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Design of a Lower-Limb Exoskeleton Drive Using an Arduino-Based Stepper Multimotor

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Abstract

Lower-limb exoskeleton is a walking aid and therapy for the lower part of the human body which is made for stroke or paralyzed sufferers. This tool is attached to the user's waist and can help the movement of the user's thighs, which in general, this tool is used for rehabilitation and assisting human work activities. Movement of the lower-limb exoskeleton consists of at least two degrees of freedom (DOF) or degrees of freedom motion, even in full it can be 6 to 12 DOF. In addition, the exoskeleton is used for therapy and is equipped with controls that really help the user to make movements, and the results can improve motor function. This movement control system generally uses a microcontroller and the drive system is a motor. Rehabilitation tools with the help of robots have been developed in many developed countries. Most of the designed rehabilitation aids have a large size and also have a heavy weight. So it requires a special place for rehabilitation. Therefore, an exoskeleton that is lightweight and also small in size is needed so that it can be used for other activities. The lower-limb exoskeleton is a combination of robotic technology and medical rehabilitation technology. In terms of design, the exoskeleton design should not only incorporate a rigid and flexible structure, but also have a high degree of resemblance to the movement of the human foot. However, there are still many problems with the lower-limb exoskeletons studied previously, which use a thick, bulky supporting frame with a low degree of freedom to partially support the wearer's weight and mobility. If the rigid supporting frame and mechanical components are tightly attached to the body, it causes movement discomfort during rehabilitation training and may also cause secondary injury to the patient. Therefore in this study, the focus was on selecting the type of motor used so that the exoskeleton can support the medical rehabilitation of patients. The type of motor used was a stepper motor type 28BYJ-48 along with a ULN2003 motor driver and Arduino Uno as the controller. Furthermore, the propulsion system and controller are implemented in a prototype lower-limb exoskeleton with a 2:1 scale of human size. The tests carried out in this study were: movement of the thigh to the right and left, movement of the knee to the right and left, and movement of the ankle to the front and back, by analyzing the rotation angle and maneuver time of the designed system. The test results show that the Stepper Motor produces better and smoother movements where the angle of rotation along with the time duration of the movement of the thighs, knees, and ankles makes the patient comfortable in making movements in the framework of rehabilitation.

Keywords
Lower-Limb Exoskeleton, Motor Stepper, Arduino, Stroke

Stroke or Cerebrovascular Accident (CVA) is the third highest cause of death in the world after coronary heart disease and cancer in both developed and developing countries (Stroke, 2013) [26]. Based on data collected by the Indonesian Stroke Foundation (Yastroki), Indonesia is the largest country and ranks first in Asia for the number of deaths caused by stroke, namely second place at the age of over 60 years and fifth at the age of 15-59 years. The result of a stroke is paralysis, one of which is leg muscle paralysis. One way to overcome stroke is by means of therapy. By means of therapy, it is hoped that stroke patients will recover more quickly (AFIANTI, 2019).[25]

Rehabilitation tools with the help of robots have been developed in many developed countries. Most of the designed rehabilitation aids have a large size and also have a heavy weight. So it requires a special place for rehabilitation. Therefore, an exoskeleton that is lightweight and also small in size is needed so that it can be used for other activities.

Lower-limb exoskeleton is a tool to help human movement to walk. The tools made will be used to help walk or treat stroke patients so that recovery time is expected to be faster. This tool is attached to the user's waist and can help move the thighs, knees, and ankles (State Polytechnic Information Center, 2016).

The development of a lower-limb exoskeleton rehabilitation robot is very useful for people with special needs for lower extremity movements. With a lower-limb exoskeleton, patients can carry out medical rehabilitation training to achieve normal walking [1].

The lower-limb exoskeleton is a combination of robotic technology and medical rehabilitation technology. In terms of design, the exoskeleton design should not only incorporate a rigid and flexible structure, but also have a high degree of resemblance to the movement of the human foot. However, there are still many problems with the lower-limb exoskeletons studied previously, which generally still use a thick, bulky supporting frame with a low degree of freedom to support some of the wearer's weight and mobility. If the rigid supporting frame and mechanical components are tightly attached to the body, it causes movement discomfort during rehabilitation training and may also cause secondary injury to the patient.

In recent years, the use of an exoskeleton has been able to assist patients in achieving their characteristic natural gait and also assist with comfortable lower-limb rehabilitation training [2].

Research Methodology

The stages carried out in this study are as follows,

1. Make observations related to problems with stroke therapy.
2. Observing and studying the existing measurement system in previous studies.
3. Conduct literature studies to study human walking movements. In addition, also studies theories related to motors and the components used.
4. Conduct interviews with previous researchers to obtain information about needs and deficiencies, as well as suggestions and input related to the design of the new system that will be created.
5. Designing a new system with a drive in the

form of a stepper motor that can be used to move the prototype smoothly (smooth). Then the system is implemented and tested on a prototype with a 2:1 scale of human size measuring the angle position and time when the tool/system is maneuvered.

Basic Literature Study

Lower-Limb Exoskeleton

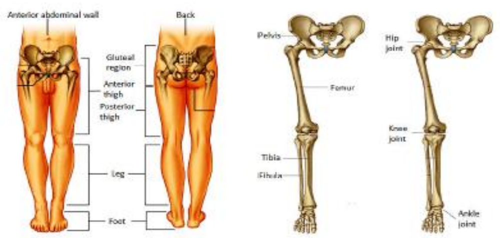
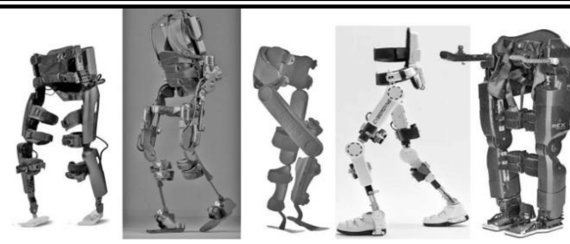


Figure 1: Lower Human Anatomical Structure

The human lower extremity is also known as the human lower-limb exoskeleton which is made up of the legs, thighs, and gluteal areas. Figure 1 shows the structure of the lower human anatomy consisting of the hip, knee and ankle joints.

The main function of the lower limbs is to support body weight and help people move. This function effectively requires the leg segments of the limbs referred to as bones which are the hip bones (Pelvis), femur (Femur), and leg bones (Tibia and Fibula). Where joints are places where bones connect. They are designed to allow movement and provide mechanical support and are classified structurally and functionally.

The human gait cycle can be thought of as a complete step or walking cycle. This cycle extends from Heel Strike to Heel Strike of one leg and includes the stance and swing phase of both legs. Basically, it can be said that the movement in the gait cycle is unfolding. When the foot is on the ground (the standing phase makes up 62% of a complete gait cycle), when the foot is down to the ground (the swing phase makes up the remaining 38% of a complete gait cycle). The running cycle is shown in Figure 3 (archive-ouvertes, 2017).



Fgiure 2: Lower-Limb Exoskeleton

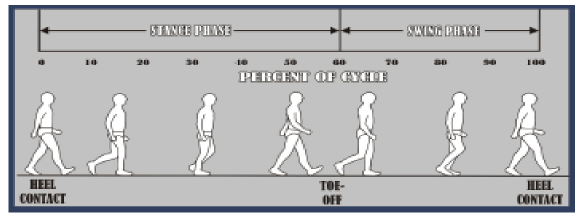


Figure 2 : Gait Cycle Maneuver

Motor Stepper

Stepper motor is a synchronous electric motor that converts digital pulse data to mechanical rotation and 1 full rotation is divided into many steps (steps). The number of rotations performed is proportional to a given digital pulse and the speed of rotation is proportional to the frequency of those digital pulses. Stepper motors can be precisely adjusted in angular position without any feedback mechanism (open-loop controller) as long as the stepper motor is carefully controlled.

Figure 4: Motor Stepper

Based on the control circuit design method, stepper motors can be divided into unipolar and bipolar types. The unipolar stepper motor controller circuit is easier to make because it only requires one On-Off signal by using a switch/transistor in each winding. For stepper motors with bipolar windings, a pulse signal is required that varies from positive to negative and vice versa [15].

Microcontroller

A microcontroller is a small computer ("special purpose computer") in one IC which contains a CPU, memory, timer, serial and parallel communication channels, input/output ports, and ADC. Microcontrollers are used in a large number of electronic systems such as computer keyboards, PLC (Programmable Logic Controllers), robots, automation systems, EDC (Electronic Data Capture) systems, and others. Microcontrollers can also be used for various applications, for example for control, industrial automation, telecommunications, and others [19].

The microcontroller is used as a command processor in the form of a program from input so that it becomes the desired output. Input from the microcontroller can be in the form of buttons, sensors, cameras, or directly from the computer. The output of the microcontroller can be in the form of motors, lights, solenoids, or sound devices, according to current developments the output of the microcontroller has been increasing and experiencing very rapid development [20].

For the implementation of the designed system, in this study, an open source platform, Arduino, was used.

Arduino Uno

Arduino Uno is a microcontroller development board that is small, complete and supports the use of breadboards. Arduino Uno was created on the basis of the ATmega328 microcontroller (for Arduino Nano version 3.x) or ATmega168 (for Arduino version 2.x). [21]. The physical form of Arduino Uno can be seen in Figure 5.

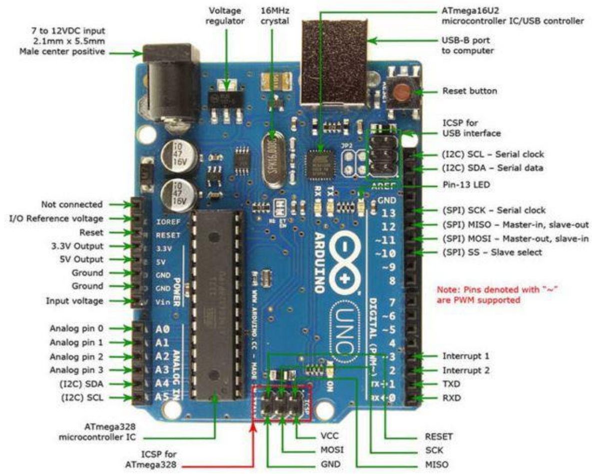


Figure 5: Arduino Uno

Software Arduino Ide

Making or writing programs on Arduino is done with the Arduino Ide software, which is software that operates on a computer. Arduino software is available for various platforms, such as Windows, Mac OS, and Linux. Arduino software functions to write programs and send them to Arduino devices [23].

Arduino Uno has an open source base and can be programmed on operating systems on Windows, Mac OS, and Linux-based computers making it easier for various groups to use it. The display of the Arduino Ide software program on a computer can be seen in Figure 6.

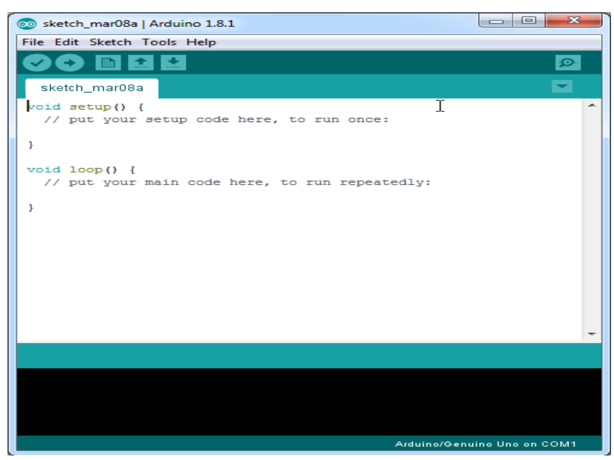


Figure 6: Software Arduino Ide

The task of the Arduino Ide software is to produce programs that can be run on the Arduino board or on other microcontroller systems. Sketch is the name of the program written on the Arduino Ide software. Sketch will later be compiled to see if there are programming languages that have errors or are lacking, after completion, the program will be sent to the microcontroller system or to Arduino to run [24].

System Design

This section will discuss the planning and manufacture of sub-systems.

System Block Diagram

The block diagram of the system as a whole is shown in Figure 7 below.

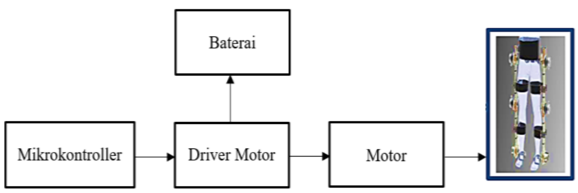


Figure 7: System Block Diagram

The drive system block diagram in Figure 4 shows the lower-limb exoskeleton sourced from program commands that have been set on the Arduino Uno (Microcontroller). The Arduino Uno program is then connected to the motor driver and converted which produces motion commands for six stepper motors according to the coding made in the Arduino Ide software.

The frame drive is a stepper motor consisting of six motors (multimotor). The six motors function to move the upper thigh, knee and heel for both the left and right legs as seen in the lower-limb exoskeleton in Figure 7 in the blue box.

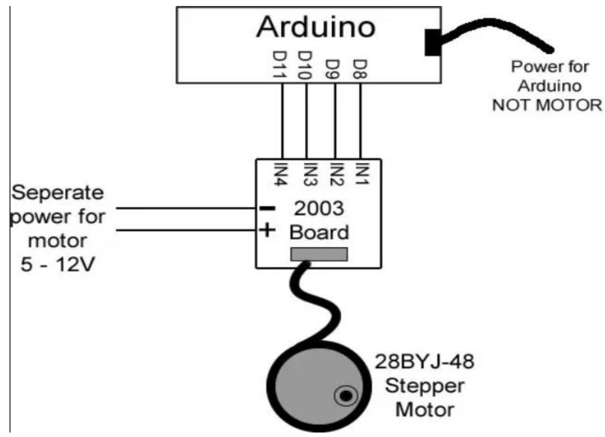


Figure 8: Motor Stepper Circuit

Stepper Motor Circuit

Arduino Uno functions as a microcontroller that can be connected to the 28BYJ-48 stepper motor via the ULN2003 motor driver. The ULN2003 motor driver requires a 5-12 Volt supply voltage.

System Implementation

In this study the designed propulsion system was implemented on a lower-limb exoskeleton with a 2:1 scale of human size made from peralon material, as shown in Figure 9.

Figure 9: Lower-limb exoskeleton with a 2:1 scale

After hardware design and software design, the next step is testing/testing the drive system. Testing is done by measuring the angle and time when the tool is maneuvered. Angle measurement is measured by using an arc to find out the value of the rotation angle. While the time when maneuvering is measured by using a stopwatch.

The ULN2003 Motor Driver requires a voltage of 7 volts to drive six stepper motors with maximum results. If using 5 volts, the stepper motor will lack voltage and cause the motor's movement to become stiff and weak. And if you use 12 volts, the stepper motor will overvoltage or overheat which causes the stepper motor to heat up quickly.

Results and Analysis

The initial angle given to the stepper motor is 90º, so that the stepper motor can move less than 90º and can move more than 90º. A stepper motor movement of less than 90º will result in a forward movement whereas if more than 90º will result in a backward movement.

This test can make a trajectory tracking lower-limb exoskeleton graph with the results of 2-step calculations. The trial uses the movement of 2 steps of the right and left feet to find out the duration of the time obtained. In the movement of 1 the first step takes 5.3s, and the 2nd step gets a total of 10.6s.

Thigh Movement

Movement on the right and left thighs is given an angle of 20º each from the initial angle of 90º. The movement of the thigh when moving forward can be obtained at an angle of 70º because the forward movement produces a movement of less than 90º and the movement of the thigh when moving backward can be obtained at an angle of 110º because the backward movement produces a movement of more than 90º. Figure 10 is a right thigh trajectory tracking chart and Figure 11 is a left thigh trajectory tracking chart.

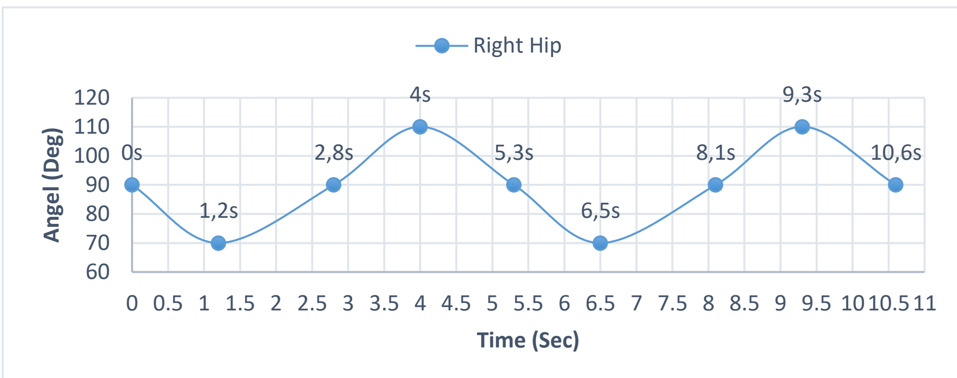


Figure 10: Right thigh Trajectory Tracking chart

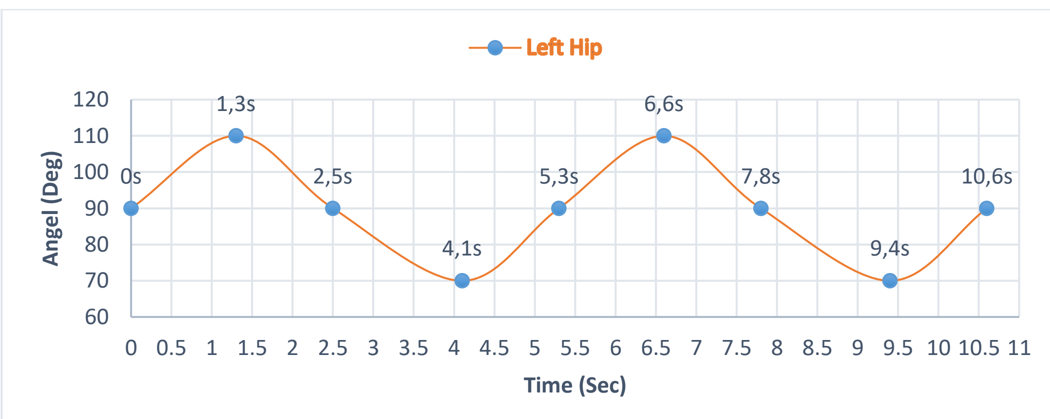


Figure 11: Left thigh Trajectory Tracking chart

There are differences in the movement of the right and left thighs due to different times and movements. The right thigh obtains an initial angle of 70 (step forward) with a time of 1.2s while the left thigh obtains an initial angle of 110 (step backward) with a time of 1.3s. From the results of the trajectory chart the movement of the right and left thighs is balanced with a delay time of 0.1s, meaning that the designed system is functioning properly with smooth movements.

Knee Movement

Movement on the right and left knees is given an angle of 30º each from the initial angle of 90º. The movement of the knee when moving gets an angle of 120º because the movement of the knee only moves backwards and then moves back to normal at an angle of 90º. Figure 12 is a trajectory tracking chart for the right knee and Figure 13 is a trajectory tracking chart for the left knee.

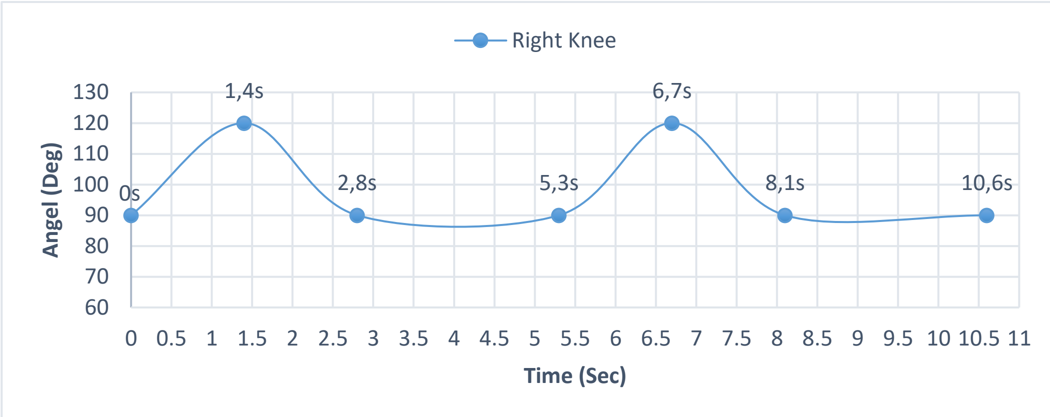


Figure 12: Right Knee Trajectory Tracking Chart

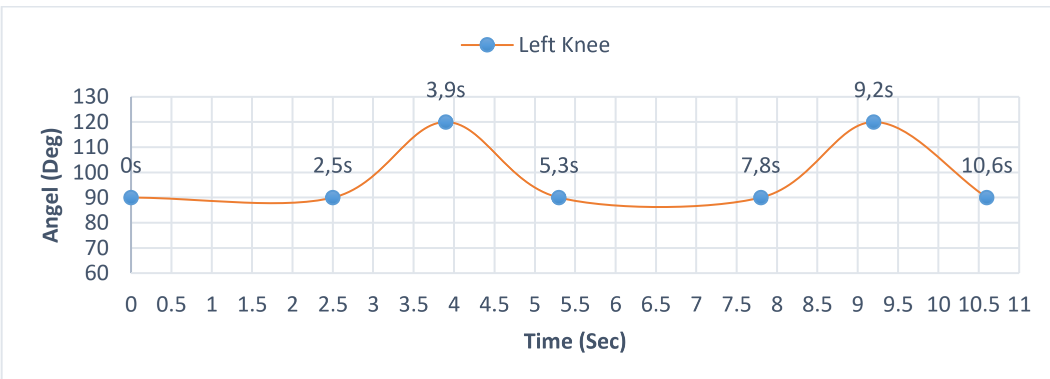


Figure 13: Left Knee Trajectory Tracking Chart

The test results in Figure 12 and Figure 13 shows that the movement of the right knee has an initial angle of 120º with a time of 1.4s (maneuvering backward). The left knee has an initial angle of 90º with a time of 0s – 2.5s (constant position) then moves from 90º to 120º from a time of 2.5s – 3.9s, delay at 0s – 2.5s due to the process of changing movement with the right leg.

Also from the results of the trajectory chart the movements of the right and left knees are balanced, meaning that the designed system is functioning well with smooth movements.

Ankle Movement

Movement at the ankle when moving forward is obtained at an angle of 40º from the initial angle of 90º. Movement at the ankle when moving backwards can be obtained at an angle of 10º. Figure 14 is a graph of the right ankle trajectory tracking and Figure 15 is a graph of the left ankle trajectory tracking.

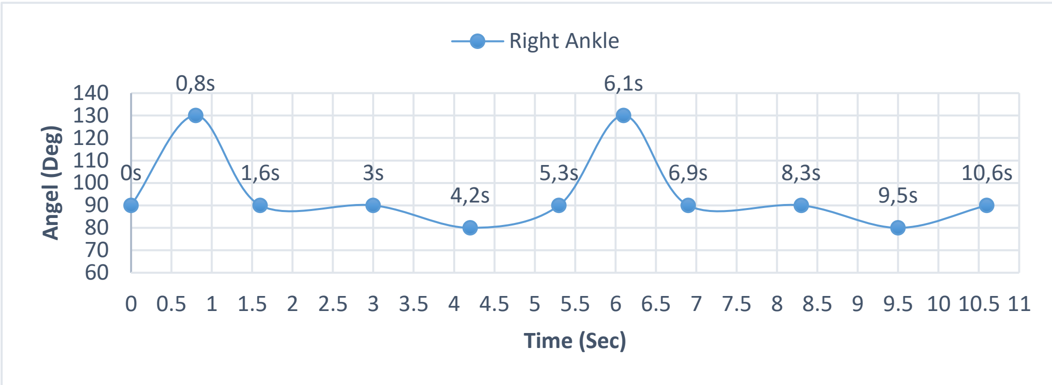


Figure 14: Right Ankle Trajectory Tracking Chart

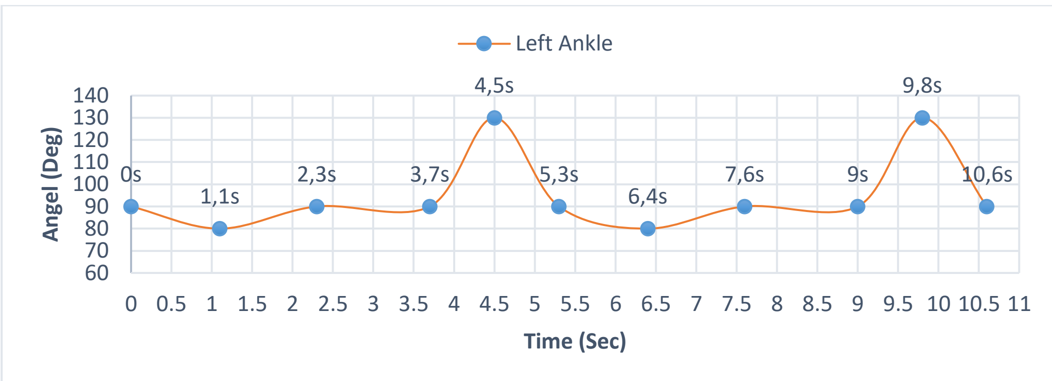


Figure 15: Left Ankle Trajectory Tracking Chart

The trial results in Figure 14 and Figure 15 show that the movement of the right ankle has an initial angle of 130º with a time of 0.8s (maneuver backwards). The movement of the left ankle has an initial angle of 80º with a time of 1.1s (forward maneuver). From the results of the trajectory chart, the movement of the right and left ankles is balanced, meaning that the designed system is functioning well with smooth movements.

Conclusion

Based on the simulation results/in the form of trajectory graphs and the analysis that has been carried out, the following conclusions are:

1. The trajectory graph of the movement of the thighs, knees and ankles shows that all movements run smoothly so that the tool designed can be used to treat stroke patients.
2. The use of stepper motors results in better and smoother movements for the movement of the thighs, knees and ankles. Also stepper motors can minimize delays and errors, so stepper motors are very good when used to move the thighs, knees and ankles of the designed system.
3. In this design, the voltage used has a range of 7-8 Volts, this is because the design uses 6 stepper motors. If using 5 volts, the stepper motor will lack voltage and cause the motor's movement to become stiff and weak. And if you use 12 volts, the stepper motor will overvoltage or overheat which causes the stepper motor to heat up quickly.
4. In general, the designed system produces accurate and precise movements when maneuvering.

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