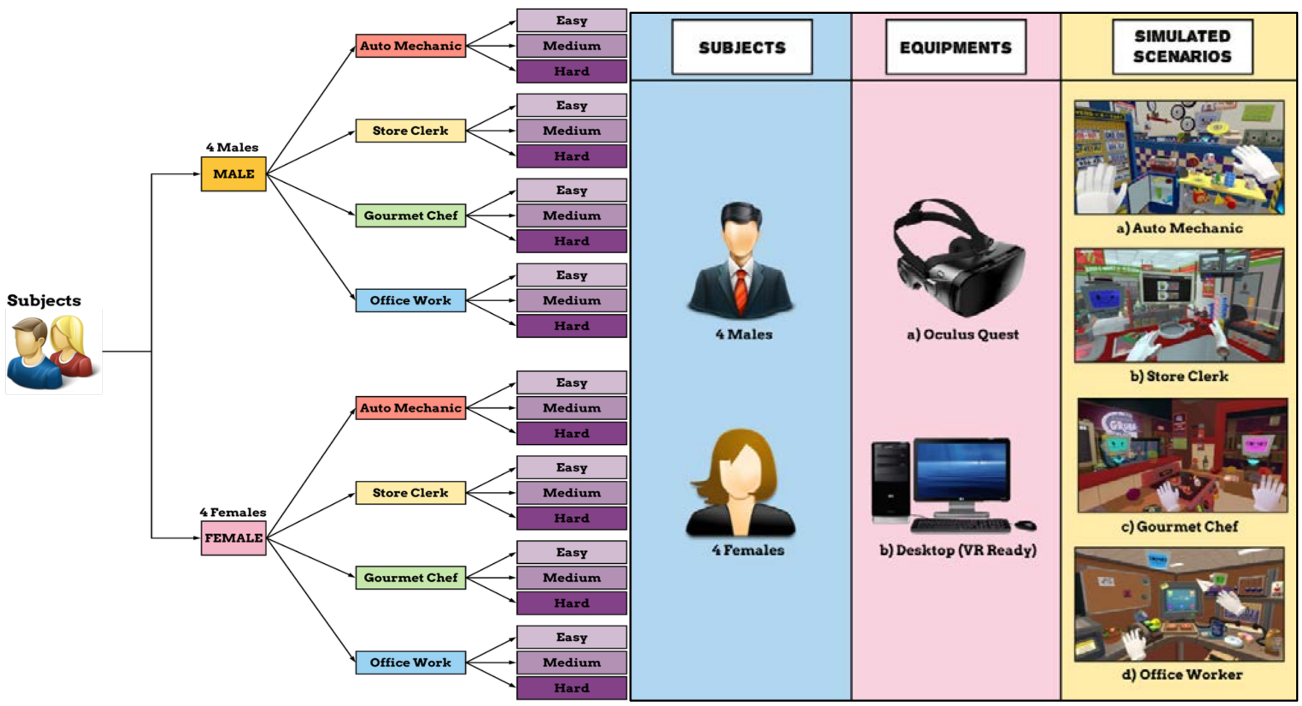

Figure 2. Experimental Design Setup and Procedure

Additionally, Figure 2 also shows the study's experimental procedure, which can be observed on the right side. Before starting the test, each subject was trained and familiarized with using the Virtual Reality interface. Each subject did a trial run on how comfortable the subjects were during navigation of the interface to remove the biases of first-time users. With that said, since the VR interface is highly customizable, it was improved continuously throughout the experiment based upon the user's performance to make it highly efficient and comfortable. As previously mentioned, once the subject was comfortable and ready in using the VR system, the testing procedures and instructions were explained to the subject in both written and verbal form. Below is the step by step procedures during the said experiment:

1. Subjects were asked to read and sign the IRB form, and the copy will be attached to the appendix section of the report.
2. Explain to the subject of the test together with the instructions in both written and verbal form.
3. Allow the subject to familiarize the experiment procedures and teach him/her how to navigate the interface.
4. Let the subject do the Job Simulation Scenarios – Auto Mechanic, Store Clerk, Gourmet Chef, Office Worker with all its difficulty levels – Easy, Medium, and Hard.
5. Test and Collect that data based upon the completion time.

2.2 Leap Motion Controller (LMC)

The rise of VR became a trend in the community; people are comfortable living in the digital universe where they can do whatever they want and go places whenever it may be. No matter how robust and infinitely transportable, however, still distant and inaccessible. Nevertheless, due to VR's invention, the glass that divides humans and technology is slowly breaking. One of the main contributors to VR's success is its function to detect and collect locomotion movements. Once the information is collected, it will then turn into several hundreds of data in order for it to become one factual information and ready to be transported to the digital environment. This research utilizes the function of motion gestures rather than holding a controller, and this is only possible because of the Leap Motion Controller (LMC). Figure 3 shows the system known as the Leap Motion Controller (LMC). LMC is a tiny device with a dimension of 3 x 1.2 x 0.5 inches. However, it has optical sensors and infrared that permit the system to acknowledge and track hands, fingers, and finger-like tools. The LMC tracks all ten fingers up to 12 inches at over two hundred frames per second. Thus, it is dramatically a lot of sensitive than existing motion sensor technologies.

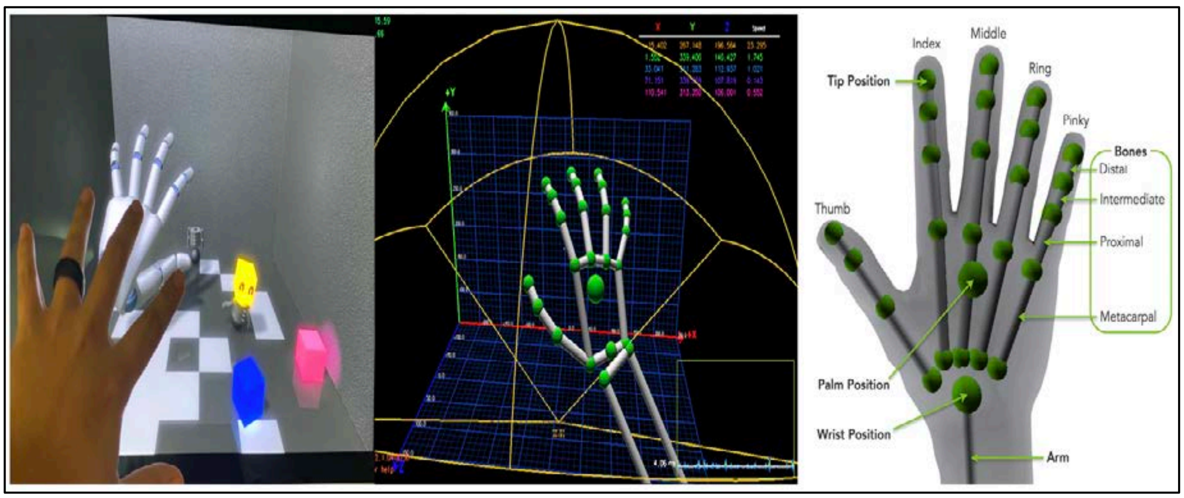

Figure 1. Leap Motion Technology

The LMC acknowledges movement patterns and gestures that would indicate a user’s intent or command and provides info concerning every finger on a hand. Furthermore, the device reports gestures ascertained in an exceedingly enclose similar approach while at the same time, predicting alternative motion following information like fingers and hands. The gestures and motions are categorized into four different subclasses which are (1) CircleGesture, (2) KeyTapGesture, (3) ScreenTapGesture, and (4) SwipeGesture. These subclasses contain different information and are associated with a gesture.

2.3 Oculus Rift Technology

The research aims to improve the users immersiveness when using VR System. Figure 4 shows the Oculus Rift, a device that the Subjects will used to have a virtual experience. During the setup of the VR for the research, all sensors will be check and equipment will be double check if they are in a working condition to operate. Furthermore, this system will be setup to mirror the Subjects’ perception in the virtual world by the using the mirror function in the system. Other hardware equipment accompanied by the system are:

1. Head Wraps
2. Virtual Camera Sensor
3. Head-mounted displays (HMDs)
4. Retina Lenses
5. Handheld virtual reality controller

Figure 2. Oculus Rift Technology System. (Reprinted from https://en.wikipedia.org/wiki/Oculus_Rift)

3. Results and Discussion

3.1 Inferential Statistics of the Experimental Design

The normal probability plot (NPP) is a graphical technique for assessing whether or not a data set is approximately normally distributed. The data are plotted against a theoretical normal distribution in such a way that the points should form an approximate straight line. Figure 5 shows the NPP of all the data collected. Based from the graph, it can be safely assumed that the data for each scenario were normally distributed since no data was beyond their specific borderline.

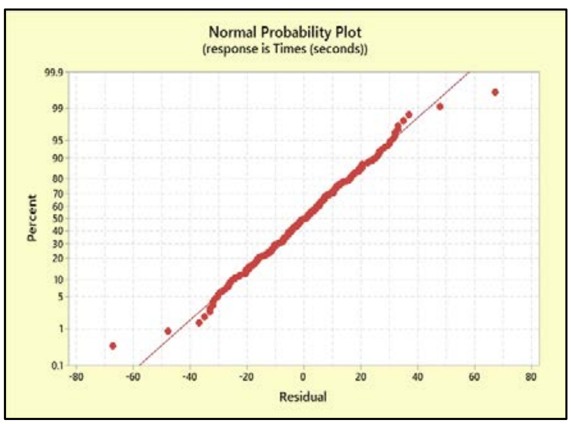

Figure 5. Normal Probability Plot of the Collected Data based on Completion Time

The results from the Analysis of Variance (ANOVA), Figure 6, show that amongst the four factors – gender, subject, scenario, and difficulty level suggested that each factor is significant except for the subject since its P-value is more than 0.05. Furthermore, in terms of 2-Way interactions, only the interaction between the gender and the subject, the Subject and Scenario, and the Subject and Difficulty are not significant since their P-value is higher than 0.05. Lastly, in 3-Way Interactions, only the interaction in both Gender-Scenario-Difficulty and Subject-Scenario-Difficulty is only significant due to its P-Value lower than 0.05.

Figure 7 shows the surface plots in both plot times (seconds) vs. Difficulty and Gender and plots of times (seconds) vs. Scenario and Gender. Results indicated that the higher level of the difficulty level in all the scenarios where the subjects are females shows a higher amount of time is needed to complete the task. Whereas on the one hand, even though there is an increase in time complete for males, it is still significantly lower than the females. Thus, it indicates that gender plays a huge factor, together with the scenarios and its difficulty in completion time.

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Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Model	77	7122332	92498	119.00	0.000
Linear	9	6064159	673795	866.85	0.000
Gender	1	1699898	1699898	2186.94	0.000
Subjects	3	5217	1739	2.24	0.088
Scenario	3	1327633	442544	569.34	0.000
Difficulty	2	3031412	1515706	1949.97	0.000
2-Way Interactions	29	958281	33044	42.51	0.000
Gender*Subjects	3	1010	337	0.43	0.730
Gender*Scenario	3	419530	139843	179.91	0.000
Gender*Difficulty	2	100652	50326	64.74	0.000
Subjects*Scenario	9	10106	1123	1.44	0.177
Subjects*Difficulty	6	9246	1541	1.98	0.074
Scenario*Difficulty	6	417738	69623	89.57	0.000
3-Way Interactions	39	99892	2561	3.30	0.000
Gender*Subjects*Scenario	9	7345	816	1.05	0.405
Gender*Subjects*Difficulty	6	4079	680	0.87	0.516
Gender*Scenario*Difficulty	6	61989	10331	13.29	0.000
Subjects*Scenario*Difficulty	18	26479	1471	1.89	0.023
Error	114	88612	777		
Lack-of-Fit	18	21083	1171	1.67	0.059
Pure Error	96	67529	703		
Total	191	7210944			

Figure 6. ANOVA Results

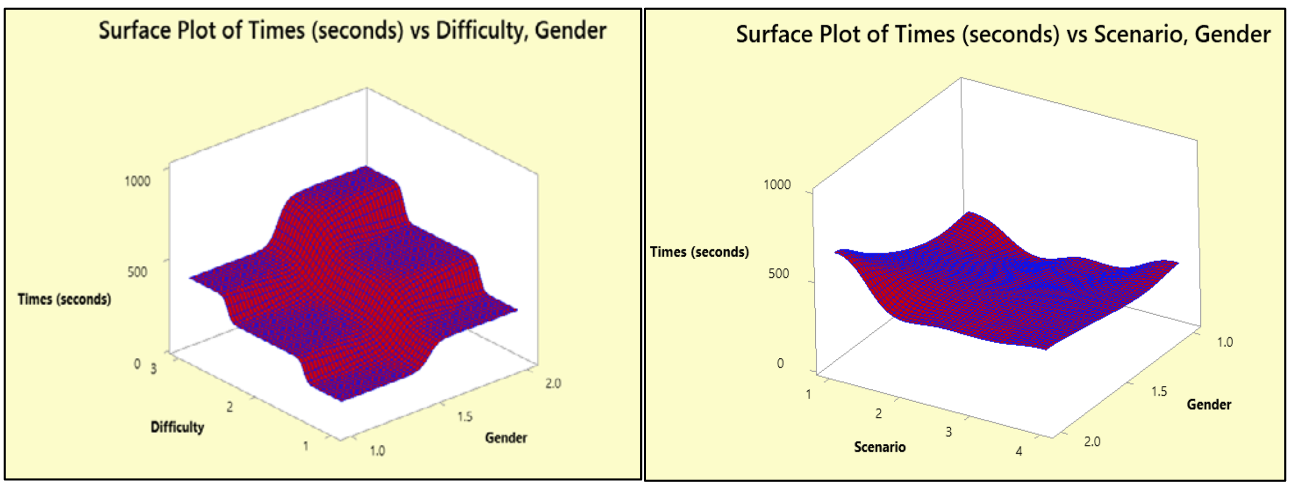

Figure 7. Surface Plot of Times (seconds) vs Difficulty and Gender Surface Plot of Times (seconds) vs Scenario and Gender

4. Conclusion

In conclusion, this research was able to achieve the desired objectives. The research integrated a motion sensor to the Oculus VR System using the Leap Motion Controller. Furthermore, by utilizing the DOE, the data collected based upon the completion time when subjects were tasks to do four different simulated scenarios – auto mechanic, store clerk, gourmet chef, and an office worker, it then revealed that factors such as (1) Gender, (2) Scenario, and its (3) Difficulty were vitals to the overall immersive performance. Results indicated that Females took a long time when completing the task compared to Males. Furthermore, the results also support multiple research about gender studies that claimed Men consistently outperform women on spatial tasks, including mental rotation, which can identify how a 3-D object would appear if rotated in space. Also, prior to VR applications and simulations, it is accepted in science and biology that males demonstrate greater activations in the striatum, orbitofrontal cortex (OFC), inferior frontal cortex, and bilateral declive when compared to females. Thus, it is easier for males to adapt and feel at ease in 3D spaced objects, which is the bread and butter of Virtual Reality Application. Overall, the experiment shows a connection between this sex-linked ability and the parietal lobe structure, the brain region that controls this type of skill – using Virtual Reality.

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