ISSN 2347 - 3983
Volume 8. No. 5, May 2020
International Journal of Emerging Trends in Engineering Research
Available Online at http://www.warse.org/IJETER/static/pdf/file/ijeter79852020.pdf
https://doi.org/10.30534/ijeter/2020/79852020

Development of Virtual Reality (VR) Application for Fine Motor Stroke Rehabilitation

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ABSTRACT

Virtual Reality Technology (VR) is one of the technologies that is often used as a platform that can be used to generate virtual environment for learning and practice in the field of medicine and rehabilitation. The objective of this study is to analyze the patient's perspective on application of stroke rehabilitation exercises for Fine Motor. In this study, we introduced a framework using VR technology with markerless motion sensors developed via the ADDIE model that consists of five phases: Analysis, Design, Development, Implementation and Evaluation. 30 patients have undergone rehabilitation sessions using VR applications in the Kuala Nerus Rehabilitation and Hemodialysis Health Organization. The study found that VR technology with markerless motion sensor implementation as a rehabilitation platform is positively accepted by most patients. However, the possibility of this VR application totally replacing manual rehabilitation is still arguable. The overall PSSUQ rating also achieve high satisfaction by scoring 1.737. An area for future study is the development towards more portable and mobile application and the usage of VR application as home-based rehabilitation platform.

Key words: Virtual Reality, Fine Motor Stroke Rehabilitation, ADDIE, Leap Motion.

1. INTRODUCTION

The Fine Motor has the highest impact in case of a stroke attack. Patients have great difficulty in managing their lives and are dependent on others to do day to day activities, especially elderlies, and its risk will increase in the future [1]. Stroke rehabilitation is needed to improve neuro-motor recovery and upper limb impairment by assessing the patient for rehabilitation planning, to observe clinical course and evaluate the rehabilitation result [2].Traditional method of rehabilitation with monotony and repetitive modules may impact patient's interest to do the exercise [3]. Various applications have been developed using the latest technology to assist stroke patients in facilitating the exercise, improving efficiency and gaining patient motivation in doing the exercises as well as assisting therapists to analyse the current ability of patients. Among the frequently used technologies is virtual reality (VR). Virtual Reality (VR) is one of the efficient technology solutions in manipulating real-life environment to simulate an interactive virtual world by developing interaction between virtual object or avatar [3] and motion using motion tracking [4] that have task-oriented modules [5]. It can also emulate real world activities of daily living (ADLs) [6]. Although the usage of VR in rehabilitation has a very positive impact [7][8], several issues have arisen such as cost of implementation, lack of acceptability among patients, and obtrusive wearables [3]. In this paper, we present a development of markerless virtual Reality (VR) application with kinematic capturing finger movement capability. In addition, this application also integrates data mining feature to analyse and produce an intelligent biofeedback. The framework of kinematic data capturing by using TSDH [9], measuring, and evaluating are discussed in detail in dedicated publications. This paper is organized as follows. In section 2, the development process of Virtual Fine Motor Rehabilitation application is presented. In Section 3, the results of interviews with patients and PSSUQ with therapist is discussed. Finally, our work in this paper is summarized in the last section.

2. DEVELOPMENT OF VIRTUAL FINE MOTOR REHABILITATION APPLICATIONS

The Virtual Fine Motor Rehabilitation application is developed using the ADDIE model which consists of Analysis(A), Design(D), Development(D), Implementation(I) and Evaluation(E). This model is a widely used model for training and e-learning application development [10][11][12].

2.1 Analysis

Initial analysis had been made through Literature Review; which involves the process of determining current trend in stroke rehabilitation and comparing existing technologies and methods. Aside from that, Survey and Interviews had been conducted with related organizations and experts. The survey and interview sessions were held at three places; the Faculty of Health Science UniSZA, Kuala Nerus

Rehabilitation and Hemodialysis Health Organization, and Occupational Therapy Unit, Hospital Universiti Sains Malaysia (HUSM), Kubang Kerian.

In summary, Fine Motor has been selected as the focus of the study due to the importance of Fine Motor which is the foundation for patient's overall healing and patient's daily activities besides the ability to walk. It is also decided that markerless technology will be more suitable for stroke patients because of its simplicity and unobtrusive approach. The extension and grasp movement will be integrated as core exercise in assessing patient finger progress.

2.2 Design

Virtual Reality (VR) has been selected as a technology that will be the platform to run rehabilitation because it has been proven capable to raise the motivation of patients in doing exercises. With markerless motion capture integration, one easy-to-use application can be generated. A biofeedback of raw exercise performance will be calculated by using regression technique and will be projected into the application interface. The rehabilitation data will be processed using the kinematic framework and will be recorded into the database including the rehabilitation result which will be viewed using web technology. A custom armrest has also been designed to support hand position during rehabilitation exercises.

2.3 Development

2.3.1 VR Armrest Support Cushion (VASC)

A support cushion for arm was designed to make rehabilitation sessions with the VR application more comfortable and will provide ideal detection distance with motion capture sensor. It is made of a standard car armrest and a custom-made wood holder. A tuning with LMC to find an optimal distance of sensor detection for hand had been tested and considered into VASC design.

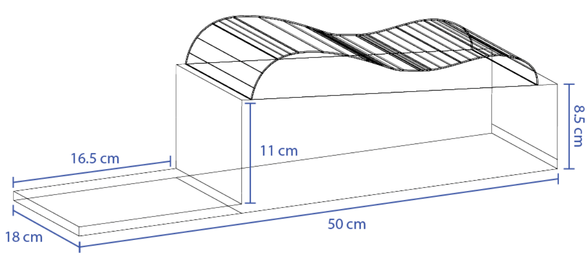

Figure 1: Armrest Holder Dimensions

Figure 1 shows armrest holder dimensions that will fit the car armrest pad. The dimensions are decided based on the average comfortable arm position for adults as well as normal height of a standard chair and desk.

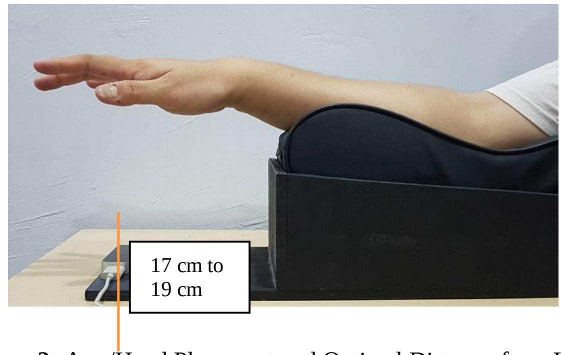

Figure 2: Arm/Hand Placement and Optimal Distance from LMC

Figure 2 shows an arm position at VASC during rehabilitation session. An optimal distance has been decided which is around 17cm to 19cm between LMC sensor and patient’s hand. LMC placement had been placed at the end of VASC holder. A margin of 15 cm to armrest cushion has been provided to make sure no sensor disruption to read the stroke patients’ finger.

2.3.2 VR Application Development

Application development phase is divided into three segments:

2.3.2.1 Capturing a Movement of Patient’s Finger

Leap Motion Controller (LMC) which is a dedicated markerless motion capture device for hand and finger motion is used. It consists of two cameras and three infrared LEDs for detection.

2.3.2.2 VR Application

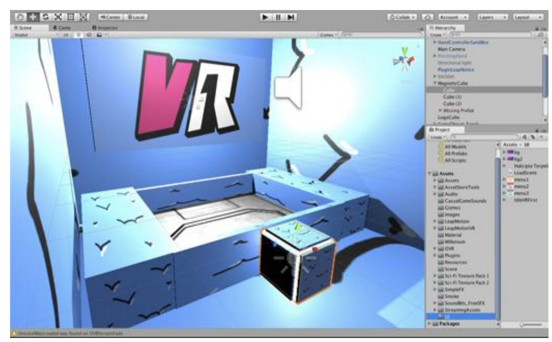

Figure 3: Development with Unity

Figure 3 shows Unity 3D development. Unity 3D is used as IDE for virtual reality application development [13] with the use of C# language as programming tool and also MySQL as a database.

2.3.2.3 Result & Reporting

Figure 4: Sample Report of Patient Index Finger Progress

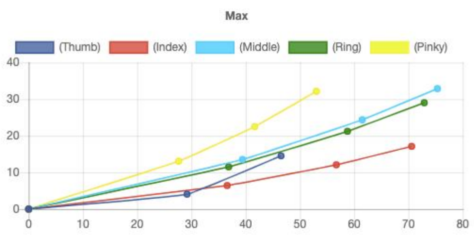

Figure 5: Sample Report of Patient All Finger Maximum Progress by TSDH

Figure 4 and Figure 5 show example reports produced by the application. Figure 4 shows a report of patient, angle by angle for Index finger and Figure 5 shows a report of patient finger maximum (extension) progress by TSDH that visually represent movement of finger which can be evaluated directly by therapists.

2.3.3 Prototype Testing and Evaluation

Figure 6: Testing and Evaluation Session

Figure 6 shows a session that was held at HUSM, Kubang Kerian for module and prototype testing and evaluation. 5 therapists from Occupational Therapy Unit were involved. They have vast experience in handling therapy for fine and gross motor stroke rehabilitation.

Table 1: Profiles of Expert

Expert	Professional Role	Experience
A	Head of Occupational Therapy (OT) Unit	13 years
B	Therapist	13 years
C, D, E	Therapists	11 years and below

Table 1 shows a brief profile of experts involved in the evaluation session. Six modules have been developed for the purpose of conformity assessment for the rehabilitation of Fine Motor which will assist full grasp and full extension of fingers exercise. The modules are; 1) transferring box into the front chamber, 2) interacting with several marbles, 3) interacting with several small boxes, 4) pushing the ball into the front chamber, 5) transferring wooden sticks and 6) pressing the piano. After a session of evaluation, three modules have been selected to be in the final module for application; 1) transferring box into the front chamber (emulate the combination of grasp and extension finger movement), 2) pushing the ball with finger into the front chamber (emulate on extension finger movement), 3) pressing the piano (emulate on grasp finger movement). A full finger extension and grasp will be carried out for the final assessment of finger movements. A set of questionnaires was also distributed to therapists to evaluate the application. The result shows the application is simple and easy to use by patients and therapeutic personnel although it requires initial guidance for patients. It is technologically interesting and will motivate patients to perform exercises.

2.3.4 Exercise Modules

Figure 7: Main Menu

Figure 7 shows the main menu of the VR application which contains three options to perform rehabilitation exercises. The three exercises have been developed with the core objective of capturing the maximum movement of the fingers for extension and grasp.

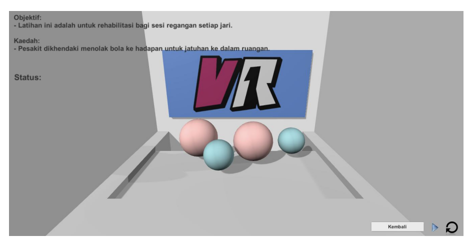

Figure 8: Exercise 1

Figure 8 shows Exercise 1 which is training to push balls. Patients are asked to put the balls into a space in front. This exercise focuses more on extension movement.

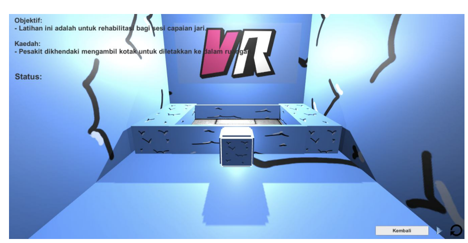

Figure 9: Exercise 2

Figure 9 shows Exercise 2 which is the training to move a box. Patients are asked to take a small box and put it into the front box. This exercise focuses more on the combination of extension and grasp movement.

Figure 10: Exercise 3

Figure 10 shows Exercise 3 which is training to press piano. Patients are asked to play a piano with all the fingers. This exercise focuses more on grasp movement.

2.4 Implementation

All patients were selected based on criteria that have been decided with the advice from stroke therapist. One of the necessary assessments for inclusion criteria is patient wrist movement should be on level 3 of The Grading of Muscle Power (MRC) which can move against gravity but not resistance.

Table 2: Stroke Patients' Demographic

Gender			Age		
Male	14	47%	Min Age	35	
Female	16	53%	Max Age	81	
Affected Hand			30-50	7	23%
Right Hand	17	57%	51-60	12	40%
Left Hand	13	43%	61 Above	11	37%
Time Since Onset of Stroke					
Minimum	2 Months		5 Years Below	26	87%
Maximum	120 Months		5 Years Above	4	13%

Table 2 shows a summary of stroke patients' demographic involved in the data collection session. A total of 30 volunteers who are eligible stroke patients were selected to undergo a rehabilitation session containing activities to evaluate the maximum movement of the fingers for extension and grasp positions. The patients and caretakers must be committed to designated rehabilitation exercises and schedule voluntarily. The VR application was setup at the chosen stroke rehabilitation center. The patients use VR application by sitting in front of the desk and their hand is placed on custom armrest. The palm of their hand is placed at the top of the motion capture sensor.

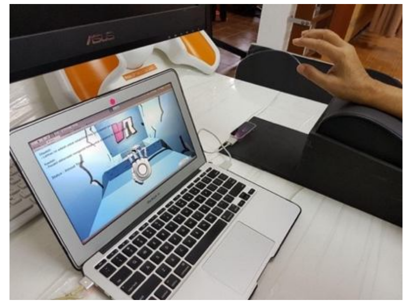

Figure 11: Data Collection Session

Figure 11 shows a data collection session that was held at the Kuala Nerus Rehabilitation and Hemodialysis Health Organization. Each session starts with a brief explanation about the research objectives, terms and conditions, expected exercise and report, as well as patients/caretaker approval. After each exercise, the patient is asked to make a maximum fingers movement for extension and grasp for final evaluation then the session concludes with a questionnaire and a token of appreciation is given.

2.5 Evaluation

The patient or caretaker were interviewed to determine the level of satisfaction of using the VR application. A session was held with all therapists at Kuala Nerus Rehabilitation and Hemodialysis Health Organization whereby the researcher demonstrates features of the application and report to fill out Post-Study Usability Questionnaires (PSSUQ) in order to collect their feedback. Some additional questions were also asked for perspective knowledge about their viewpoint on markerless VR application for fine motor stroke rehabilitation.

3. RESULT AND DISCUSSION

Usability study is very important to ensure stroke patients and therapists are comfortable with the application implementation and meet their respective expectations when using the application.

3.1 Stroke Patients

Eight questions have been used to interview a total of 30 stroke patients. Most of them can answer the questions without assistance from their caretaker. The session was conducted after application exercise had been done. The responses are summarized in Table 3.

Table 3: Usability Study Results from Stroke Patients

ITEM	1	2	3	4	5
(Q1) I've heard/seen about applications using VR technology for rehabilitation	28		1		1
(Q2) I am interested to use an application like this to make a rehabilitation exercise because the colors, fonts and layout layouts are interesting	0	2	4	16	8
(Q3) I think this app is easy	0	1	8	14	7

to use to make rehabilitation exercises					
(Q4) I feel fun making rehabilitation exercises using this kind of application	0	0	4	12	14
(Q5) My motivation increased when using applications like this to make rehabilitation exercises	0	1	6	18	5
(Q6) If given the option, I prefer to run a rehabilitation exercise using the app instead of the usual way.	0	5	12	6	7
(Q7) I will present more often to the rehabilitation center because there are applications like this	0	1	3	13	13
(Q8) I need an application like this to run a rehabilitation session at home	1	5	3	11	10

Table 3 shows Usability Results from Stroke Patients. The result of thirty patients' interview on the 5 Likert scale answer are grouped and analyzed in three segments; Disagree (1-2), Undecided (3), Agree (4-5).

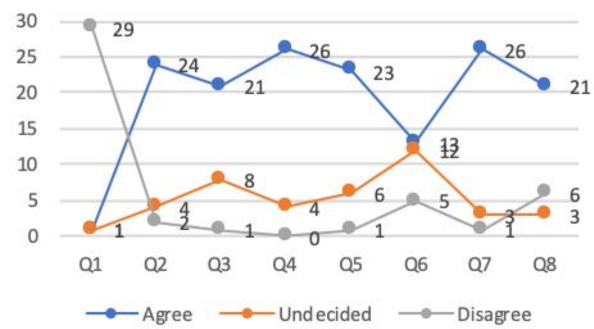

Figure 12: Results on Usability Questionnaire

Figure 12 shows Usability Results based on 3 segments. Questions 1 shows 97% (n=29) of the patients had never known, seen or heard any form of Virtual Application for stroke rehabilitation before, only 3% (n=1) had known, seen or heard about VR technology are being used for stroke rehabilitation. Although this VR technology is a technology that has long existed, its use is not widespread and most patients still do not know the ability of such technology to undergo stroke rehabilitation.

Questions 2 shows 80% (n=24) found the VR application interesting in terms of colors, font and application layout; 13% (n=4) responded undecided and 7% (n=2) said this VR application is not interesting. The application was designed to be as simple as possible to accommodate the general patient population with the age range of more than 50 years old. Majority of them like the overall impression of the application. It is important to make sure the quality of look and feel for the application is attractive to gain patients satisfaction [14].

Questions 3 shows 70% (n=21) of the patients agreed that this VR application is easy to use. The use of markerless motion sensor technology helps patients to undergo rehabilitation without leaving it in the patient's hands, making it easy for patients to start rehabilitation. Therefore, 27% (n=8) felt the VR application is still obtrusive although markerless technology is used. Questions 4 shows 87% (n=26) felt that it was fun to exercise with this application. It is because they exercise with new method and it is a break from old manual exercise routines. But the rest of them still need time to familiarize with the new process.

Questions 5 shows 77% (n=23) felt their motivation increase when using this application. It is because VR Technology has managed to create a new and more interactive atmosphere than the usual rehabilitation exercise. Questions 6 shows there were mixed reactions about questions of preference using VR application over traditional method for questions Q6. 43% (n=13) of the patients preferred VR applications while 40% (n=12) of the patients thought they need both because they feel VR application should complement traditional method. 17% (n=5) chose traditional method over VR application because they need therapist interaction and human touch to do the exercise.

Questions 7 shows 87% (n=26) of the patients said they will come more often if VR application is available at rehabilitation centre. The application attracts more interest in stroke patients to do more exercise and indirectly they will come to rehabilitation centre more often.

Questions 8 shows 70% (n=21) of the patients felt the need of having this VR application at home to do the exercise while others feel VR application is too complicated for them to handle at home. This means through the implementation of VR and markerless technology, it was able to attract patients to come to the rehabilitation centre and also gain an interest for patient to use this kind of technology to do exercise at home.

3.2 Therapists

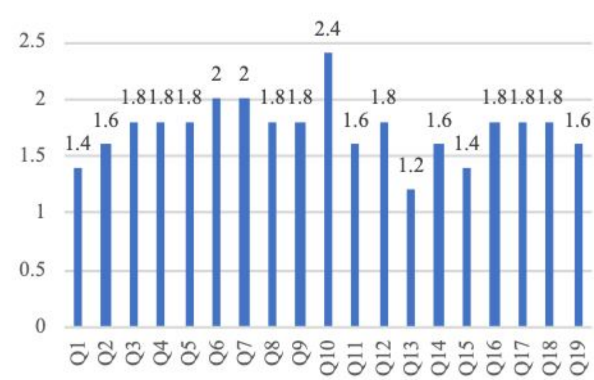

Figure 13: PSSUQ Rating

Figure 13 shows PSSUQ rating. Nineteen PSSUQ questions were answered by five therapists. It is a 7-step Likert scale where 1 means strongly agree and 7 means strongly disagree. The PSSUQ contains 19 questions to indicate the overall satisfaction in these 3 categories; Usefulness (questions 1-8), Information Quality (questions 9-15) and Interface Quality (questions 16 -19) [15].

3.2.1 Usefulness

Table 4: PSSUQ Rating on Usefulness

Question	Mean
Usefulness	
1. Overall, I am satisfied with how easy it is to use this system.	1.4
2. It was simple to use this system.	1.6
3. I could effectively complete the tasks and scenarios using this system.	1.8
4. I was able to complete the tasks and scenarios quickly using this system.	1.8
5. I was able to efficiently complete the tasks and scenarios using this system.	1.8
6. I felt comfortable using this system.	2
7. It was easy to learn to use this system.	2
8. I believe I could become productive quickly using this system.	1.8

Table 4 shows PSSUQ Usefulness rating. This segment has eight questions and indicates system usefulness scores. Overall score for usefulness was very good although two questions reach a mark of 2.0. It can be established that users think the system is very useful but there is a slight difference in terms of comfort and ease of use.

3.2.2 Information Quality

Table 5: PSSUQ Rating on Information Quality

Questions	Mean
Information Quality	
9. The system gave error messages that clearly told me how to fix problems.	1.8
10. Whenever I made a mistake using the system, I could recover easily and quickly.	2.4
11. The information (such as on-line help, on-screen messages and other documentation) provided with this system was clear.	1.6
12. It was easy to find the information I needed.	1.8
13. The information provided for the system was easy to understand.	1.2
14. The information was effective in helping me complete the tasks and scenarios.	1.6
15. The organization of information on the system screens was clear.	1.4

Table 5 shows PSSUQ Usefulness rating. This segment has seven questions and indicates Information Quality scores. Overall scores for Information Quality are also very good except for one question that have scored above 2.0. Since the application only have a 2-tier navigation, there is no need for complex instructions for navigations or error handling, but users do feel that there is a system limitation. However, it is not jeopardizing the overall experience because the score is still in reasonable range which is 2.4.

3.2.3 Interface Quality

Table 6: PSSUQ Rating on Interface Quality

Questions	Mean
Interface Quality	
16. The interface of this system was pleasant.	1.8
17. I liked using the interface of this system.	1.8
18. This system has all the functions and capabilities I expect it to have.	1.8
19. Overall, I am satisfied with this system.	1.6

Table 6 show PSSUQ Usefulness rating. This segment has four questions and will indicate Interface Quality scores. All scores for Interface Quality are very good. All results are below 2.0.

4. CONCLUSION

A VR application integrated with robust framework paired with markerless motion sensor has been designed and developed in this study in order to recognize stroke patients and therapist perspective of the VR technology usage as fine motor rehabilitation tool for stroke and also to create a framework to produce intelligent biofeedback for analyzing finger movement progress and performance through rehabilitation exercises. Both interview and questionnaire results from patients and therapists were very promising.

ACKNOWLEDGEMENT

This research was supported in part by e-Science Fund by MESTECC and UniSZA Virtual Reality (VR) grant.

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