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Integration of Flex Sensor into Wrist Exoskeleton for Rehabilitation of Stroke Patient

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ABSTRACT

The purpose of this project was to develop an exoskeleton for wrist rehabilitation of stroke patients. Currently, various methods of rehabilitation existed to treat limb paralysis from a stroke. However, we were trying to develop a new therapy method that is more effective. The project was a combination of mirror therapy and exoskeleton to test the effectiveness of brain stimulation and limb stimulation. This project focuses on the wrist movement, which consists of flexion and extension. Exoskeleton for the wrist was developed with a flex sensor as input and servo motor as output. The result from comparing the difference in duration at peak angle for both the hand controller with the Master circuit integrated and the wrist exoskeleton with the Slave circuit integrated shown that the delay time between the Master and the Slave was 0.26 seconds. The wrist exoskeleton project was successful since the delay time between the hand controller and the wrist exoskeleton was less than 0.3 seconds. The small amount of delay time between Master and Slave is important to achieve a Mirror Therapy effect. The expectations for this project are that the exoskeleton developed will help recover the wrist movement for stroke patients and further enhance the exoskeleton technology in Malaysia.

Keywords: *Stroke; Neuroplasticity; Mirror Therapy; Hand Exoskeleton; Hand Mechanics.*

Introduction

Stroke patients suffer from limb paralysis due to damaged brain pathways which control the movement of the affected limb. The stroke effects differ with parts of brain damage and the level of severity. Strokes cause various health effects such as body weakness, loss of touch, and difficulty in communication, vision, and movement. Since different parts of the brain affect different areas and have different functions, the effect of stroke on certain parts will impair the function of the affected brain parts [1].

To repair the impaired function of the brain parts, the concept of neuroplasticity is used. Neuroplasticity is defined as the brain's ability to reorganize itself by forming new neural connections throughout life. Neuroplasticity allows the nerve cells in the brain to compensate for injury and disease and to adjust their activities in response to new situations or changes in their environment. Figure 1 below shows a simple diagram of how Neuroplasticity works.

Figure 1: How neuroplasticity works.

If the damaged brain parts and the affected limb functions are stimulated, a new neuron pathway will be formed from the brain to the impaired limb. This enables for the affected limb functions to be resumed. Neuroplasticity can also be called brain plasticity or brain malleability [2]. To stimulate both the brain and the affected limb, mirror therapy and exoskeleton is used. Mirror therapy (MT) is a rehabilitation and clinical therapy in which a mirror is placed between the arms or legs. The image of moving a non-affected limb will give the illusion of normal movement in the affected limb through the mirror [3].

Current research shows that mirror therapy treatment gives positive impact to the body and nervous system in patients who suffer from motor impairment [4]. An exoskeleton is important in assisting and rehabilitating the movement of impaired motor of limb such as hand movement which consists of pinch, grip, and other finger movement [5]. It can greatly improve the impaired motor functions movement and therapy results while reducing staff cost. [6]. The rehabilitation using exoskeletons method provides exercise for the patients to help recovering motor function and stimulate the nervous system of the target limb [7]. Thus, this project aims to design an exoskeleton specifically for the wrist combined with mirror therapy concept to rehabilitate the movement of the affected wrist for stroke patients. Currently, there are a few solutions present to recover the motor function of the affected limb, but it is not very effective. Some of the solutions for rehabilitation for stroke patients to recover lost motor function are mirror therapy and exoskeleton. Thus, to increase the effectiveness of these therapy, both of these concepts will be combined by creating a controller at the left hand and the movement of the wrist at right hand supported by an exoskeleton will follow the movement of the left hand. The flex sensor will be attached at the wrist of the left hand as input and the servo motor at the exoskeleton will act as output. Based on the World Health Organization statistics, an estimate of 15 million people suffers strokes worldwide each year. From these numbers, 5 million people die and another 5 million people suffer from permanent disability which is 1/3 of the stroke patient [8]. Thus, it is common for stroke patients to suffer from limb paralysis due to the effect of stroke. To recover from limb paralysis, various rehabilitation methods were designed to help stroke patients to recover the lost motor function.

However, there is no effective method yet for stroke patients to recover from the limb paralysis. For mirror therapy, the patient stimulates the brain to repair and create a new pathway to the motor function of the limb, but the motor function itself has not been repaired. Using external support such as exoskeleton, it will stimulate the motor movement of the limb, but the damaged brain part for the function is not repaired.

Thus, to solve this problem, both methods will be combined which is mirror therapy and exoskeleton. Since some stroke patients suffer from hand or leg paralysis, the focus of this project will be on hand movement. Various movements can be made from the hand such as pinching, gripping, flicking, palming, and wrist flex. However, the exoskeleton developed will only focus on wrist flex. For this project, several problems can be identified such as the design for the wrist exoskeleton, the coding for the flex sensor to control the movement of the servo motor, and the data required to test the functionality of the hand exoskeleton.

Methodology

Components

Firstly, a wrist exoskeleton for therapy of a stroke patient with hand paralysis was required to be built. To control the movement of this wrist exoskeleton, a device called a hand controller was needed. This hand controller would be worn at the left hand while the wrist exoskeleton would be worn on the right hand. When the left hand flexed its wrist upwards, the hand controller would detect that movement and send the signal to the wrist exoskeleton on the right hand. This wrist exoskeleton would copy the movement of the hand controller and help the right wrist flex upwards too. This will create a mirror therapy effect. The circuit that sent instruction was called Master and the circuit that received instructions was called Slave. To build a wrist exoskeleton and a hand controller, a few components are required such as 2 Arduino and its cables, 2 circuit boards, a flex sensor, 2 Bluetooth module, 2 analog micro servo motors, Velcro tape, wires, thread, 3D printer, and a PLA (Polylactic Acid) filament. Figure 2, and Figure 3 show the Hand Controller the Wrist Exoskeleton. Figure 2 shows the Hand Controller with its components labelled and Figure 3 shows the Wrist Exoskeleton and its components labelled.

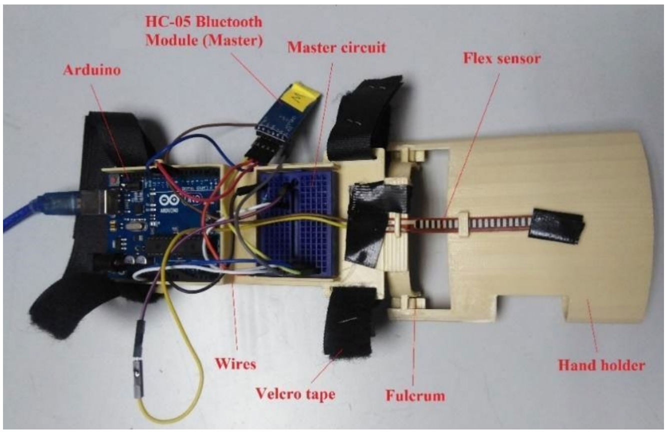

Figure 2: Components for Hand Controller.

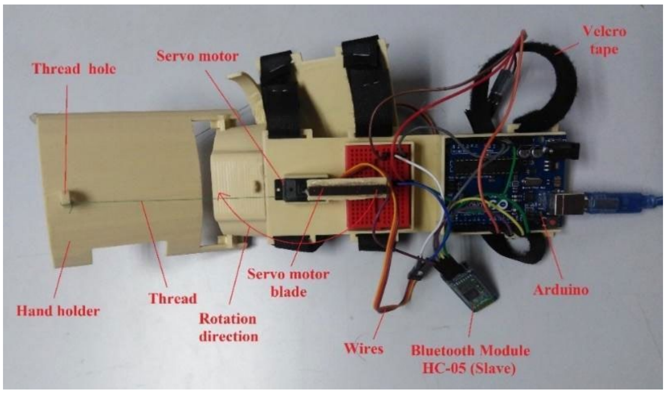

Figure 3: Components for Wrist Exoskeleton.

Complete Circuit

The complete circuit consisted of two separate circuits. One circuit was a 'Master' circuit and the other circuit was a 'Slave' circuit. The Master circuit acts as the controller and would receive input from the flex sensor while the slave circuit acts as the output circuit and would generate output through the servo motors. Both of these circuits were connected by Arduino Bluetooth modules, HC-05. One Bluetooth module would send the input value from the flex sensor and the other Bluetooth module would receive the input. Figure 4 below shows the Arduino code for the Master circuit and Figure 5 below shows the Arduino code for the Slave circuit. The master circuit would be integrated at the wrist controller while the slave circuit would be integrated into the wrist exoskeleton. The synchronized movement of both hands would generate Mirror Therapy effect.

Master_flex_coding §

```
#include <SoftwareSerial.h>
SoftwareSerial BluetoothSerial(6, 7); //  TX,RX

int flexpin = A2; // analog output at A2
int flexposition ; // declare variable flexposition
int servoposition ; //declare variable servoposition

void setup()
{
  Serial.begin(9600); //serial begin at 9600 baud
  BluetoothSerial.begin(9600); //bluetooth serial begin at 9600 baud
}

void loop()
{
  flexposition = analogRead(flexpin) ; //read analog value of flex sensor
  BluetoothSerial.write(servoposition); //send the angle value to bluetooth serial

  if (flexposition < 982)
  servoposition = 0;
  else if (flexposition > 982 && flexposition < 989)
  servoposition = 90;
  else if (flexposition > 986)
  servoposition = 180;
}
```

Figure 4: Master circuit code.

Slave_Servo_coding §

```
#include <SoftwareSerial.h>
SoftwareSerial BluetoothSerial(12, 13); //  TX,RX
#include <Servo.h>

Servo myservo1;
Servo myservo2;
int servoposition; //declare variable servoposition

void setup()
{
  Serial.begin(9600); //serial begin at 9600 baud
  BluetoothSerial.begin(9600); //bluetooth serial begin at 9600 baud
  myservo1.attach(9); //servo attach at pin 9
  myservo2.attach(7); //servo attach at pin 7
}

void loop()
{
  if (BluetoothSerial.available()>0)
  {
    servoposition = BluetoothSerial.read(); //read angle value from bluetooth serial
    myservo1.write(servoposition); //move servo motor 1 according to angle value
    myservo2.write(180-servoposition); //move servo 2 motor according to angle value
    Serial.println(servoposition); //print the motor angle in serial monitor
  }
}
```

Figure 5: Slave circuit code.

CATIA Design

The wrist exoskeleton model was designed using CATIA V5. A detailed 3D model was designed based on the initial sketch. There are 2 parts of the model, the wrist exoskeleton and the hand controller. A Master circuit would be integrated into the hand controller and a slave circuit would be integrated into the wrist exoskeleton. The hand controller would function as the input of the wrist exoskeleton so that the wrist exoskeleton moved exactly like the hand controller to create a mirror movement effect. The wrist exoskeleton would be designed for the right hand while the hand controller would be designed for the left hand. The model would be first designed in parts and all the parts would be assembled later. Figure 6 below shows the Hand Controller assembly design in CATIA and Figure 7 shows the Wrist Exoskeleton assembly design in CATIA

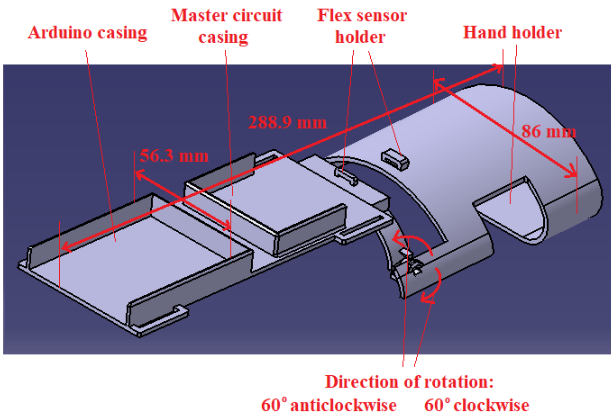

Figure 6: Hand controller CATIA assembly (Master circuit).

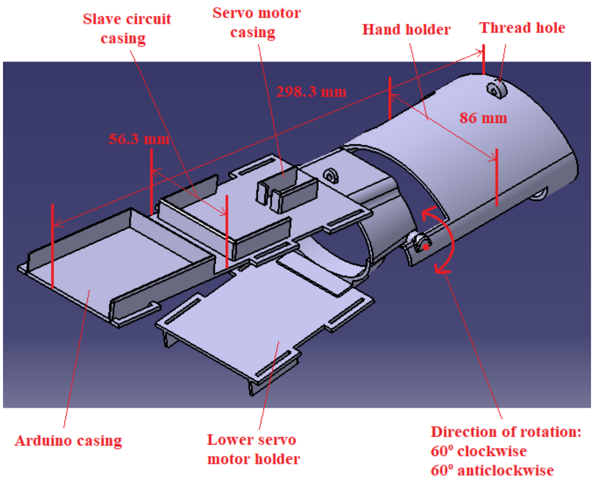

Figure 7: Wrist exoskeleton CATIA assembly (Slave circuit).

System Design

After the model in CATIA was completed, the 3D model was printed using a 3D printer. The material used for the model was PLA filament. After finishing printing all the parts for both the wrist exoskeleton and the hand controller, the parts would be assembled into a complete model. The master circuit was integrated into the hand controller and the slave circuit was integrated into the wrist exoskeleton. The wrist exoskeleton was worn on the right hand and the hand controller was worn on the left hand.

To move the wrist exoskeleton by flexing upwards and downwards, a pulling action using servo motors and thread system was used. To flex the right wrist upward, the left hand with the hand controller would need to flex its wrist upwards (Figure 8). The angle of bent received from the flex sensor would send the signal to the wrist exoskeleton through its Bluetooth module. After receiving command from the hand controller, the upper servo motor would rotate 180° anticlockwise with its blades initially pointing towards the hand to pointing away from the hand. The thread was tied up at two points, one at the wrist exoskeleton's thread hole and the other end is at the end tip of the servo motor blade. When the upper servo motor rotated its blade 180° anticlockwise, the thread would pull the hand holder by its thread hole. Since the movement of the wrist exoskeleton's hand holder is fixed at fulcrum, this would cause it to flex upwards. (Figure 9) While the upper servo motor rotated 180° anticlockwise, the lower servo motor would rotate 180° clockwise from its blade's initial position facing away from the hand to facing towards the hand. This would allow freedom of movement for the upper thread.

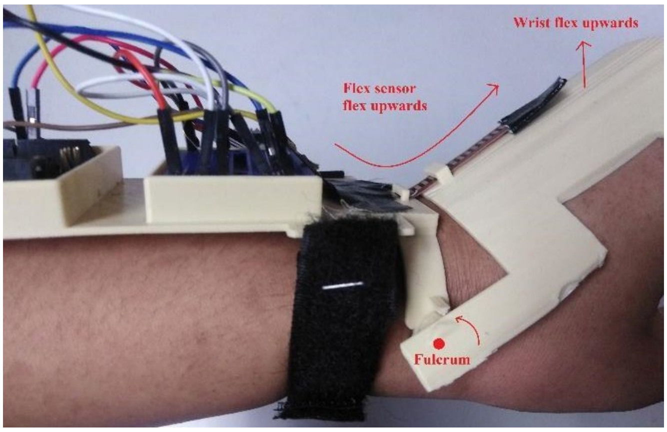

Figure 8: Hand controller flex upwards.

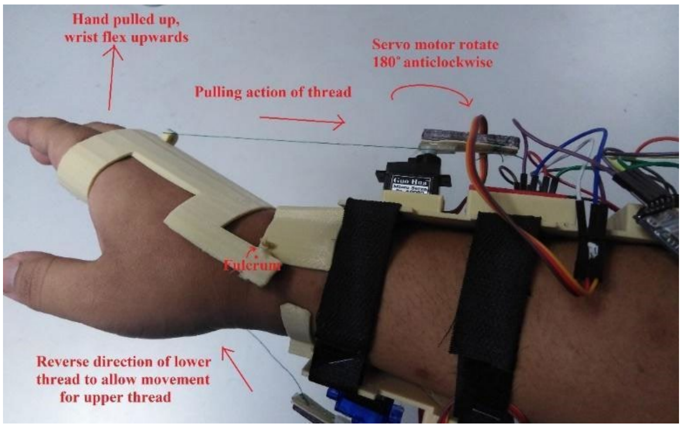

Figure 9: Wrist exoskeleton flex upwards.

To flex the right wrist downward, the left hand with the hand controller would need to flex its wrist downwards. (Figure 10) The change of bent angle detected from the flex sensor would send the signal to the wrist exoskeleton through its Bluetooth module. After receiving command from the hand controller, the lower servo motor will rotate 180° anticlockwise with its blades initially pointing towards the hand to pointing away from the hand. The lower thread which was tied at the wrist exoskeleton's lower thread hole and at the end tip of the servo motor blade would pull the hand holder downwards by its thread hole when the lower servo motor rotated its blade 180° anticlockwise. Since the movement of the wrist exoskeleton's hand holder is fixed at fulcrum, this will cause it to flex downwards. (Figure 11) While the lower servo motor rotated 180° anticlockwise, the upper servo motor would rotate 180° clockwise from its blade's initial position facing away from the hand to facing towards the hand. This would allow freedom of movement for the lower thread.

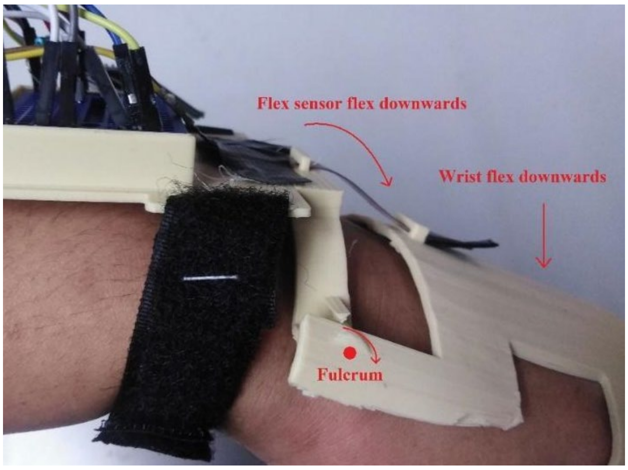

Figure 10: Hand controller flex downwards.

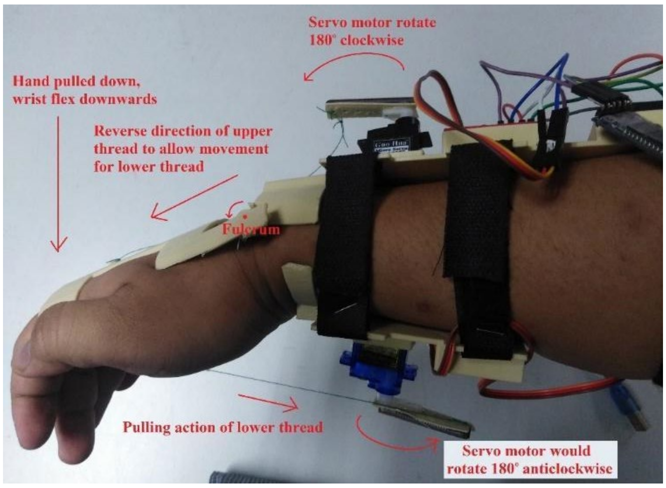

Figure 11: Wrist exoskeleton flex downwards.

Result Evaluation

The movement of the hand controller and the wrist exoskeleton were compared. To achieve mirror therapy effect, both the Hand Controller and the Wrist Exoskeleton should move around the same position and the amount of delay time between these two movements should be small which would be at least less than 0.3 s or 0.4 s for acceptable delay time [10]. Kinovea software version 0.8.15 was used to measure both the time and movement angle between the hand controller and the wrist exoskeleton. The time was recorded for one complete animation for the hand controller which was from the wrist flexing downwards as initial position and continued to flex upwards and ended back at its initial position which is the wrist flexing downwards. The test was conducted two times. The time for one complete animation for the first test for the hand controller was 2.00 seconds while for the second test was 2.22 seconds. The angle of movements between these two models were recorded and graphs are plotted to compare the movement and delay time between the hand controller and the wrist exoskeleton. Figure 12, Figure 13, and Figure 14 shows the movement angle measured at different angle positions from the initial position.

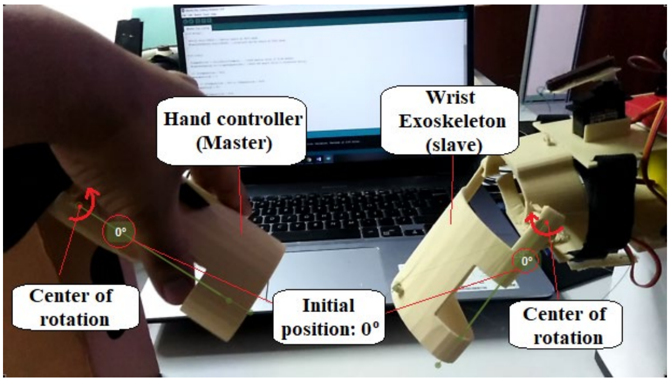

Figure 12: Measuring movement angle at initial position using Kinovea software.

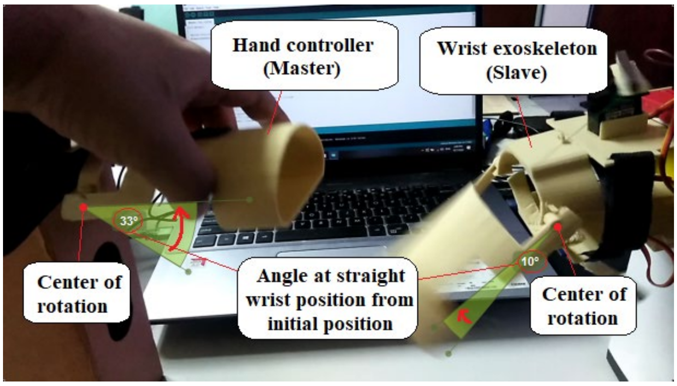

Figure 13: Measuring movement angle at straight position using Kinovea software.

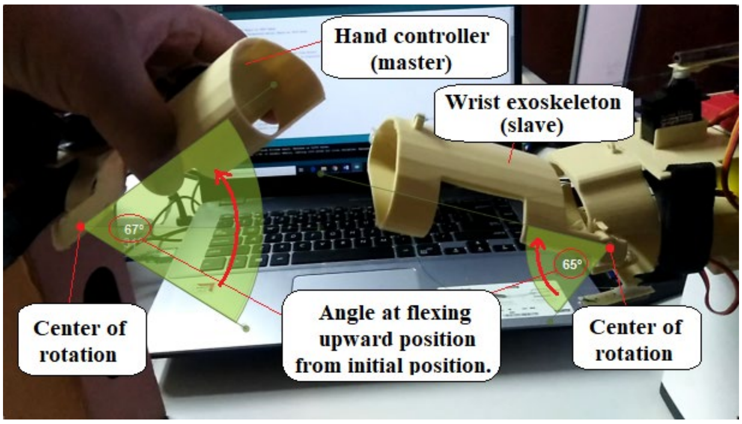

Figure 14: Measuring movement angle at upward position using Kinovea software.

Results and Discussions

Master and Slave Comparison in Time and Angle

The duration and angle from initial position for both the Master circuit and Slave circuit were measured using Kinovea software version 0.8.15 and were recorded. The data were recorded in Table 1 and a graph was plotted as shown in Figure 15 based on the table to calculate the delay time between the Hand Controller which was the master circuit and the Wrist Exoskeleton which was the Slave circuit. The test was conducted for the second time where the second data were recorded in Table 2 and the graph was plotted in Figure 16. This was done to achieve more accurate results.

Table 1: Duration and angle for Hand controller and Wrist exoskeleton at each positions

Duration for 1 complete animation: 2.00 s			
Time	Angle from initial position		Description
	Hand controller (Master)	Wrist exoskeleton (Slave)	
0.00	0	0	Wrist flex downwards
0.51	33	10	Wrist at straight position
0.91	67	65	Wrist flex upwards
1.62	31	62	Wrist at straight position
2.00	0	29	Wrist flex downwards

Table 2: Duration and angle for Hand controller and Wrist exoskeleton at each positions

Duration for 1 complete animation for second test: 2.22 s			
Time	Angle from initial position		Description
	Hand controller (Master)	Wrist exoskeleton (Slave)	
0.00	0	0	Wrist flex downwards
0.47	32	14	Wrist at straight position
0.74	66	69	Wrist flex upwards
1.75	33	65	Wrist at straight position
2.22	0	25	Wrist flex downwards

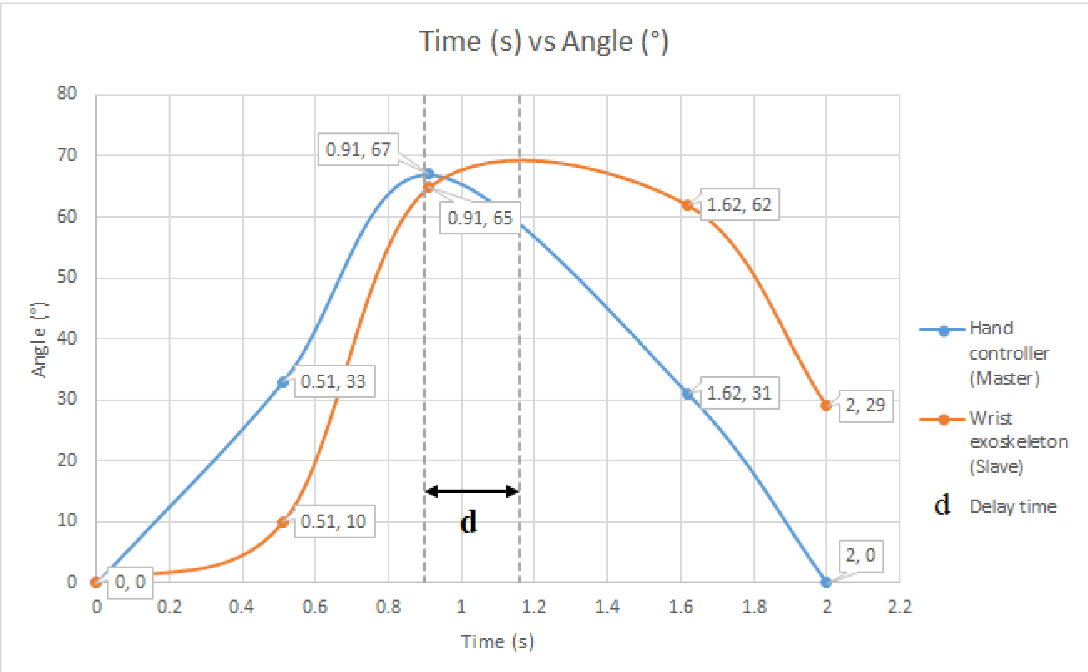

Figure 15: Comparison of Angle for each Master and Slave first test.

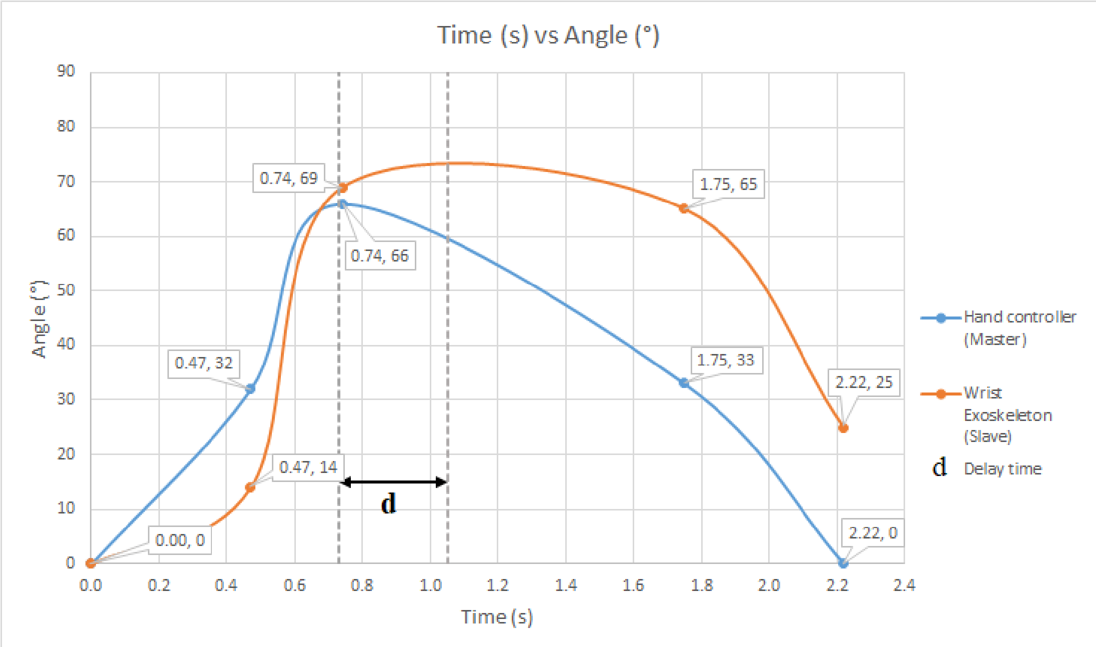

Figure 16: Comparison of Angle for each Master and Slave second test.

Firstly, both the hand controller which was the Master circuit and the Wrist Exoskeleton which was the Slave circuit were at initial position where both wrists were flexed downwards. The angle at initial position was set as 0°. There are five points in the graph which indicated the movement of the Master and Slave from flexed downward which was the initial position, to the straight wrist position, flexed upward position, back to the straight wrist position and finally returned to flexed downward position again for one complete animation of the hand controller which were indicated as five points on the graph in both Figure 15 and Figure 16.

Each frame of the Master and Slave movement were captured using the Kinovea software version 0.8.15 due to its advantage to view and analyse the video frame by frame. This made it easier to see the movement of both the Master and Slave as it moved from one position to another position and measured the angle at each position frame by frame. The duration on each frame was also mentioned in the Kinovea software which made it easier to determine the time at each five positions for one complete animation.

The delay time between the Hand Controller and the Wrist Exoskeleton was measured by calculating the difference of the duration at peak angle for the Master and Slave which could be seen in the graph in both Figure 15 and Figure 16 as a range value for d.

For the first test, by referring to Figure 15, the time at peak angle for Master was 0.9 seconds and the time at peak angle for slave was 1.16 seconds. The delay time calculated from the difference of the peak time was 0.26 seconds. For the second test, by referring to Figure 16, the time at peak angle for Master was 0.73 seconds and the time at peak angle for slave was 1.05 seconds. The delay time calculated from the difference of the peak time was 0.32 seconds. The average value of delay time for both tests was 0.29 seconds.

Since the average delay time between the Master and Slave was less than 0.3 seconds or 0.4 seconds, the wrist exoskeleton project was considered successful. A robotic hand or exoskeleton would be considered usable if the delay time between the Master and Slave was below 0.3 seconds or 0.4 seconds [10].

Conclusions and Recommendations

In conclusion, the objectives for this project were achieved. A model of a hand controller and a wrist exoskeleton were successfully designed using CATIA software. The Arduino circuit consisting of a Master circuit and a Slave circuit were also successfully integrated into both the hand controller and the wrist exoskeleton respectively. Next, the angle of wrist movement for both Master and Slave at each position were successfully measured and compared for both the hand controller and the wrist exoskeleton. The results were recorded and plotted into the graph.

The results show that the average delay time between the Master circuit and the Slave circuit was 0.29 s. This result shows that the wrist exoskeleton project was successful since the delay time between the hand controller and the wrist exoskeleton was below 0.3 seconds. When both the hand controller and the wrist exoskeleton moves at the same position with small delay time, a Mirror Therapy effect can be achieved.

For future projects, there are few parts that can be improved. Firstly, to get more accurate results, the test to calculate delay time should be repeated more frequently to achieve more consistent results. The coding could also be altered so that the input from the flex sensor will match more accurately with the angle of rotation of the servo motor. Next, the design of the overall wrist exoskeleton should be improved such as designing a better and more flexible casing for the flex sensor. The torque of the servo motor can be increased by using a stronger servo motor compared to the analog micro servo motor which is a metal gear analog servo motor to increase the pulling strength of the wrist exoskeleton and move the human wrist more easily. Moreover, new flex sensors should be used since old flex sensors may have reduced sensitivity due to prolonged use. Furthermore, a soft material such as cloth should be integrated in the wrist exoskeleton to provide comfortability to the wearer. Lastly, stronger material should be used for the wrist exoskeleton to increase its overall strength and endurance limit.

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