GAMING TECHNOLOGY BASED ANKLE DORSIFLEXION AND MARCHING WHILE SITTING IN LOWER LIMB REHABILITATION THERAPY

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***Abstract*— Rehabilitation programs are crucial for regaining basic life functions that are affected because of surgeries. Due to its repetitive and time-consuming exercises, many patients neglect or refuse to proceed with the rehabilitation treatment. This brings forth the need for home-based rehabilitation treatment. Therefore, this study aims to develop a game-based rehabilitation system to assist patients in performing lower limb rehabilitation exercises. In this study, there will be two main lower limb rehabilitation exercises which are ankle dorsiflexion and marching while sitting. These two focus on the ankle, hips and thighs muscle groups. The movement of both exercises is tracked by an inertial measurement unit (IMU) sensor placed on the thigh and on top of the foot. This sensor will measure the movement of the thigh and the ankle flex angle. The device will act as input for engaging games developed using a library called Pygame on Python to help patients from getting bored doing repetitive therapy. There are two games developed for marching and ankle exercises. The game will take raw data from the IMU sensor and process it. When the reading passes a set threshold, the game input will trigger. The scoring of the game is through the amount of successfully jumping across an obstacle and collected coins. Raw data of the sensor and the final score of each session are stored in a Firebase cloud database, Firestore. The results show that the game-based rehabilitation therapy system can help doctors by providing the necessary data for them to accurately analyze the movement graphs of each patient's session. With adequate data, they can provide a personalized rehabilitation plan for their patients. This study helps and motivates patients to keep doing their rehabilitation exercises diligently and makes it easier for doctors to monitor the progress of the patients.**

Keywords—IMU, PyGame, python, IoT, MPU6050, home-based rehabilitation

I. INTRODUCTION

Rehabilitation has been a staple treatment in treating people from addiction, muscle weakness after surgery and recovery after injury during sports. Repetitive exercises for a long period of time causes the patients to be discouraged and neglect the treatment. This called for a new alternative that could help motivate the patients to see their treatment to the end to gain their basic life function back. Some of the causes that require rehabilitation are hemiparesis, injury or surgery and multiple sclerosis.

There are various medical conditions that require some sort of rehabilitation to regain daily life functionality. Some of the common ones are Hemiparesis, injuries or accident and multiple sclerosis. Hemiparesis is the weakness of one side of the body and is a common result of a stroke. According to the authors in [1] that in 2019, there are 47,911 incident cases and 19,928 deaths due to stroke. Recovery often involves physical therapy. Most injuries received from sports or accidents require some form of rehabilitation. A person recovering from fractures, ligament or tendon injuries, and muscle tears usually need to do rehabilitation especially if it's their lower limb parts. Muscle, tendon, and ligament injuries are common amongst athletes. Lastly there is Multiple Sclerosis. Multiple sclerosis is a progressive neurological disease where the body's immune system mistakenly attacks the protective covering of nerve fibers in the central nervous system. There are various symptoms of sclerosis such as muscle weakness, tremors, numbness in the limbs, and difficulty in controlling muscle functions. To combat and make a full recovery from these medical conditions, the patient can undergone rehabilitation therapy. The therapy will aim to improve strength, mobility, and flexibility training. These exercises will improve muscle strength, balance when walking and increase the limb's range of motion. Specific symptoms will require different exercises in rehabilitation.

Over the years, rehabilitation practices have been evolving parallel to the emergence of new technologies. Traditional rehabilitation is done at the hospital by physical therapists guiding the patients throughout the therapy session. Introduction of new and innovative technology helps to improve rehabilitation to be more effective and less taxing. Some advancements of technologies are remote rehabilitation, allowing patients to do therapy at the comfort of their homes. This reduces the frequent visits to the hospital, thus making therapy more accessible. Then rehabilitation is integrated with Virtual Reality (VR) or game-based that could distract the patient from the feeling demotivated by the boring and repetitive therapy sessions.

Repetitive exercise causes patients to be discouraged and refuse to complete their rehabilitation treatment. Frequent trips back and forth to the hospital just to complete the treatment are also key factors in a patient's neglect of their progress. The cost and time incurred from the travel are a burden for many patients. Their inability to walk and drive would also require assistance from others to take them to the hospital. The disinterest among patients is also apparent. They

get bored easily during the treatment period and neglect the importance of the treatment. Currently, research and studies about ankle dorsiflexion and marching while sitting rehabilitation are less studied and this type of system is not available in the current market. Therefore, a home-home based ankle dorsi flexion and marching while sitting rehabilitation system with computer gaming is needed to mitigate this problem.

Thus, the aim for this study were as follows: (1) To develop the prototype of the game-based ankle dorsiflexion and marching while sitting exercises in rehabilitation therapy; (2) To develop the game for a game-based ankle dorsiflexion and marching while sitting exercises in rehabilitation therapy; (3) To implement a data management system that captures the sensor's data and game final score for monitoring patient's progress; (4) To test and evaluate the proposed game-based ankle dorsiflexion and marching while sitting rehabilitation therapy system.

II. METHODOLOGY

To create an engaging and exciting environment for patients doing their rehabilitation therapy, a game-based lower limb rehabilitation therapy system is developed. This system integrates various software tools such as, Arduino IDE, Python, Firebase. There are 3 main components of the device. First one is the data acquisition system that is responsible for collecting the movement data during therapy sessions. Then the data will be sent to a python code and processed to be use as input for a game built on PyGame library. The Third component is the cloud database. All the results and score from the game will be stored here. This simple device aims to help guide patient performing the therapy at the comfort of their home. Throughout the exercise therapy, the acceleration and rotational acceleration of the patient's lower limb is measured and saved into the Firebase. The block diagram of the whole system is shown in figure 1.

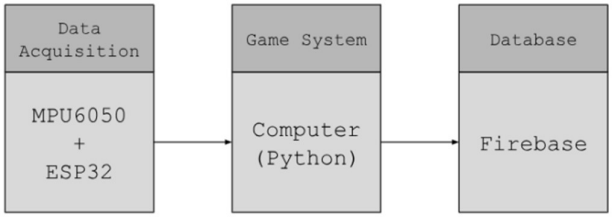

Figure 1. Block diagram

A. Hardware Components

The complete setup of the system can be seen in Figure 2. There are 3 main components.

1. **MPU6050 sensor**. This sensor is responsible for tracking Z-axis acceleration of the patient's thigh and also the Y-axis rotational acceleration of the patient's ankle.
2. **ESP32**. This microcontroller will collect and process the MPU6050 raw sensor data into a readable form and send it to the Python code through serial communication connection.
3. **Computer (Python)**. The data receive from the ESP32 will be processed again to trigger the game's input when the sensor reading go above a set threshold.

The proposed system will integrate all three components to create an end to end system that goes from collection of data, process of data, game environment and database storage. Figure 2 shows the complete system incorporating all components.

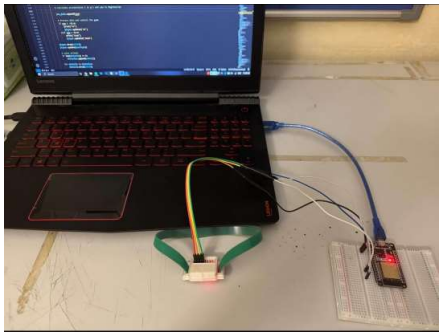

Figure 2 Complete System

B. Data Acquisition System

There will be two exercise turned into games in this project. The first one is Marching while sitting (Hurdles Game) and the second one is ankle dorsiflexion (Flying Bird Game). For Hurdles game, The MPU6050 will be strapped on the patient's thigh. This setup allows the game to be controlled by the change in Z-axis acceleration data from the MPU6050. For Flying Bird game, the same MPU6050 will be strapped on the patient's foot. For this setup, the game is controlled by the rotational acceleration in the Y-axis from the MPU6050. Figure 3 below shows a visualization of the sensor location.

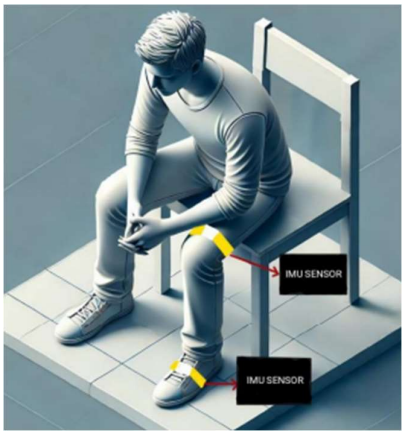

Figure 3 Sensor location

Figure 4 illustrates the actual system securely strapped and tested on a person. The MPU6050 sensor located on the person's thigh right above the knee.

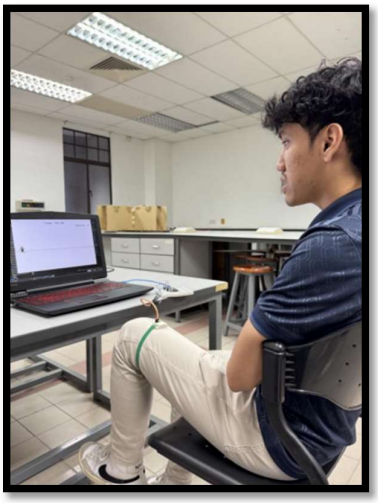

Figure 4 Marching while Sitting Setup

The configuration of the ankle dorsiflexion game needs the person to put it on their foot. Figure 5 shows the setup of the Flying bird game.

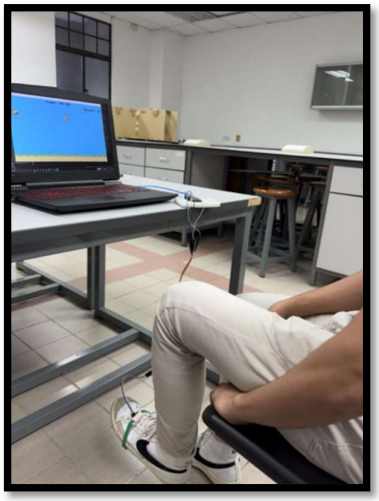

Figure 5 Ankle Dorsiflexion Setup

C. Games Environment (PyGame)

Each exercise will have their own game that simulates the moving motion of said exercise. The First game is called Hurdles because the setting is about a man running and jumping across a set of hurdles. The in-game character can jump whenever the patient raises their leg above the threshold value set at -0.6g. The threshold value is set at -0.6g because the MPU6050 is set up upside down on the patient's leg. So, when idling the MPU6050 reading will be roughly around -1.0g. With the settings of the game being a hurdles sport event, it gave the patient a sense of relevancy between their exercise and the game. The game will run for 15 minutes straight, and the scoring will be tracked by how many successful jumps across the hurdles managed by the patient.

This game also provide two levels for the patient to choose. The higher level will be more difficult due to the increase of game speed. This level will be suitable for advanced patients that are not new to therapy. The finished product of the Hurdles game is in Figure 6.

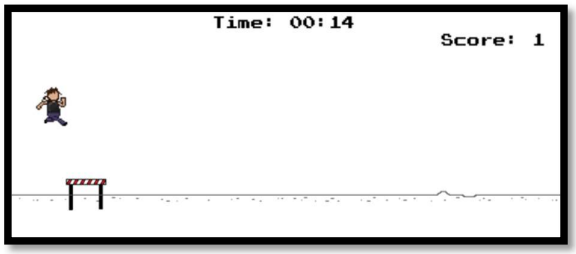

Figure 6 Hurdles Game

For Flying bird game, The in-game character can fly up and down depending on whenever the patient lift or lowered their foot passed the threshold value set. The threshold value is set at -30°/s for "UP" motion and 30°/s of "DOWN" motion. The finished product of the ankle dorsiflexion game is Figure 7. The concept of this game is that the bird is controlled by the patient, and it can fly up and down. The coins will be generated alternatively between top and bottom positions. The patient will have to flex or relax their ankle to collect all the coins. The game will also run for 15 minutes, and the scoring will be based on how many successful coins are collected.

Similarly to the Hurdles game, this game also have different levels of difficulty. Level 1 will have the bird flying at a slow speed but when level 2 is chosen, the game speed will increase significantly which make it harder for the patients to collect the coins. Figure 7 shows the finalized Flying Bird Game.

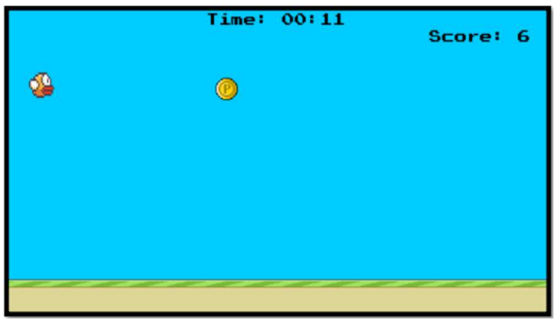

Figure 7 Flying Bird Game

D. Cloud Database (Firebase)

The database is one of the key aspects of the game. This database will do a variety of things from user registration, log in verification, user data storage, final score of each session and the raw data file of the MPU6050. The database used for this project is Google's free cloud database, Firebase. There will be three features used for this project, Firestore, Authentication and storage.

Figure 8 Account registration Menu

Figure 8 shows the account registration page for the game. New patients will input their name, email address and password to create their own account. This will ease the process of data management in the database. This information will be sent to Firestore database for future reference. In Figure 9 is the stored information of each registered patient.

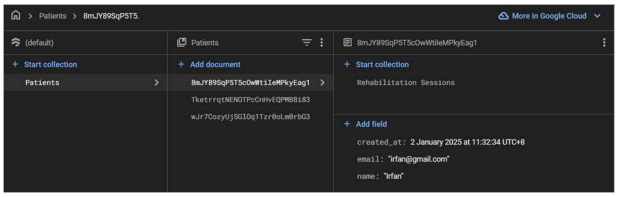

Figure 9 Registered patient's information

To track each patient's rehabilitation progress, the final score and raw data of each session will be stored into the Firestore database to allow doctors to access and evaluate the patient's condition. The final score will be saved into a subcollection called "Rehabilitation Sessions". The format for each session scores are saved in this format "{Game Type}_{Level}_{Date}_{Time}". This helps the data to be easily managed and access. Figure 10 shows how the score is saved into each individual patient's folder.

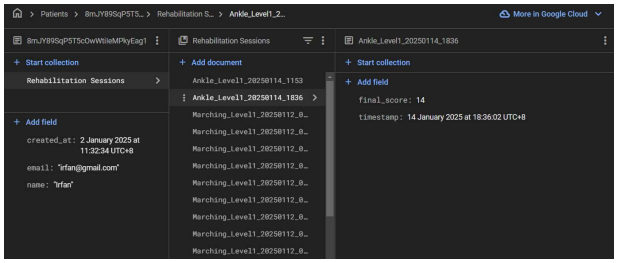

Figure 10 Rehabilitation final score in Firestore

The raw MPU6050 sensor data is also saved and sent to the Firestore database. The file contains the data that will be saved locally and sent to the database. The format file name for it is "{Patient's name}_{Game type}_{Level}_{Date}". Figure 11 shows examples of raw data files saved in Firestore.

Figure 11 CSV file of sensor's raw data

III. Results and Discussions

When a patient successfully logged in, they will be greeted with the main menu screen that they can select which exercise they want to do and which level of difficulty. Figure 12 shows all three screen.

Figure 12 Main menu, Game selection, Level selection screen

A. *Marching while Sitting graph analysis*

The Z-axis acceleration raw sensor data that have been saved in Firestore can be extracted into a readable graph. The graph shown below is taken for an interval of 30 seconds. We can see that the intervals between every peak is consistent, about 36ms. This can be a point of reference to gauge if the patient manages to jump across the hurdles. Shorter or longer intervals could indicate the patient lack of strength and control to lift their leg in time. Besides that, every peak reached a reading above -0.5g. This could be an indication on the current muscle strength of the patient. The graph is shown in Figure 13.

Figure 13 Hurdles game level 1 Graph

B. *Ankle Dorsiflexion graph analysis*

This game is controlled by the Y-axis of angular acceleration of the MPU6050. It will detect an increase or decrease in the ankle's angle. From the graph, we can see that the peaks alternate at a consistent interval. This can help doctors to determine the current muscle strength of the patient. The graph in Figure 14 shows the Flying Bird level 1 graph.

Figure 14 Flying Bird Game level 1 Graph

IV. Conclusion

In a nutshell, the first objective for this project is success with the creation of game-based lower limb rehabilitation therapy. Both games can be controlled by the MPU6050 sensor attached to the patient's thigh or foot accordingly. The games can be expanded to various levels that vary in either the game speed or obstacle frequency. After the end of each game session, the results are successfully sent to Firebase database for future reference by doctors.

The next objective is also achieved after several testing sessions in the optimization of the game-based ankle dorsiflexion and marching while sitting rehabilitation therapy system. The graph trends of each result give a consistent

pattern. This game will be used marching in sitting and ankle dorsiflexion to motivate patients to complete the treatment.

The last objective also manages to give a satisfactory result. The doctors can access and analyze the progress of each of their patients from the two references, final score and MPU6050 raw data graphs. The scoring trend can be observed from the first session with session in the later stage of their rehabilitation. Aside from that, the doctors can also observe the movement trend of the patient's marching motion or ankle dorsiflexion capability.

V. Future works

The proposed system serves as a steppingstone for the future because it has many potentials for improvement and upgrades. For example, in the game development part we could add more diverse and different kinds of game that could differ in terms of difficulty and taken data. This will give a sense of new and fresh air every time the patient does a session. Each session will have different game settings thus becoming more engaging for them. Furthermore, the system could be upgraded to allocate more exercises by adding a few more sensors to track and record the movements. Having more options and treatment for various muscle groups will expand the pool of patients that could also benefit from the game-based rehabilitation system. Lastly, a more user-friendly graphical user interface (GUI) could be developed for the doctors to access the treatment data and graphs to allow them to adjust the treatment plan individualized to each patient. The patient's progress can be tracked and monitored remotely without the patient coming to the hospital.

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