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Upper Limb Rehabilitation Device with Force Control Feedback using ESP32 Microcontroller

Nurul Atikah Mohd Zakri[1], Hisyam Abdul Rahman[1]*

[1]Faculty of Electrical and Electronic Engineering,
Universiti Tun Hussein Onn Malaysia, Batu Pahat, Johor, 86400, MALAYSIA

*Corresponding Author Designation

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Abstract: Upper limb rehabilitation device was proposed instead using old-training rehabilitation in hospital or medical hubs. Exercise therapy is an effective rehabilitation treatment, and the goal is to improve the motor coordination, and to prevent secondary complications, such as muscle atrophy and muscle spasticity. In addition, the upper limb rehabilitation training method is the therapist one-to-one manually assisted motor training in medical treatment, which is having several limitations. It uses most basic principle of motor function recovery as the medical theoretical basic of rehabilitation training. It contains two main aspects, central nervous system who have degree of plasticity of the brain injury and motor function recovery of the patient. In this paper, game-based therapy will be exposed to the patient which is having better performance and convenience ways than traditional rehabilitation. A simple video game will be created using Unity Engine software. Since stroke patients have difficulty moving their hands, the mechanical structure of this study is based on a human arm anatomy skeleton that provides physical assistance and supports stroke patient movement during therapy. The upper limb rehabilitation exoskeleton has one degree of freedom (DOF) and a range of motion (ROM) from 0º to 90º. The resistive training motion of the patient's flexion or extension can be mimicked or followed by the force control technique.

Keywords: Upper Limb Device, Stroke, Game-Based Therapy

1. Introduction

World Health Organization (WHO) stated that stroke is at second place leading causes of death and disability [1, 2]. Stroke has been characterized as a neurological deficit referring to focal injury of central nervous system and the major cause of disability [3]. Stroke patient will be undergoing a process that is called therapy rehabilitation for a long term regarding their sickness. It is very important to take early treatment to ensure the chance to recover back from stroke. Furthermore, repetitive functional motion is very affective therapeutic treatment for patient sickness [4].

Corresponding author: arhisyam@uthm.edu.my

Hence, a game-based therapy concept is introduced for the stroke patient as the therapy treatment by exercising and doing repetitive functional motion of their muscles which is good for their recovery. A game-based therapy concept is well known as the best choices for rehabilitation for strokes patient [5]. While joining a game-based therapy session, it will help to boost their excitement and attention to keep doing the rehabilitation therapy without feeling bored. Meanwhile, a game-based therapy also can be do at home which is less stress and enjoyable for the patient [6-8].

The main objective of this work is to create an upper limb rehabilitation device that will control through a simple game-based concept. For the hardware design is upper limb exoskeleton that use one degree of freedom that resembles elbow joint and preassembly cuff. The main controller is ESP32 will be used to control the movement of the hardware part. The exoskeleton will be created using Solid Works software via 3D printer. The exoskeleton device will be linked with 5 kg loadcell and servo motor. The system of upper limb device will be using servo motor linked with 5 kg loadcell to create the movement and ESP32 will control the degree of free dorm of the upper limb exoskeleton.

2. Materials and Methods

2.1 System architecture

The mechanical design of this work as shown in Figure 1 is based on the skeleton of the human arm, which supports the action of the stroke patient and offers physical aid [9, 10]. This work uses a single degree of freedom exoskeleton in 3D for the upper limb. This elbow exoskeleton consists of seven parts in total, including an upper arm segment that connects the two upper arm cuffs and a motor adapter, which is connected to the second upper arm cuffs and connects to the servo motor. Each of the three cuffs in this elbow exoskeleton has a different size depending on the hand level, starting with the upper arm cuff and ending with the lower arm cuff. The load cell and lower arm cuff are where the interface motor and other sides are attached to the load cell.

The system uses the ESP32 as its primary microcontroller. The mechanical framework of the upper limb rehabilitation device is attached to the load cell and servo motor. When force is supplied to a device joint, the servo motor is employed to control the joint. As an input force for the measurement, the load cell is fastened to the apparatus. The motor can be more accurately controlled to deliver the necessary force for the stroke patient by using the force control feedback. Using the Unity Engine, a video game is created. The laptop or computer is used to connect the ESP32's serial port to the laptop or computer, which then sends data from the ESP32 to Unity, which moves the flappy bird in Unity using that data [11-13].

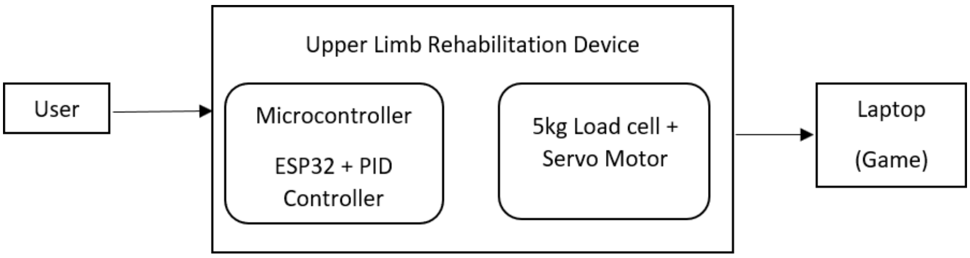

Figure 1: Block diagram for the system architecture

2.2 Flowchart

The flowchart for the game level is shown in Figure 2(a) and Figure 2 (b). The game level that the stroke patients must select depends on their level of force. The flowchart for force control using a PID controller is shown in Figure 2(b). Force delivered to the load cell initiates the process. The input to the controller is the difference between the desired force and the actual force. The upper limb exoskeleton will move forward (flexion) if the output from the PID controller is greater than 50 grams and it will move backward if the input of applied force is less than -50 grams (extension).

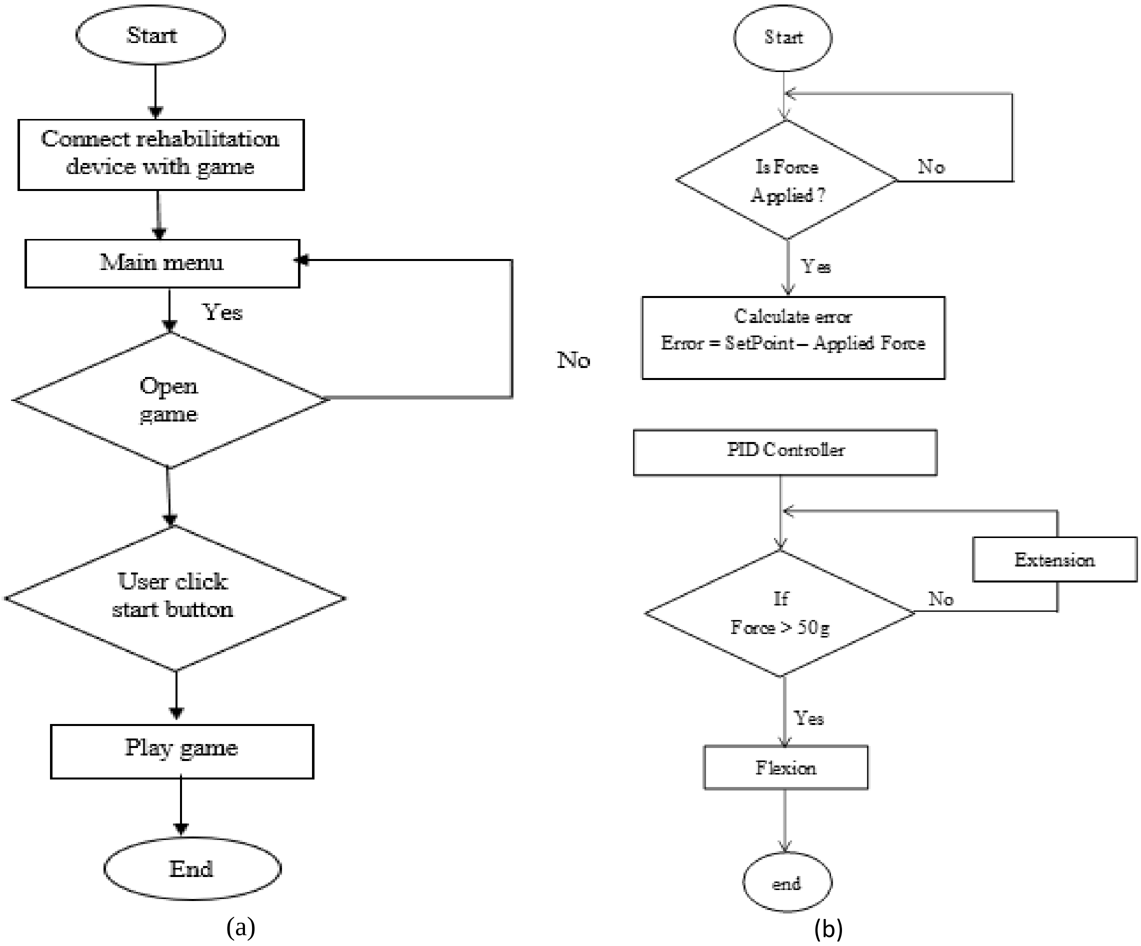

Figure 2: Flowchart of (a) game level and (b) force control

2.3 Mechanism structure

This work uses a single degree of freedom exoskeleton in 3D for the upper limb as shown in Figure 3. There is a total of seven pieces in this elbow exoskeleton. The first component is the cuff, which consists of three cuffs of varying sizes, starting from the upper arm cuff and ending with the lower arm cuff. Four screws are used to secure each cuff. The second component is the upper arm segment, which joins the motor adapter and two upper arm cuffs. Motor adapter is the third component. The second upper arm cuffs and the servo motor will both be connected by a motor adapter. The interface motor is the fourth component, and the load cell is attached to the other side. The last one is the lower arm cuff, which is secured with four screws after being attached to the load cell [14].

Figure 3: User play the flappy bird game using upper limb rehabilitation device

The range of motion for this upper limb exoskeleton is from angle 0° to angle 90° and it has one degree of freedom (DOF) via an elbow joint as shown in Figure 4. This device physically provides a supportive torque to the joint of the stroke patient, enabling the patient to move their hand while playing the flappy bird game, which requires moving the bird in the y-axis from 0° to 90°. Table 1 shows the data specification for this upper limb exoskeleton.

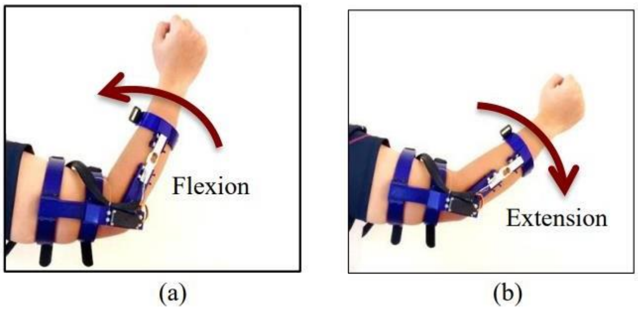

Figure 4: Elbow joint movement (a) Flexion (b) Extension

Table 1: Data Specification of Upper Limb Rehabilitation

Category	Data Specification of Upper LimbRehabilitation
Range of motion	0º - 90º
Degree-of-Freedom	1 DOF
Elbow Joint Movement	Flexion or Extension
Length	30cm / 304.8mm
Weight	250 grams

The usual range of elbow mobility for a human is 0° to 135°, whereas the normal range for a rehabilitation device is 0° to 110° [7]. For this work, the upper limb rehabilitation device's final range of motion (ROM) is limited from angle 0° to angle 90° after going through various testing ranges of motion. This upper limb rehabilitation device has a minimum range of motion (ROM) at angle 0°and a maximum range of motion (ROM) at angle 90°.

2.4 PID controller

The block diagram of a PID controller is shown in Figure 5. To calculate the command torques of the controller, a PID controller was developed. When a user exerts some force on this upper limb rehabilitation device, the force is then sensed by the load cell and scaled by the controller, which then sends the input to the motor to manage the motor torque in order to modify and assist the user movement.

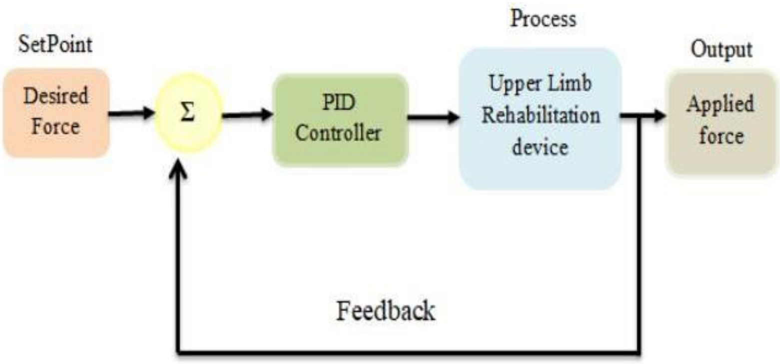

Figure 5: Block diagram of PID controller

Without PID Controller, the error from the desired force and applied force is directly use as the input to the servo motor [15]. The equation 1 shows the calculation of the error.

$Error = SetPoint - Applied\ Force$ (Eq.1)

Proportional Gain (Kp): The output for P controller is calculated as follow in equation 2.

$P = Kp.\ e(t)$

Kp = Proportional gain, e(t) = error (Eq.2)

Integral Gain (Ki): The output for P controller is calculated as follow in equation 3.

$PI = Kp.\ e(t) + \int Ki.\ e(t)dt\ r\ 0$ (Eq.3)

Ki = Integral gain and r = Total time of operation of the controller

Derivative Gain (Kd): The output for PD controller is calculated using equation 4.

$PD = Kp.\ e(t) + Kd.\ de(t)\ dt$ (Eq.4)

Kd = Derivative gain

Proportional Integral Derivative (PID): The equation 5 shows the output of PID controller.

$PID = Kp.\ e(t) + \int Ki.\ e(t)dt\ r\ 0 + Kd.\ de(t)\ dt$ (Eq.5)

2.5 Flappy Bird Game

According to Figure 6, the two primary scenes created for this game development are the main menu scene and the game scene.

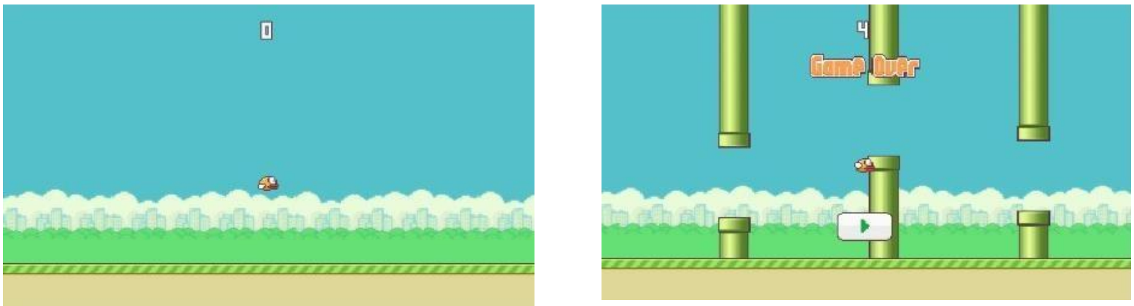

Figure 6: Main menu and play game scene

The angle of servo motor input will be control using Flappy Bird game. During the game, the bird supposed to fly according to the data that receive from unity to ESP32 using serial communication. The info obtained from the motor angle, which determines whether the bird will fly high or low. Because the bird only needs to fly up and down, only the value on the y-axis will change in this flappy bird game. The y-axis value will change depending on the servo motor angle received from the ESP32 using the serial monitor. The bird will fly from bottom to top using the device's range of motion, which has been set from 0° to 90°. Range of motion where the servo motor angle 0° is the minimum range of y-axis the bird can fly low and the angle 90 °is the maximum range of y-axis the bird can fly to the top. This means that the minimum range of motion equals the minimum the bird can fly low on the y-axis and the maximum range of motion equals the maximum the bird can fly high on the y-axis. To get the highest score, the bird must overcome the obstacle. The game ends when the bird touches down on an obstacle or a pipe. Figure 6 shows the bird's maximum range at the top, which is -2.3. The range between the bird's maximum and minimum values is 7.

To ensure that the data sent from the ESP32 microcontroller to unity is correct, some calculations were calculated using the following equation

Min ROM = min bird can fly on y-axis 0 ° = -2.3f

Max ROM = max bird can fly on y –axis 90 ° = 4.7f

Range bird can fly on Y-axis = max bird can fly - min bird can fly

= 4.7f - (-2.3f)

= 7f

3. Results and Discussion

Figure 7 represents a successful connection between ESP32 and Unity, with input from servo motor angle based on user movement successfully sent through serial port using serial communication to move the bird. ESP32 will sent the data through Unity via code command to activate the games. When it successful sending the signal to Unity, Unity will receive strings from ESP32 and will display the bird script in unity display page.

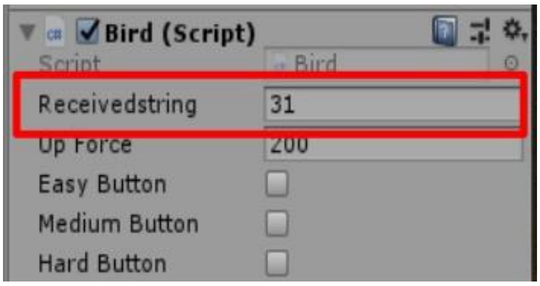

Figure 7: Data send from ESP32 to Unity

4. Conclusion

In the conclusion, the upper limb rehabilitation device using force control feedback has already accomplished the first goal of designing and implementing a simple upper limb rehabilitation device. Using 3D printing, a single degree of freedom upper limb rehabilitation device was designed and developed. The servo motor and 5kg load cell are used to control the upper limb rehabilitation device. The Flappy Bird video game was successfully developed afterward. Each time a player scored a three-point increment, the game became more tense. Using UART connectivity, the game may communicate with the upper limb rehabilitation device. Using the serial interface between the Arduino and Unity, a connection between the hardware and software has been successfully established. This connection is based on two-way communication, which means that both Arduino and Unity will receive and transfer data. The second goal, which was to design and construct a single degree of 69 freedom game-like based system, was fulfilled indirectly because of this. The Proportional-Integral-Derivative (PID) controller was used to control the force control feedback. Manual tuning was used to fine-tune the gains of each output by adjusting three parameters: proportional controller (P), proportional integral (I), and proportional derivative (D). According to the findings and research, this upper limb rehabilitation gadget is safe for stroke patients to use for rehabilitation. It can also increase stroke patient motivation since the patient can train their hand while playing the flappy bird game by selecting the appropriate game level based on their force capabilities**.**

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