# Development of a 3D Virtual Rehabilitation for Hand Stroke Patient

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## ABSTRACT

Stroke can be result in impaired hand and finger function, which may affect any individual that diagnosed with stroke with the ability to perform daily living activities. Traditional Rehabilitation approaches may provide limited opportunities for repetitive hand and finger exercise. This research presents the development of a 3D virtual rehabilitation (VRehab) system designed to support hand stroke rehabilitation, particularly finger flexion and extension movements. The system was developed using unity software as the main development platform and integrated with a 5DT data glove to capture finger movements in real-time. The development process involved the design of 3D virtual environment, user interface, rehabilitation tasks, interaction mechanisms, and different levels of task difficulty. The 3D virtual environment consists of house, garden, and park settings, while the rehabilitation activities involve object grabbing tasks that require users to perform specific finger movements. The system was further implemented with gameplay logic for hand movement recognition, task interaction and navigation between rehabilitation scenes. Supporting software including Shapr3D, Canva, Glove Manager and Microsoft Excel was also used during development process. Clinical engagement and field observation were conducted to provide practical feedback on the system VRehab design and its relevance to rehabilitation practices. The result from the VRehab system provides an interactive and structured environment for repetitive finger movement exercises and demonstrates the feasibility of integrating a data glove with unity-based virtual rehabilitation platform. The system development is intended to serve as a complementary tool to traditional method stroke rehabilitation.

**Keywords**: 3D Virtual Rehabilitation, stroke rehabilitation, finger movement, 5DT data glove, Unity, Virtual Reality

## INTRODUCTION

Stroke is a medical condition that can affect a person's movement and ability to perform daily living activities (ADLs). Stroke patients may experience problems with their hand and finger movement, which can make it difficult for the stroke patient to perform Daily Living Activities (ADLs) independently. Rehabilitation for stroke patient is very important because this helps them practice and improve their effected movement.

Traditional method or conventional method are commonly used to help stroke recover their movement. However, repeated exercises can sometimes affect the patient's motivation and interest in continuing rehabilitation. Because of this, new technologies such as Virtual Reality (VR) can be used to support rehabilitation.

In Brunei, a lack of Virtual Reality technology being used for hand stroke rehabilitation, as traditional rehabilitation methods were still commonly used. This created an opportunity to develop a VR-based system that could support hand and finger movement rehabilitation.

The 3D Virtual Rehabilitation (VRehab) system was developed to support hand stroke rehabilitation by combining hardware and software. The system uses a 5DT Data Glove to detect finger movement and using a

Unity software to create the 3D Virtual Environment. The 5DT data glove can measure the flexion and extension movements of the fingers during the rehabilitation activities.

The development of VRehab system focused on creating a virtual environment, connecting the data glove to the system and developing a user interface for the rehabilitation activities. The system includes object-grabbing tasks where user use their finger movement to interact with the objects in the virtual environment. A different difficulty levels were also included to provide different levels of rehabilitation tasks.

Therefore, this research focuses on the development of a 3D Virtual environment system for hand stroke rehabilitation. This research discusses the hardware and software used, the development of the virtual environment, the user interface, the rehabilitation tasks, and the interaction between the 5DT glove and the unity system.

## LITERATURE REVIEW

### Stroke Rehabilitation

Stroke remains one of the most dangerous neurological disorders worldwide, stroke is characterized by the abrupt interruption of blood supply in the brain that result in some injuries of neurological dysfunction, but in most cases permanent disabilities (Chan, 2025). Stroke are also commonly referred to as a “Brain Attack”. The World Health Organization (WHO) defines stroke as a neurological deficit and can lead to death. Despite a major of prevention and management were made to avoid stroke, stroke still remain the second leading cause of death and the third leading cause of disability worldwide, which accounted for 7 million deaths annually (Feigin, 2025)

Recognizing stroke symptoms early and getting an immediate medical help can make a very different outcome. For Ischemic stroke, the treatment such as clot-dissolving drugs or a mechanical thrombectomy can restore blood flow if it was performed within few hours (Alotaibi, 2020). Meanwhile, for hemorrhagic stroke, a surgical procedure and a careful blood pressure control are often required (Snegalatha., 2024).

After an emergency stage, where stroke has occurred, rehabilitation becomes more crucial. Rehabilitation helps stroke patients to regain and recover their lost skills, improve their mobility, and regain their independence on doing their Daily Living Activities (ADLs). With modern technology approach, such as Virtual Reality-Based Stroke Rehabilitation are increasingly used for rehab as this approach are more engaging and effective (Gao, 2023). These modern methods give patients a movement practice in a safe, controlled space, which help the brain to form a new connection, as this process are known as a neuroplasticity.

### Virtual Reality for Rehabilitation

Virtual Reality is a computer generated that creates an artificial 3D environment in which the users can experience and interact with the 3D environment and objects that represent the real-world scenarios (Cvetković, 2021). Virtual Reality systems aim to stimulate human senses, particularly on vision and hearing, in a way that makes the user feels the realistic of a 3D virtual environment (Ezhil, 2022).

The main objective of virtual reality is to stimulate a sense of presence, where user physically feel the 3D environment rather than just observing the environment from an external perspective. Unlike Conventional screen media, Virtual reality also allows users to interact with the virtual environment using the user’s natural movement such as head rotation, hand gestures and body motion, which enhances realism and real engagement (Hartmann, 2021). As a result, virtual reality has evolved from an experimental technology into a practical tool that are used in education, training, entertainment and healthcare applications (Choy C. S., 2023)

Virtual reality has increasingly been used and explored in rehabilitation due to its ability to simulate real-life task within a controlled, safe and repeatable virtual environment (Khokale R. , 2023). A virtual reality-based rehabilitation systems allow patients to perform therapeutic activities through interactive and task-oriented exercises that can be adapted to individual abilities and recovery stage (Aderinto, 2023).

The immersive and engaging nature of a virtual reality has shown that a virtual reality can enhance patient motivation and participation, which are very critical factors in achieving an effective rehabilitation outcome (Khokale R. , 2023). In addition, virtual reality also supports repetitive practice of movements, which is essential for motor learning and neuroplasticity, particularly in neurological rehabilitation such as post-stroke recovery (Hamad, 2022). Virtual reality can also provide real-time feedback on patient performance, which allow users to correct their movement and it also allows therapist to monitor the patients progress more effectively (Aderinto, 2023).

In conclusion, virtual reality gives a promising complementary tool to conventional rehabilitation approaches rather than a replacement (Khokale R. , 2023).

**The Effectiveness of Virtual Reality vs Traditional Method**

Stroke rehabilitation has evolved significantly over the years, from using a traditional or conventional method to a more advanced technology assisted method such as 3D Virtual Rehabilitation. A traditional method remains the main foundation of recovery for a stroke patient, but this method has a certain limitation, such as repetitive routines, limited engagement, less motivation and always dependent on therapist supervision (Shin S. , 2025). However, for virtual rehabilitation, it introduces an interactive, game environment that can encourage stroke patient, making the rehabilitation more enjoyable, motivating and effective (Khokale R. , 2023).

Several studies have confirmed that a Virtual Reality Rehabilitation produces better recovery outcomes than traditional method rehabilitation. Faryal Ali (2023) conducted a randomized trial comparing between Virtual reality-based rehabilitation with traditional rehabilitation among stroke patients. The results showed that both group of Virtual reality-based rehabilitation and Traditional rehabilitation improved, but the group from virtual reality-based rehabilitation achieve higher scores in both balance and functionality.

**Table 1: Table shows patient that receiving a Virtual Reality-Based rehabilitation achieved greater improvement compared to those who are receiving Traditional Rehabilitation** (Ali, 2023)

| Time Point | VRBR Group (mean ± SD) | CPT Group (mean ± SD) | p-value |
|---|---|---|---|
| Baseline | 20 ± 3.5 | 19 ± 4 | - |
| 3 months | 24 ± 4 | 21 ± 3.5 | 0.03 |
| 6 months | 27 ± 5 | 23 ± 4 | 0.01 |
| 9 months | 30 ± 6 | 25 ± 5 | 0.005 |

**Challenges and Limitations of 3D Virtual Rehabilitation**

Challenges and limitations in the development and implementation of 3D virtual rehabilitation for stroke recovery are discussed. Cost and accessibility have been one of the main hurdles to widespread use of high-quality virtual reality systems that provide accurate tracking as such systems still remain costly (Burdea G. C., 2002). Motion sickness such as nausea and dizziness during virtual reality sessions is another limitation where patients are not engaged and limit the length of treatment (Hamid, 2014).

There are also challenges associated with technical limitations typically on an affordable motion capture systems that don't have the level of precision needed to track with high accuracy for the performance of fine motor skills, which is the key aspect for a successful hand and upper limb rehabilitation (Tsoupikova, 2015). Additionally, no standard protocols or measures that would be used to determine the efficacy of virtual reality rehabilitation exist (Adamovich, 2021).

Continuing the engagement of the patients over long periods of rehabilitation is still a problem due to boredom, which may be associated with repetitiveness of the tasks within virtual reality environments and reducing the overall effectiveness of therapy in general (Tsoupikova, 2015). Finally, the transition to home-based rehabilitation brings physical issues including stability of internet for communication purposes and where to turn when these delicately balanced systems run into technical issues for determining patient progress

and success. Finally, the transition to home-based rehabilitation brings physical issues including stability of internet for communication purposes and where to turn when these delicately balanced systems run into technical issues for determining patient progress and success (Hamid, 2014).

## SYSTEM DEVELOPMENT METHODOLOGY

The 3D Virtual Rehabilitation (VRehab) system was developed to support hand stroke rehabilitation, with a focus on improving finger movement. The development combined hardware and software components to create an interactive 3D rehabilitation environment.

**Table 2: Hardware and Software used**

| | |
|---|---|
| | Shapr3D |
| | Unity Software Engine |
| Software used | Canva |
| | Glove Manager |
| | Microsoft Excel |
| Hardware used | 5DT Data Glove |
| | Laptop with Intel Processor and NVIDIA Graphic Card |

**System Worflow**

The system was designed with a simple workflow to guide the user through the rehabilitation activities. The workflow includes the Lobby, prayer section, difficulty selection, instructions and rehabilitation task scene. The user will select a difficulty level before starting the rehabilitation task. The system will then guide the user to the selected rehabilitation activity within the virtual environment.

The workflow allows the user to move between different scenes during the rehabilitation session.

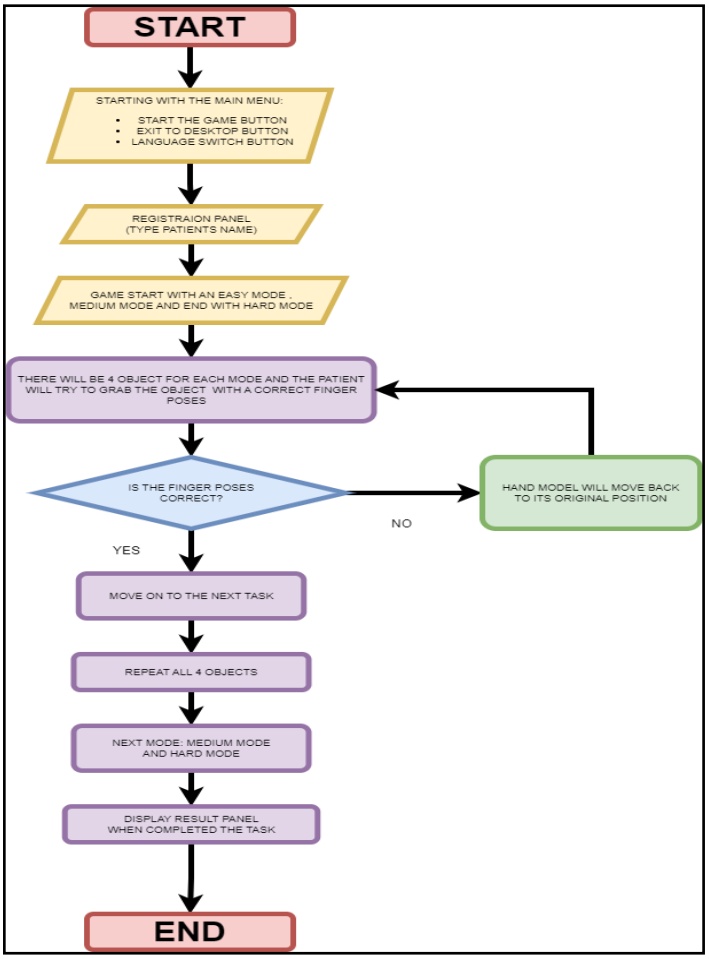



**Figure 1: System Workflow**

**Hardware Used**

The 5DT Data Glove was the main hardware component used in the development of the VRehab system. The glove was used to measure finger flexion and extension movement in real time. The glove records movement from five fingers, which are the thumb, index finger, middle finger, ring finger and little finger.

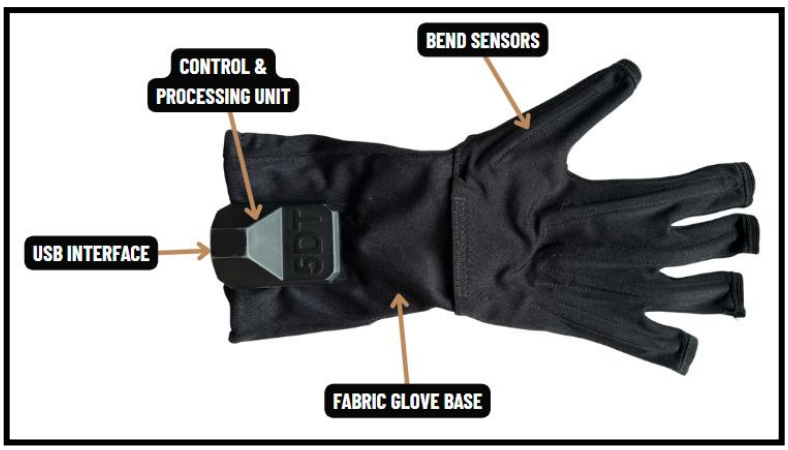



**Figure 2: Image of a 5DT data glove component**

The 5DT data glove contains a fabric glove base, bend sensors, a control and processing unit and a USB interface.

**Table 3: 5DT data glove components**

| No. | Component | Function |
|---|---|---|
| 1 | Fabric glove base | Provides a flexible and comfortable structure for housing sensors, fits securely on the user's hand to enable accurate motion tracking |
| 2 | Bend sensors | Embedded along each finger to detect flexion and extension movements by measuring resistance changes as fingers bend |
| 3 | Control and processing unit | Gathers data from all sensors, processes the signals, and transmits them to external software (e.g., Unity) for real-time interpretation |
| 4 | USB interface | Enables connection between the glove and the computer, transmitting motion data for visualization and interaction in the virtual environment |

**Software Used**

**Unity software**

Unity software was used as the main development platform for creating the 3D rehabilitation environment. The unity software main responsibility is to create the environments, place 3D objects, develop the user interface, and create the gameplay function

The unity software was used to create a 3D virtual environment which this environment was divided into **3** places:

**House**

3D model of a house which this is one of the 3D model environments for the Virtual rehabilitation. This house environment serves as a visual home-like atmosphere to help stroke patient to feel more comfortable. This also include the idea of aligning with the goal of the rehabilitation which is enhancing the patient daily living activities (ADLs). While the house is not interactive, the environment that surround the house acts as a background element that creates a familiar context for user as them begin their rehabilitation.



**Figure 3: 3D Model of a house in Unity software**

**Garden**

the garden area which is to enhance the aesthetics environment for the rehabilitation system. This environment includes trees, grass textures, flower in a pot, vegetables, fences and tables. The garden helps to simulate a calming outdoors setting to make it more engaged for the stroke patients.



**Figure 4: Garden area view in VRehab system**

**Recreational Park**

The Recreational Park includes a water fountain, benches, lamp, signage, trees, a lake, a dustbin for the stroke patient to perform their rehabilitation session.

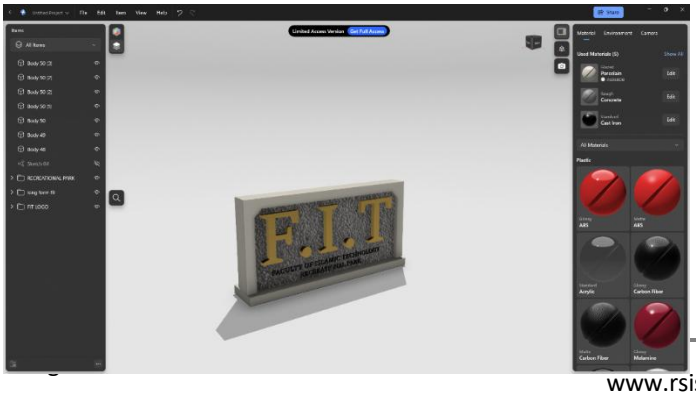
**Figure 5: Recreational Park Layout in VRehab system**



**2- SHAPR 3D**

Shapr3D was used to support the development of 3D models and objects for the virtual environment. A completed model 3D design of the F.I.T recreational park signage using the Shapr3D software. The materials applied in the 3D model include a text of 'F.I.T recreational park', a concrete stand wall for the text background, giving the signage a solid and realistic look, unfortunately, the materials are only allowed for preview inside the Shapr3D software and cannot be export into a file.

**Figure 6: Signage design from Shapr3D**



## 3- CANVA SOFTWARE

One of the main uses of Canva software was to create the main logo for the virtual rehabilitation system (VRehab). The logo includes the name of the research and reflects its purpose as a Rehabilitation tool. This logo was placed on the Main Menu and other panels such as difficulty selection panels.

In addition, Canva software was also used to design all the Main menu panels, Doa before Rehab panel, Difficulty selection panel, Instruction panel, Task Completed panel, Task Fail panel and Gameplay panels. The design was kept simple, clear and visual friendly to support stroke patients who may have difficulty with reading, concentration and navigation. The colours were chosen to be soft and not distracting, while all the fonts in the system chosen for readability.

## 4- GLOVE MANAGER

Glove Manager is an official software provided by the same manufacturer for the 5DT glove, which was the main hardware input for the virtual rehabilitation system. The software primary function is to allow real-time monitoring, calibration and data streaming of a finger flexion values from the 5DT glove sensor. This allows any researcher or therapist to monitor and log how the patients finger moved while performing the rehabilitation session.

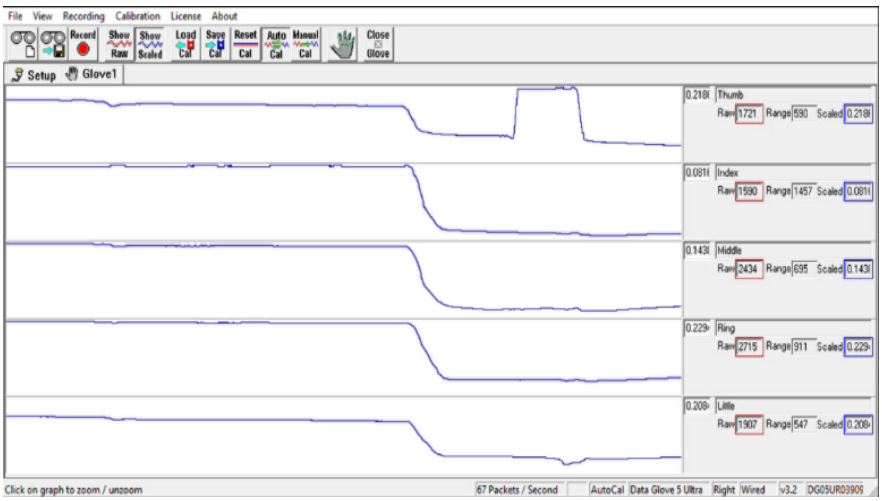
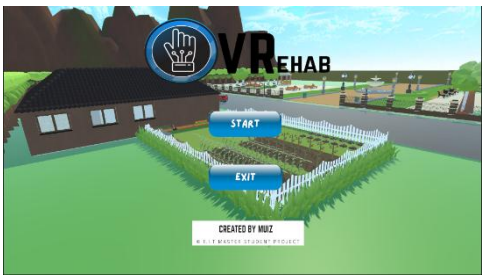
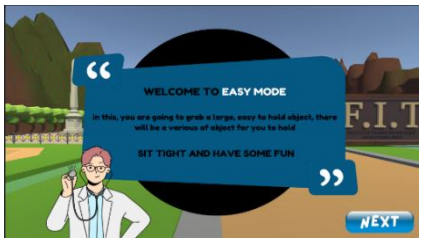
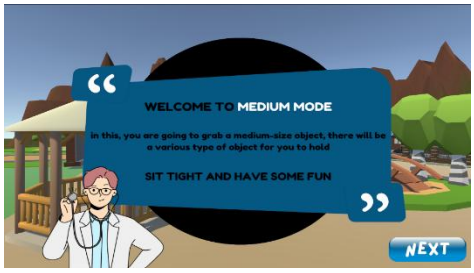



**Figure 7: Real-time sensor data from the 5DT data glove to the glove manager User Interface Development**

The user interface was developed to guide the user through the different stages of the rehabilitation system.

| Scene name | Purpose of the scene | Main Components |
|---|---|---|
| **3D Model Scene**  | Stores the 3D model of the environment that can be copied for reusing the 3D environment on various scene for development | 3D model environment |

| | | |
|---|---|---|
| **Lobby Scene**<br> | Serve as the main menu for the user to begin the VRehab system | UI Interfaces, Start Button and Exit button |
| **Doa Scene**<br> | Where the User needed to recite the doa before starting the Rehabilitation session | Doa Image, Next button and Exit Button |
| **Easy Task Scene**<br> | The main rehabilitation session scene, where the user doing their rehabilitation session with the connection of the Data glove | 3D Hand Model, Large size 3D object and Camera |
| **Medium Task Scene**<br> | The main rehabilitation session scene, where the user doing their rehabilitation session with the connection of the Data glove | 3D Hand Model, Medium size 3D object and Camera |
| **Hard Task Scene**<br> | The main rehabilitation session scene, where the user doing their rehabilitation session with the connection of the Data glove | 3D Hand Model, Small Size 3D object and Camera |

**Gameplay and interaction mechanism**

The gameplay system was designed to manage the interaction between the user, the virtual hand model and the virtual objects in the rehabilitation environment. The gameplay system combines sensor data, movement verification and task advancement to provide a responsive and organized rehabilitation system. The logic maintains a continuous monitoring and evaluation of the patient's actions so that only valid movements are used to interact with the system.

Four main scripts are used to support the gameplay system including GrabPoseDetector script, HandMover script, GameManager script and SceneNavigation script. These scripts handle pose recognition, hand movement, task management and scene transitions respectively.

**Figure 8: List of Script to use for gameplay and interaction**

| Script Name | Function Description |
|---|---|
| GrabPoseDetector | Detects and validates finger positions from the 5DT data glove based on predefined threshold values to determine whether a correct grab pose is performed. |
| HandMover | Controls the movement of the hand model, including moving towards the object, returning to the initial position, and completing the task based on pose detection. |
| GameManager | Manages the overall gameplay logic, including countdown, timer system, task completion, failure conditions, UI feedback panels, and data logging. |
| SceneNavigation | Handles scene transitions within the system and manages application exit functionality, including resetting stored user data. |

# RESEARCH FINDINGS

## 1- CLINICAL FEEDBACK

the 3D Virtual Rehabilitation (VRehab) system was presented to the clinical staff from a rehabilitation centre in Brunei to obtain feedback on its feasibility and relevance to rehabilitation practice. The feedback indicated that existing rehabilitation practices mainly focused on upper-limb recovery, while specific finger rehabilitation received less attention. The clinical staff suggested that further development of the VRehab system should consider actual rehabilitation practices and patient capabilities. They also recommended observing actual patient rehabilitation sessions to ensure that the system design is suitable for clinical workflows and patient needs.

Overall, the clinical feedback showed positive acceptance of the VRehab system and supported its potential as a complementary tool for hand and finger rehabilitation

## 2- FIELD OBSERVATION

A two-day field was conducted at the rehabilitation centre to understand the actual rehabilitation practice and patient's needs. The observation involved two teams

**Table 4: Team that are invovled during the feild observation**

| Day | Clinical Team |
|---|---|
| Day 1 | Operational Team |
| Day 2 | Physiotherapy Team |

The observation focused on the rehabilitation activies performed, patient participation, movement limitations, equipment and technology used, and difference between upper limb and lower limb rehabilitation.

**Table 5: List of Patient during the observation on the operational team**

| Patient No. | Gender | Affected Area | Rehabilitation Activity | Noted |
|---|---|---|---|---|

| | | | | |
|---|---|---|---|---|
| 1 | Male | N/A | Regular check-up, given a stretchable rubber cloth to use for home-based hand exercises | Mostly recovered |
| 2 | Male | Left hand | Undergo 30 minutes session of robotic assisted arm rehabilitation | Robotic arm system used to assist the upper limb movement with a game interface |
| 3 | Female | Right hand | Cup grabbing task, required a full concentration | Patient expressed a cognitive fatigue due to a mental focus required to move her hand |
| 4 | Female | Left hand | Two sessions, sit and stand exercise and object grabbing task | Patient expressed a trembling hand during grabbing task |
| 5 | Male | Left hand | Grabbing object and move them from left side to the right side | Task performed manually assisted by their caretaker |
| 6 | Male | Right hand | Single session, grabbing object | Unable to complete the task |

## 3-DEVELOPMENT FINDINGS

The completed VRehab system successfully combined a virtual rehabilitation environment, UI interface features, and a hand interaction tasks into one functional prototype. 3 different environment locations, namely House, garden and recreational park, were developed to provide variation during rehabilitation sessions and reduce boredom from repetitive training. This system also includes three difficulty level, which is Easy, Medium and Hard mode, allowing rehabilitation task to be adjusted according to patient ability and their rehabilitation progress.

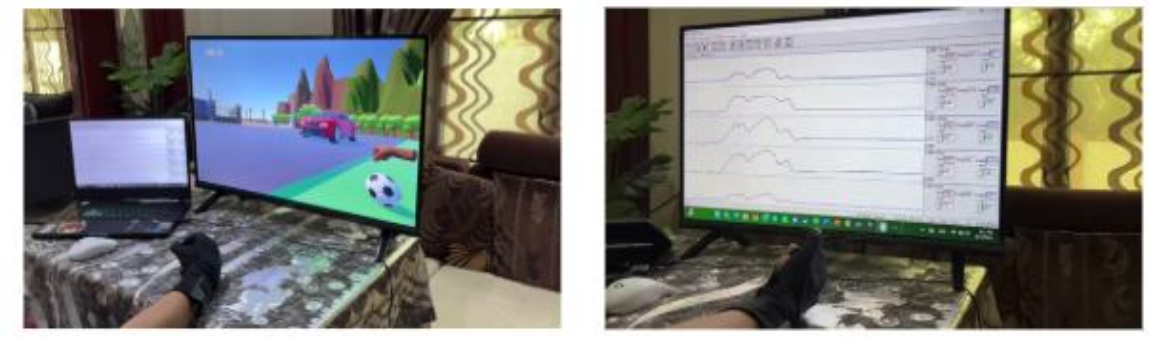


**Figure 9: Pilot testing session using the VRehab system**

## 4-EXPERIMENTAL FINDINGS

Due to participant availability constraints within the research period, the experiment was conducted using one participant who is not a stroke patient but experienced a weakness and discomfort on the thumb movement. The participant reported pain during flexion and extension together with a popping sensation, although the exact cause was unknown.

**Figure 10: Experimental Participant Background Information**

| Item | Description |
|---|---|
| Participant Code | P1 |
| Participant Type | Non-stroke participant |
| Reason for Selection | Limited access to stroke patients in Brunei during research period |
| Main Condition | Weak thumb movement with discomfort |

| | |
|---|---|
| Affected Finger | Thumb |
| Symptoms Reported | Pain during flexion and extension, popping sensation |
| Cause of Condition | Unknown |
| Number of Session | 3 sessions |
| Duration | One day experimental session |

**Table 11:** Summary of experimental session findings

| Session | Observation | Participant feedback |
|---|---|---|
| Session 1 | Pain reported during thumb extension movement | Mild discomfort during early movement |
| Session 2 | No pain or discomfort observed | Movement felt easier and more comfortable |
| Session 3 | Finger fatigue after repeated exercise | Felt good despite temporary fatigue |
| After session | General condition imrpoved | Thumb felt better than before session started |
| Follow-up | Planned next week session (not continued) | Participant stated their thumb had recovered |

**Table 12:** Average overall performance across all three sessions

| **Finger** | **Session 1** | **Session 2** | **Session 3** |
|---|---|---|---|
| **Thumb** | 0.295 | 0.329 | 0.389 |
| **Index** | 0.135 | 0.415 | 0.625 |
| **Middle** | 0.141 | 0.646 | 0.714 |
| **Ring** | 0.267 | 0.586 | 0.642 |
| **Little** | 0.241 | 0.342 | 0.402 |

From the results, all fingers show an increasing trend from session 1 to session 3, indicating the progressive finger movement throughout the experimental sessions. The Thumb increased gradually from 0.295 in session 1 to 0.389 in session 3. Although the increase was smaller compared to other fingers, the findings of this sessions are important because the Thumb finger are the main affected area that are reported by the participant.

The index finger showed a more notable increase from 0.135 in session 1 to 0.625 in session 3, while middle finger recorded the highest overall values, increasing from 0.141 to 0.714 across all three sessions. This suggest that stronger and improved finger movement after repeated sessions. Similarly, the ring finger increased from 0.267 to 0.642, showing clear improvement in later sessions

The little finger also improved from 0.241 in session 1 to 0.402 in session 3. Although the increase was more moderate compared to the middle and index fingers. This indicates stable but lower movement progression.

## CONCLUSION

The research successfully developed a **3D Virtual Rehabilitation (VRehab) system** to support hand stroke rehabilitation, with a focus on finger movement. The system combined the **5DT Data Glove** with **Unity** to create an interactive three-dimensional rehabilitation environment. The developed system included virtual environments, a user interface, different difficulty levels, and object-grabbing rehabilitation tasks. The 5DT Data Glove allowed the system to detect movements from the thumb, index, middle, ring, and little fingers during the rehabilitation activities. The research findings showed positive feedback from the professional staff involved in the clinical engagement and a positive short-term movement response during the experimental session. Overall, the developed VRehab system shows potential as a supportive tool for finger movement training and repetitive hand exercises. However, further testing with a larger number of participants and clinically diagnosed stroke patients is needed to further evaluate the system.

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