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Integration of a Heart Rate Monitoring System in a Virtual Reality Relaxation Therapy for Supporting an Immersion Level Measuring Technique

I. Mahalil, M. E. Rusli and A. M. Yusof

College of Computer Science and Information Technology, University Tenaga Nasional, Putrajaya Campus, Jalan Ikram-Uniten, 43009 Kajang, Selangor, Malaysia;
Imranmahalil@gmail.com, Ezanee@uniten.edu.my, Azmiy@uniten.edu.my

Abstract

Objectives: The aim of this research is to study the reliability of a heart rate levels monitoring system used in a virtual reality stress therapy. This integrated heart rate monitoring system can be used for measuring the therapy's effectiveness. This reliable method provides a real time data together with a set of questionnaire that complements each finding during the ten minutes relaxation therapy. Note that questionnaire is answered upon the completion of the experiment. **Methods:** VR Immersion is supported by a realistic virtual environment viewed by using a 360° head tracking display device. In addition to that, and 360° realistic surround sounds with interactive device further enhanced participants' immersiveness. As mentioned above, in this paper, a heart rate monitoring device called Hotler was used during a therapy session. This device is recording the heart rate in real time. For this purpose, a heart rate monitoring device and questionnaire are used instead of just questionnaire for understanding the commonality between them in relation to immersion levels. **Findings:** The findings show that 15 out of 24 participants have given a score of 14 over 20 which indicate that they have immersed while undergoing the treatment. Note that an average of 12.33 is obtained from the 15 participants' questions form. This is supported by the heart rate data where in most cases, it shows that participants' heart rate has become normal. The majority of them have reached a heart rate of 76.1. This normal hate rate is found to be synchronized with data from the questionnaire. From these relations, heart rate and questionnaire, it suggests that participants are relaxing using virtual reality therapy system that their heart rate after therapy tends to stabilize normally. **Applications:** This research shows that VR-based relaxation therapy can be effective as indicated by immersion questionnaire with a support by heart rate monitoring device.

Keywords: Heart Rate (HR), Immersion, Virtual Reality Therapy (VRT)

1. Introduction

The element of high immersion contributes to the effectiveness for Virtual Reality (VR) participants' experience[1,2]. In this study, a realistic 360° head tracking device and 360° realistic surround sounds are integrated with the system to increase participants' immersion level that leads to an effective therapy[3]. Previous researchers have defined immersion as users ability to interact with an artificial environment as if they are actually. The term VR immersion according to the Oxford English Dictionary 2016 is described as "a computer-generated environment that, to the person experiencing it, closely resembles reality. It is a realistic simulation of an environment, including three-dimensional graphics, by a computer system using interactive software and hardware". The degree to which the virtual or artistic environment faithfully reproduces reality determines the level of suspension of disbelief that effects users' vestibular adaptation. As a result, it creates better immersion for a positive output[4]. For the purpose

**Author for correspondence*

of identifying this 'positive output' in a real time, an autonomic heart rate monitoring device called Zephyr is used along with the questionnaire given at the end of the experiment.

2. Methods

Virtual realities have many characteristics which contribute to its immersiveness and effectiveness. Among the characteristics are the aspect of the human-computer interface being provided, interaction ability inside the virtual world, usability of the system, and effective framework designs. Immersiveness if often to a common term called presence where presence is highly influenced by an immersive level[5,6]. Based on these reasons, method being used need to recognize the unique requirement of presence and immersiveness. Presence usually is measured together with immersion, however, immersion is often measured on its own as well to identify whether VR system is effective[7] or not. Till now, most of the presence and immersion level are measured through users' feedback[8] on questionnaires.

3. Virtual Reality and Immersion Factors

An effective VR system often comes with a realistic 3D environment, gadgets such as trackers, controllers, Head Mounted Device (HMD). The integration of these gadgets enables the user to interact and eventually immersed while in the virtual environment. This attributes or functionality must be achieved or else, a given VR-based application will be less effective. Immersion effectiveness are not only influenced by user's interaction ability but also by the VR engine itself. Doug's[9] has stated that the level of immersion in a VR system depends on the rendering software and display technology, Head Mounted Display (HMD), the most common display device used for visualizing the virtual world. This HMD which also comes with tracker generates a form of spatial immersion called presence. According to Oculus Rift® VR, low-latency and precise tracking of movements[9,11] are the two most important factors that determine particular HMD effectiveness.

In general[3,11–13], they are many other factors that influence the level of immersion and presence while in VR system and they are:

- Wide field of view (80° or better): Immersion level increase with the wider field to view the virtual environment.
- Adequate resolution (1080 p or better): Resolution determines how sharp the visual will be displayed.
- Low pixel persistence (3 ms or less): This VR research was at zero ms pixel persistence.
- High enough refresh rate (>60 Hz, 95 Hz is enough but less may be adequate) Global display where all pixels are illuminated simultaneously (rolling display may work with eye tracking).
- Optics (at most two lenses per eye with tradeoffs, ideal optics not practical using current technology).
- Calibration Rock-solid tracking - translation with millimeter accuracy or better, orientation with quarter degree accuracy or better, and volume of 1.5 meters or more on a side.
- Low latency (20 ms motion to the last photo, this research latency is at zero ms which is considered very smooth).

As of today, the VR engine technology, hardware and software involve in creating VR-based systems are now able to meet the conditions stated above.

3.1 Sense of Immersion in VR

To create a sense of full immersion, the 5 senses (sight, sound, touch, smell, taste) must perceive the digital environment to be physically real with a sense of being there[15]. It is lucky enough that as of today, immersive technology has managed to create the same sensory effect as in a real world particularly in the areas of visualization (visual), surround sound (auditory) and interaction feedback. Researchers and scientist, particularly in the area of VR, agreed that the more technology sensory being applied, the higher the immersion level will be[16].

As mentioned above, many factors that based on the 5 senses determine users' immersiveness and presence in a VE. Each of these factors are associated with several VR technologies as explained below:

- The visual technology uses 3D display, stereo, anaglyph, holography, head-mounted, Cave automatic virtual environment and many more.

- Auditory technology such as virtual 3D audio effect and surround sound which replicates a human audio system.
- Tectile technology such as haptic and force feedback by means of physical resistance to interaction with the hardware.
- The olfactory technology uses machine olfaction hardware system such as perfumes for smell.
- Gustation technology uses artificial flavor for the sense of taste.

A 3D display is a type of display device capable of conveying depth perception to the viewer by means of stereopsis for binocular vision. The basic technique of this 3D display with stereovision is by presenting 2D offset images separately to the left and right eye. Both of these images are then combined in the brain to give the perception of 3D depth. Although the term "3D" is ubiquitously used, it is important to note that the presentation of dual 2D images is distinctly different from displaying an image in three full dimensions. The most notable difference to real 3D displays is that the observer's head and eyes movements will not increase information about the 3-dimensional objects being displayed[18]. This definition of 3D displays is a representation of a three-dimensional Cartesian coordinate system with the X-axis pointing towards the observer. The x, y and X-axis creates an illusion of a 3D perception of depth by images.

In general, a 3D display device's quality is measured by the level of visual immersion. Visual immersion is referred to the impact to how close the system's visual display is to a real-world visual. As stated by Aila, in her study highlighted that 3D displays with immersive effect is important particularly in VR system[19]. She also claimed that visual immersion may affect the fidelity of a VR system. In another research[8] has found out that how user answers the questions is influenced by the quality of visual immersion. In[8,20] in a similar research has further listed the factors that determine visual immersion and these factors are:

- Field of View (FOV)—the size of the visual field (in degrees of visual angle) that can be viewed instantaneously,
- Field of Regard (FOR)—the total size of the visual field (in degrees of visual angle) surrounding the user,
- Display size,
- Display resolution,
- Stereoscopy—the display of different images to each eye to provide an additional depth cue,
- Head-based rendering—the display of images based on the physical position and orientation of the user's head (produced by head tracking),
- Realism of lighting,
- Frame rate, and
- Refresh rate.

In another explanation by Saar, (2014), he described in details the technologies which can perceptually bluff human' senses that make them immerse in the virtual world:

- Visual: As mentioned earlier, visual technology includes several methods and each of the technology aimed to display a virtual world in a 3D mode similar to the way human's eyes perceive objects in a real world. A good visual technology would result in a good virtualization effect and this effect to visual sense playing an important role to determine a real and unreal object. Note that in a VR environment, visual sense is the most important among the other five senses. Among the factor that contributes toward a high-quality virtual world that effects a visual sense is the resolution of the computer displays itself. The higher the resolution the more accurate and shaper the visual displayed will seem like as to the real world (Raskar et al. 1999).
- Sound: In a VR system, the computer often sending the audio through headset and those audio are the script, environment sound, etc. There are many types of sound generated by the computer system such as mono and stereo. Mono refers to 2D sound and it is usually used in music. This 2D sound can be heard from a single direction only. On the other hand, stereo sound is a 3D sound and often used for movies and VR system. In a VR system, headsets are commonly used to hear the stereo sound. Stereo sound is a method of sound reproduction that creates a multi-directional inaudible perspective. The concept of stereo derives from two ears of a listener, usually for 2-channel stereo. Channels in a stereo sound system can control the point of the sound distance can be heard. This is controlled

by the volume in the channels, each channel can be set at either at the left or right side of the sound system. Stereo Surround sound is created by multiple channels. This feature allows users to hear a sound from a moving object. In a VR system, it is possible to set a position that determines the sound effect and when it should be heard. For example, if a bird is chipping and flying from the back to the front, users can experience the sound effect of the bird as is the sound is coming through from the back of users' head to the front side. The same effect can be applied to a nonphysical object such as wind mentioned by Brutzman, (1998). The realism of the sound can deeply effect the immersion level and the realism perception while in the virtual world as researched by Steuer, (1992).

- Haptics and force feedback (tactile): Haptic refers to a type of interface that exerts controlled forces on the human body using a passive connection that constantly remains in contact with the limbs of the operator. In a few VR systems, the integration of haptic or kinaesthetic devices is applied to increase the effect of realism. Force feedback is the resistance force that the users' need to apply to the device to interact with a virtual object. This interaction creates the sense of touch by applying force or motion to user Fisch and Mavroidis (2003). It allows interaction force on virtual objects similar to real life situation where a sense of feedback is passed by to users. This haptics and force feedback are important to enable users to interact with the virtual world more naturally. As mentioned by Burdea (1999) that VR is not considered perfect or complete without interaction ability. For that reason, users must have a control or access in the virtual world. This control may come from a controller or even by moving their head's orientation. The ability to manipulate by using any parts of the body that affect the virtual world is defined as interaction (Burdea, 1999).
- Smell and test replication (olfactory and gustation): As of today, smell and taste is a more advance type in the current stage of virtual reality technology. The perception of smell and taste requires a reasonably advance virtual reality system to enable these features to work. For example, when users pick up a flower in a virtual reality world, user should be able to smell the scent of the flower as highlighted by Fisch et al. (2003).

In this research, only visual and audio factors are applied in the developed system. In principle, once human' senses reach a sufficient belief that a displayed digital environment is real, user would then anticipate that they can interact with it in a natural and intuitive manner.

3.2 VR Research Setup

In this study, human senses being optimized including the sight and sound. All VR related researchers agree that to create a sense of full immersion, the five senses (sight, sound, touch, smell, taste) must be able to perceive the digital environment to be physically real[5]. A virtual reality system must be able to transform users' believe that they are in a real world. In general VR technique is capable of tricking human senses into deceiving what is a virtual as real.

In this study, a setup as shown in Figure 1 is used during the experiment.

Figure 1. On-going VR-based relaxation therapy.

Figure 2. Forest virtual environment.

In this setup, it involves a 3D HMD Display with head tracking of 360° viewing and surrounds sound wireless headset. Users are also asked to sit on a full leather relaxation chair with leg rest.

During the study, three virtual environments are available to the users. These environments are forest, paddy field and beach.

Figure 2 shows the starting location of the forest scene. To the left are the forest trees, in the middle are the gentle waterfall cascading and forest rocks and stones.

Figure 3. Beach virtual environment.

Similar to above Figure 3 shows the starting location of the beach scene as viewed by the users using 3D HMD. A sea water with light and clear sands with rich green palm trees generate a realistic looked at a beach.

Figure 4. Paddy field virtual environment.

Figure 4 shows the view of the paddy field with background of forest trees, the wood path leading to the coconut tree developed and incorporated in this virtual environment.

4. Questionnaires

Immersion and presence are usually studied together because without the feeling of being present in the virtual reality application it would not be immersive. From the study by Mel, the measurement of VR system immersion effectiveness can be done thru questions and user experience. The questions used in this research are taking into consideration the following factors:

- Control factor. Degree of control, immediacy of control, mode of control,
- Sensory factor. Sensory modality, consistency, degree of movement perception,
- Distraction factor. Isolation, selective attention, interface awareness,
- Realism factor. Scene realism, information consistent with the real world, reduces the anxiety of fear that the user is in a VE.

Control factors are referring to users' ability to determine their own actions and movements while in a virtual environment. For this purpose, in this research HMD with tracker enables users to view the surrounding based on their head orientation. Sensory factor refers to human five-sensory modalities. In a VR application, the effect must coincide with the sensory factors. The effect also influenced by behaviors distraction factor that refers to how much users' focus and concentration have been sacrificed. Similar to the above three factors, this last factor, realism is also a critical factor. A poor quality VE will eventually distract users' believe and reduce their immersion level. Based on the four factors above related questions are later developed and used in this study[3,25]. It is supported by[2], of his study 'Enhancing User Immersion in the VR' using CryEngine 3[2]. In another research by[5], she had defined and measured the immersion by using PANAS questionnaires. In addition, this questionnaire also consists of Witmer and Singer presence questionnaire with one question for each immersion factor as mentioned earlier:

- Control factor question: "How much were you able to control events?
- Sensory factor question: "How much did the visual aspects of the environment involve you?"
- Distraction factor question: "How aware were you of events occurring in the real world around you?"
- Realism factor: "How much did your experiences in the virtual environment seem consistent with your real world experiences?" The element of immersion contributes to the effectiveness for Virtual.

5. VR System Framework

In this study, a framework suggested by[2] is used as a reference.

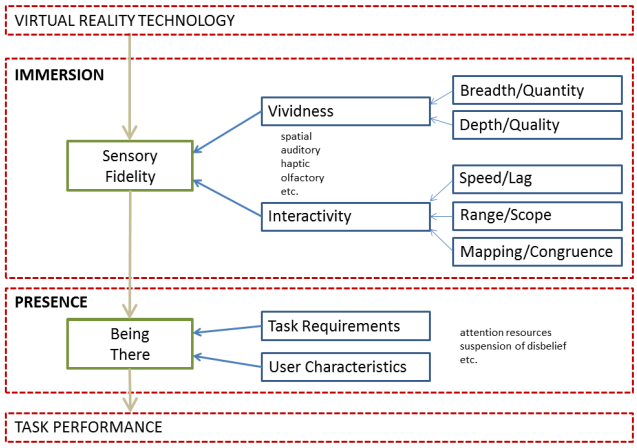


Figure 5. Immersion framework design.

The ability to interact while in a VR system is important so the user would fully immerse in it. However, as mentioned earlier low latency plays an important role to make the VR application immersive (Newton et al. 2013).

Newton (2013) had used this framework intensively when studying the effect of sensory fidelity in relation to hyper-immersive. In another research, Saar (2014) and Bowman et al. (2007) had also conducted another study that related to hyper-immersive by using Sidney framework.

The findings from the studies above show that an effective and comprehensive framework to apprehend VR immersion. The process flow of immersion with the understanding of sensory fidelity composes of vividness and interaction is covered in detail to apprehend VR immersion effectiveness.

6. Participants

15 participants are voluntarily involved during the experiment. In this experiment, a VR-based stress therapy is used as a platform where a guided of navigation is used. As mentioned earlier, guided refers to a situation where participants' movement in a virtual world is determined by the system automatically.

This group of participants had a limited exposure to the VR-based system so their bias towards this therapy method would be minimal. The ages of the participants ranged from 20 to 35 years old. The group consisted of 11 men and 4 women for testing.

7. Procedures

In this experiment, users are required to sit on a relaxation chair in a secluded room where they are initially briefed and signed a consent form. During a briefing, participants were informed that they can withdraw from the experiment at any time without any explanation required. The procedure defined in this experiment is similar to a procedure of[27] research. The snapshot of the ongoing therapy experiment is seen in Figure 1. For a purpose of determining participants' immersion levels[1,5], suggestion are referred accordingly. It consists of a questionnaire developed by Mel.

Survey: During the experiment, participants provide two types of data, one that comes from a survey and the second one is recorded automatically in a real time mode. For this purpose of a real-time recording, a heart rate monitoring device is used. The first data is used to measure the immersion level of the virtual reality application while second data reflects the effectiveness of the VR therapy (before and after therapy).

8. Heart Rate Device

Heart rate monitoring device is used to measure participants' BPM. An Android based mobile application is used to retrieve and store data in a real-time.

9. Zephyr HxM Bluetooth Monitoring Device

Zephyr, a Bluetooth connectivity device used in this experiment transmits the information in a real time. The Zephyr come with a chest strap, where fabric is implemented in it, has sensors that can detect the heart beat signal and transmit it to the monitor clip. The results show on a display represent participants' heart bit.

10. Results

The results of the experiment are divided into two: immersion and heart rate. Immersion is based on a questionnaire and while heart rate comes from the device itself).

10.1 Immersion Results

The immersion average level from all three environments (i.e. paddy field, beach and forest) is 14.17 over 20. The total score is derived from the four immersion questions that carries a maximum score of five each. Findings also show that the maximum immersion score is 19 while the minimum immersion score is 9. Paddy field immersion score is 19 with a minimum score of 9. On the other hand,

beach's maximum immersion score is 18 with a minimum score of 10, whereas in the beach scene, participants' maximum score is 17 and minimum of 10. Forest immersion score is 18 with a minimum score of 10.

Based on these data, it shows that all virtual environment used in this study have successfully achieved its objective that participants will undergo the VR-based treatment. This result also suggests that highest immersion score is obtained from a scene of a virtual beach. The possible reason may cause by the participants' familiarity of the beach environment that full fill their expectation.

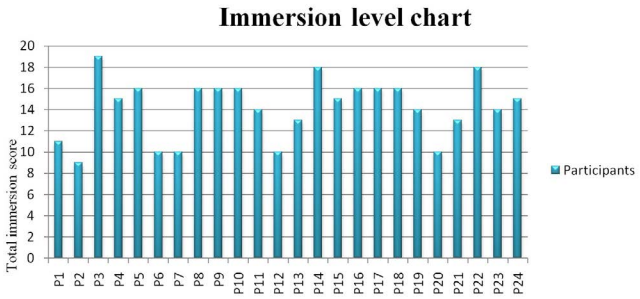


Figure 6. Immersion total score (beach).

Figure 6 of an immersion score of a beach environment shows that more than 90% of the participants' scores are higher than the average score of 10. This suggests that a combination of effective visualization and stereo system have successfully delivered an immersive VR system.

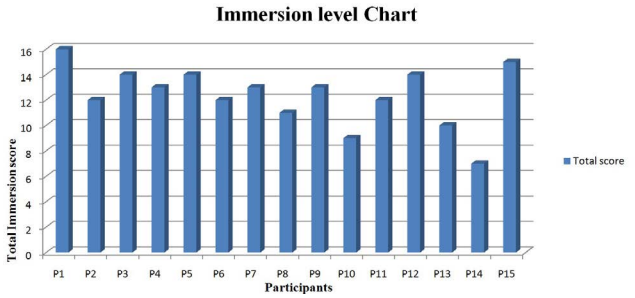
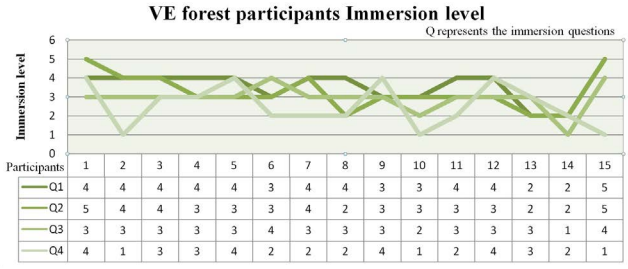


Figure 7. Immersion total score (forest).

Table 1. Immersion score of each question (forest)



Participants	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Q1	4	4	4	4	4	3	4	4	3	3	4	4	2	2	5
Q2	5	4	4	3	3	3	4	2	3	3	3	3	2	2	5
Q3	3	3	3	3	3	4	3	3	3	2	3	3	3	1	4
Q4	4	1	3	3	4	2	2	2	4	1	2	4	3	2	1

As shown in Figure 7 and similar to the beach virtual experience, immersion total score is generated from the questionnaire answered at the end of the experiment. The highest immersion score derived from this experiment is 15 over 20 and the lowest total score is 7.

From this Table 1 where score from VE forest is shown, it is observed that a feedback score of question 1 is consistent among all participants. Note that score from other environments: paddy and beach are also quite similar. Question 1 represents a control factor in the VRT where most participants agreed that HMD's tracker provided in the system is reasonably effective to increase their immersive level. Question 2 represents the sensory factor: the sound and display. 50% of the participant rates the sensory high with a score of 5 and 4 while the other half rate it 3 and 2. Question 3 which represents a distraction factor is scored with an average of 3.4 out of 5. This indicates that participants are quite immersed in the virtual world and not really aware of actual surrounding factors. This eventually enables them to concentrate on the therapy session. Lastly is the realism factor, represented by question 4 where half of the participants rated it high while half rated it low. The participant's mood depends on the individual.

10.2 Synchronization Relation of Heart Rate Data to Immersion

It can be anticipated from this relaxation therapy, as shown in the heart rate chart in the reference, the heart rate result in the final minutes of the therapy from each participants' to be calm and relaxed. In this research the final minutes from 8 to 10 minutes (460 seconds – 600 seconds) of all participants averages around 74 bpm. This heart rate results supports that the VR therapy were able to make people immerse for a calm relaxation with a normal heart rate. This findings can be applied to others VR-based treatment for example, in an acrophobia VR system. In this similar system the immersion results are good this would mean that the feeling of height in the VE is realistic. Similarly in this VR-based therapy, a good immersion results indicate that participants are relaxed and their heart rate have reduce steadily during therapy. The relation of a VR's system effectiveness is synchronized with out-come of its immersion. In this paper, the immersion results were high leading to a better heart rate bpm.

10.3 Heart Rate Results

In this section, the discussion focuses on findings based

on participants' heart rate while undergoing the VR stress treatment. Basically, it is observed from a real-time data that during the first minute, the average heart rate is 74.1 bpm. Participants' 1 to 5 shows that their heart rate is normal throughout the experiment. Participants' 5-10 started out with a high heart rate during session same as participants' 10-15. At the 5th minute, the average recorded for all five participants is 76.1. This is a below average heart rate. These results show while undergoing VR-based relaxation therapy, participants' heart rate can neutralize at a normal bpm. Normal heart rate is an indication of relaxation that the body is not under stress or tension.

11. Discussion and Future Works

Based on the result of the questionnaire, it shows that this research VR-based relaxation therapy that focuses on immersion levels is effective and it is validated by the questionnaire and also heart rate reader. The result from the two methods suggests that data from both methods are synchronized where both suggest that immersion can be achieved while using VR-based application.

As for the future works in improving the immersion experience, treadmill setup is to experiment with the design of this VRT. Omni treadmill is one of the future leading products to aid participants' immersion factor of control to improve.

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