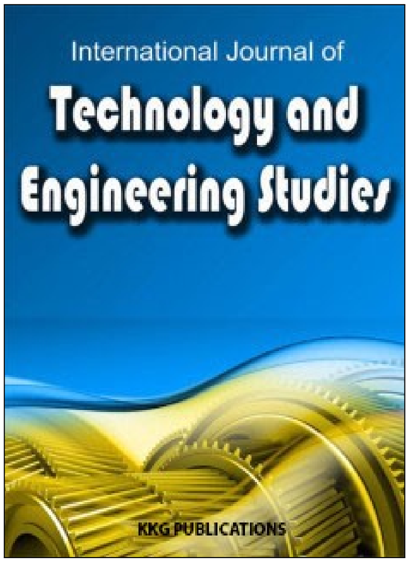

Biped Robot for Walking and Turning Motion Using Raspberry Pi and Arduino

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BIPED ROBOT FOR WALKING AND TURNING MOTION USING RASPBERRY PI AND ARDUINO

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Abstract. The purpose of this research is to investigate the link-up of two microcontrollers to control the biped robot whereby the dependence of hardware is decreased, and more concentration is given to software. The Biped Robot in this project has to be lightweight, small, and cheap. Arduino and Raspberry's Pi microcontrollers were used for this project. Implications of this study result in expanding the control or biped robots to depend on a single microcontroller and more to expand the dependence on software, thus reducing the cost of hardware. The performance of the Biped Robot was analyzed by dividing the motion of the Biped Robot into five parts: Standing Straight, Sway Right, Left Leg Forward, Sway Left, and Right Leg Forward. Next, the forward kinematics calculation of the Biped Robot was performed. Finally, the Biped Robot managed to walk and turn and the objective had been achieved.

INTRODUCTION

Biped robot is under the family of humanoid robot. Unlike normal robots, the body shape of the humanoid robots resembles the human body shape. There are several functions for this human body shape. The human body shape will help the humanoid robots to interact with human tools and environment. For example, the legs of the humanoid robots will help the robot to climb stairs like humans.

On the other hand, robots that use wheels for movement can only move on a flat surface. These robots will have difficulties going up the hill and will never be able to climb stairs and cross obstacles like humans. This will give these robots the ability to reach any location that is reachable to humans.

Next, humanoid robots assist for the experimental purposes. To learn more about the human's bipedal locomotion, biped robots can be used. Since biped robots have joints that almost replicate human's knees and ankles, physiotherapists can research about the way actual humans walk by using biped robots. Other than that, biped robots assist in the research of prosthetic legs. There are many amputees that are suffering in their lives. Those amputees are forced to live lives without even being able to perform normal daily tasks. The research in biped robots will lead to the inventions of better prosthetic legs for the amputees [1]. The purpose of this research is to further enhance the design of the biped robot from the software

section whereby in the past, researchers had always depended on a single microcontroller to control the entire design. This research allows the designed robot to be controlled by both the Raspberry Pi and Arduino. The Raspberry Pi is considered as the "Brain" of the design while the Arduino functions as the "Nervous System". The "Nervous System" literally stands for the movement of the servo motors which will be used for movement of the robot.

LITERATURE REVIEW

Before the implementation of this project, much research was done on the works of other experts in the field of Biped Robot. These researches were focused on stability of moving object, bipedal locomotion, properties of acrylic and servo motor control. All these researches were necessary to have clear picture on the concept of Biped Robot.

[2], carried out a research on model predictive control of a walking bipedal robot using online optimization. To solve the problem arising in the control system of a walking biped robot, the researcher employed approximate models and high performance algorithms. By using approximate model of the biped robot, the reactions during the movement could be found even before the fabrication of the biped robot starts. This method is highly cost-efficient. The thesis focused on the model predictive control of a walking bipedal robot, which is approximated by an inverted pendulum, using online optimization. [3], carried out a research on simulation and control of biped walking robots. The thesis covered simulation and control of biped walking

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robots. Simulations and experiments were performed with the robots Johnnie and Lola developed at the Institute of Applied Mechanics, Technische Universitat Munchen, Germany. The thesis also presents a hierarchical system for real-time walking control. Original aspects comprise of a trajectory generator based on spline collocation and a stabilizing controller based on fusion position/force control.

[4], carried out a research on bipedal walking for a full-sized humanoid robot utilizing sinusoidal feet trajectories and energy consumption. Development of a full-sized humanoid robot can be made simple as long as the bipedal walking method is easily designed. The designs present two versions of a new group of super lightweight (less than 13 kg), full-sized (taller than 1.4 m) humanoid robots called CHARLI-L (Cognitive Humanoid Autonomous Robot with Learning Intelligence Lightweight) and CHARLI-2. These robots have exclusive designs compared to other full-sized humanoid robots. CHARLI-L utilizes spring assisted parallel four-bar linkages with synchronized actuation to realize the goals of lightweight and cost efficiency. Based on the experience and lessons learned from CHARLI-L, CHARLI-2 uses gear train reduction mechanisms, rather than parallel four-bar linkages, to boost actuation torque at the joints while further reducing weight.

[5], carried out prototype design of an autonomous biped robot using Arduino. The purpose of developing this robot is to show amalgamation of all the three complicated but extremely interesting domains like Artificial Intelligence, Bipedal Structures and Sensors and also, to show the impact of open source projects like Arduino in implementation of embedded products and artificial intelligence.

[6], designed a biped robot platform based on real-time motion generation monitored by MATLAB adopted. MATLAB has been selected for this work due to the fact that it is one of the most widely used software and it is almost accessible in all educational institutions around the world. Thus, students can easily modify and improve the code provided. In this work, as an example, the dynamic motion of the robot is analyzed by measuring the Zero-Moment-Point (ZMP), which is a criterion that ensures the stability of the robot.

[7], designed a biped robot, using Arduino coding language. The coding language was part of the motion planning of the robot movement which needed ultrasonic sensors.

[8], designed a self-balancing robot using PLC and Raspberry Pi. The Raspberry Pi here is used as a Master Controller in providing constant PWM pulse for the motor, which is part of the main design. [9], designed a remote-controlled BRAT biped robot with the presence of both Arduino and Raspberry Pi. However, there was no direct interaction between both platforms as the Arduino was used to control the motor movements of the robot and Raspberry Pi was used to stream footage from the Raspberry Pi camera board.

METHOD AND MATERIALS

In this project, the legs of the biped move in a series of pre-programmed steps. The biped robot will continue walking until it reaches an obstacle. After reaching the obstacle, the legs of the robot will make a 180-degree turn. Once the turn has been made, the robot will continue walking in the opposite direction.

Forward Kinematics

Pulse Width Modulation (PWM) needs to be used to control the position of the servo motor shaft. A servo motor can rotate at an angle of 180 degrees. The control pin of the servo motor will be expecting a pulse every 20ms.

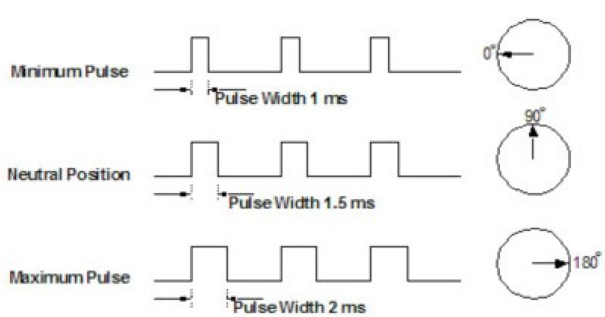

Fig. 1. Pulse width modulation

When a pulse with a width of 1ms is sent to the control pin, the servo motor shaft will be at the angular position of 0 degree.

For pulse widths of 1.5ms and 2.0ms, the angular position will be 90 degrees and 180 degrees respectively. 1ms is the minimum pulse and 2ms is the maximum pulse. Fig. 1 explains the process above [10], [11], [12].

Solidworks Design

Before preparing the actual hardware of the Biped Robot, it was designed using Solidworks software as shown in Fig. 2. To prepare the main assembly, several parts need to be prepared in advance. Those parts are known as small acrylic piece, big acrylic piece, servo motor and servo motor bracket. Once those parts had been prepared, they were assembled together to create the Biped Robot design [13].

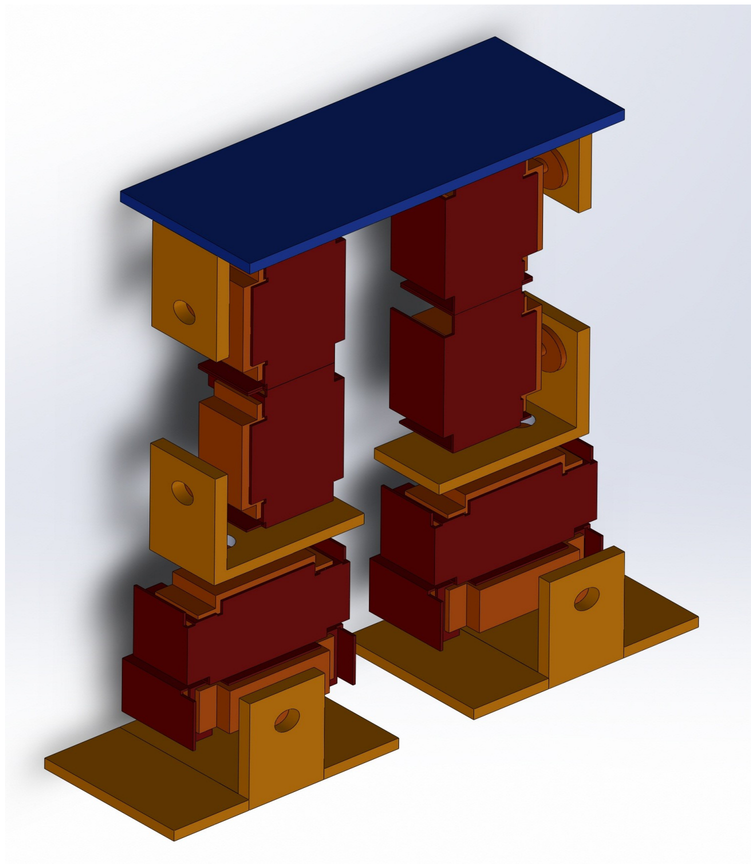

Fig. 2. Overall design of the Biped Robot

Fabrication of the Biped Robot

First, eight servo motors were bought for the Biped Robot. The type of servo motor that was bought was 1501MG RC Servo Motor. This servo motor operates at a torque of 15.5 kgcm when supplied with 4.8V and 17 kgcm and 6V. The servo motor comes with colour coded wires. Orange wire for PWM input, Red for positive voltage input and Brown for ground [10], [11]. The design dictates that the servo motors are the main building blocks for the Biped Robot. Therefore, all the other parts of the Biped Robot need to be attached around the servo motors. The problem with this concept is that holes

can't be drilled into the servo motors. Without the holes, extra parts like acrylic and servo motors can't be attached with the servo motors using screw and nut. Attaching the other parts using glue is also not desirable. It is because the glue will make the parts permanently attached to each other.

Even though servo motors are the main building blocks for the Biped Robot, acrylic was also used to create the body of the biped robot. Acrylic was chosen to form the base and top of the Biped Robot. The attachment between the servo motors was also achieved using the acrylic.

Microcontrollers

A thorough research was done on the programming language for Raspberry Pi microcontroller [14], [15] as shown in Fig. 3. The detailed knowledge of Python programming language will assist in the full utilization of the Raspberry Pi. Research was also done on the utilization of Arduino Leonardo microcontroller. For Arduino, C language was studied.

Fig. 3. Raspberry Pi

In this project, Arduino Leonardo as shown in Fig. 4 was used to control the servo motors and Raspberry Pi was used to control the ultrasonic range finder. The ultrasonic sensor finds the position of the obstacle and sends the distance information to the Raspberry Pi microcontroller. Then, Raspberry Pi will send the instruction to Arduino Leonardo microcontroller. Based on the information received from Raspberry Pi, Arduino Leonardo will control the orientation of the servo motors.

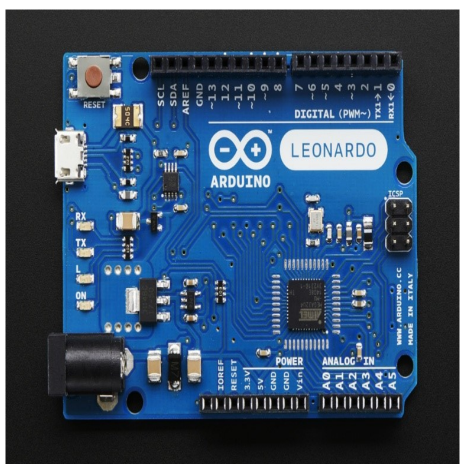

Fig. 4. Arduino Leonardo

Programming of the Biped Robot

The rotation of the servo motors was controlled by Arduino microcontroller. This microcontroller was programmed using C language. The servo motors will rotate according to the codes in the Arduino microcontroller. A sensor was fixed to the Biped Robot. This sensor is an SN-HC-SR04 Ultrasonic Range Sensor. This sensor is controlled by Raspberry Pi microcontroller. The function of the sensor is to measure the distance of the obstacle at the front and send the info to the Raspberry Pi. After processing this info, the Raspberry Pi will send out an instruction to the Arduino Leonardo microcontroller.

The programming of the Raspberry Pi [14], [15] was done using Python computer language as shown in Fig. 5. Python is one of the easiest to understand among the various types of computer languages. The programming was done using simple English words like ‘setmode’ and ‘print’. The important parts of the python codes used in the Biped Robot are explained in this section.

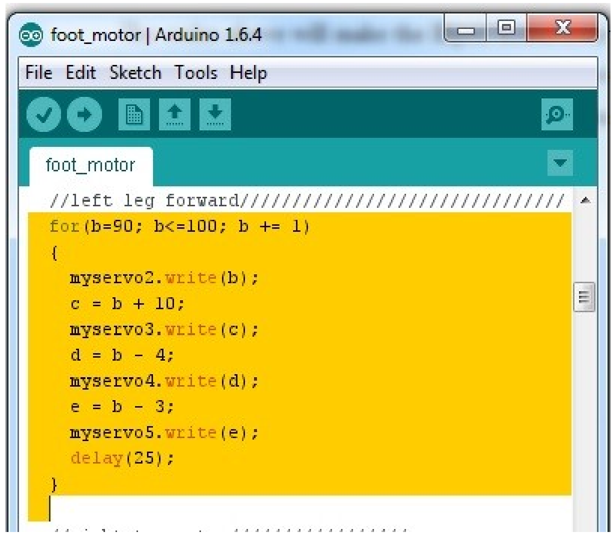

Fig. 5. Arduino codes

Wiring of the Biped Robot

Five pins from the Raspberry Pi will be connected to the control board as shown in Fig. 6. The Raspberry Pi will be located at the left side of the control board. Pin 15 of the Raspberry Pi will be connected to the input pin of the Arduino. Pin 15 acts as a digital output pin. Pin 2 of the Raspberry Pi will be connected to the Vcc pin of the ultrasonic sensor. On the Raspberry Pi, Pin 2 is the 5V power supply. Pin 6 of the Raspberry Pi will be connected to the ground. Pin 7 of the Raspberry Pi will be connected to the Trigger pin of the ultrasonic sensor. Pin 7 acts as a digital output pin. Pin 13 of the Raspberry Pi will be connected to Echo pin of the ultrasonic sensor through a voltage divider. The function of the voltage divider is to control the voltage that enters pin 7. Without the voltage divider, 5V will enter pin 7. This much of voltage will damage the Raspberry Pi. With the use of voltage divider, only 3V will enter the pin 7 of Raspberry Pi [14, 15].

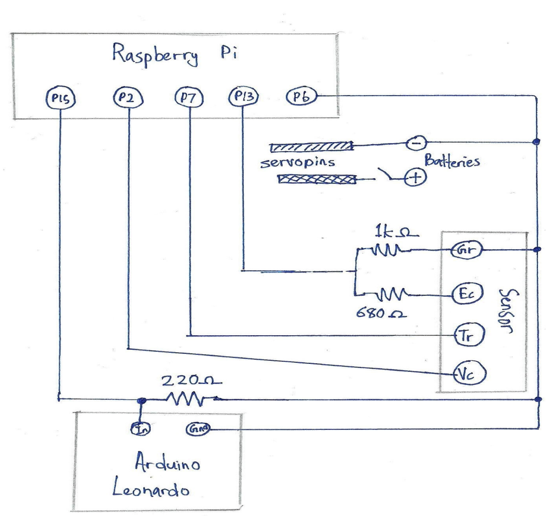

Fig. 6. Wiring diagram

After the start of the program, as shown in Fig. 7, all the variables will be declared. The distance of the obstacle will be obtained from the Raspberry Pi. Based on this information, the Biped Robot will make the next decision. If the distance is more than 25cm, the robot will continue walking. While walking, the Raspberry Pi will continuously check whether the distance is more than 25cm. Once the distance drops to below 25cm, the robot will start turning to the right. After the turning sequence has ended, the Raspberry Pi will check again whether the distance is more than 25cm.

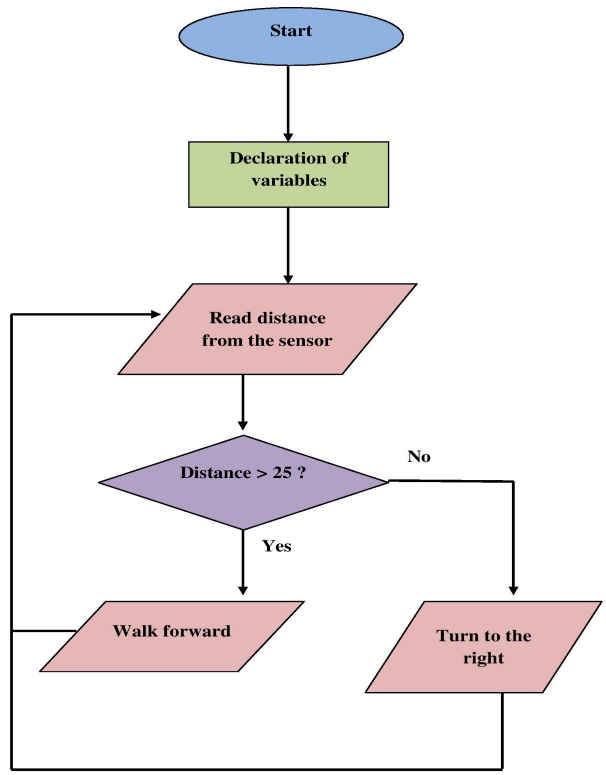

Fig. 7. Programming flow chart

Communication between Raspberry Pi and Arduino Leonardo

One of the key elements of this project is the communication between Arduino Leonardo and Raspberry Pi. The task of controlling the Biped Robot is shared between Arduino Leonardo and Raspberry Pi. The servo motors which are outputs of the Biped Robot are controlled by Arduino Leonardo. The ultrasonic sensor which is the input of the Biped Robot is controlled by Raspberry Pi.

This communication is achieved by using digital output pin of Raspberry Pi and digital input pin of Arduino Leonardo. The Arduino Leonardo is programmed in a way so that when detecting a digital input in one of the pins, the signal will direct the Biped Robot to turn right. On the other hand, the Raspberry Pi is programmed to send out a digital output when the distance of the obstacle gets closer than 25cm [14], [15].

The digital output pin of Raspberry Pi is connected to digital input pin of Arduino Leonardo as though a push button is connected to an input pin. When the distance of the obstacle becomes less than 25 cm and the Raspberry Pi sends out the digital signal, the Biped Robot will turn to the right.

With the usage of two microcontrollers, the burden on the Arduino Leonardo had been reduced. The Arduino already has the task of controlling seven servo motors at one time. Therefore, the Raspberry Pi can take care of monitoring the obstacle distance. The usage of two microcontrollers also helps for troubleshooting. When one microcontroller is having a problem, the codes of that microcontroller can be edited without affecting the other microcontroller. Another factor is that Arduino Leonardo is much efficient in controlling multiple servo motors than Raspberry Pi.

RESULTS & DISCUSSION

For the walking motion of the robot, it needs to repeatedly perform several types of movements. The types of movements are straight standing, left leg forward, and right leg forward as shown in Figure 9, 10, and 11. These steps need to be performed in the right order for the biped robot to walk correctly. On each of these movements, the balance of the biped robot will be different. Even though the balance level will be different, each movement will make sure that the biped robot will not topple over.

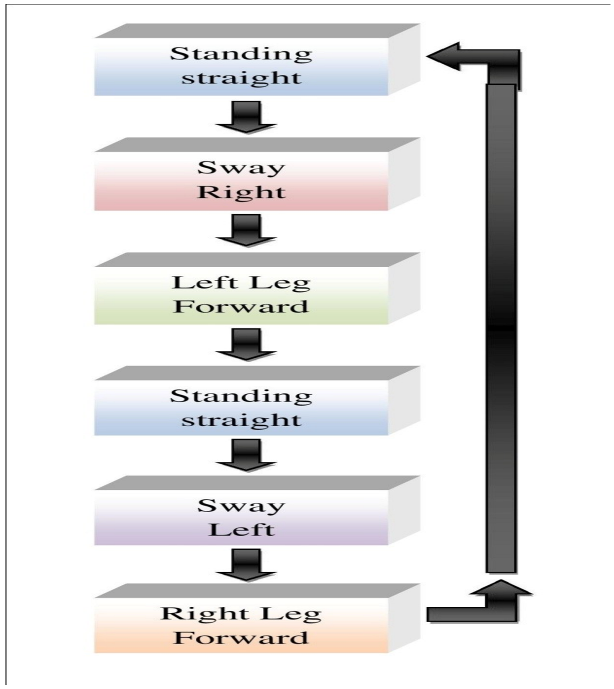

Fig. 8. Walking steps flowchart

Fig. 8 shows the sequence of walking steps that the robot must follow to walk forward. These walking steps are continuously repeated until an obstacle is faced. The timing gaps between each step are also important. If the timing is not correct, the Biped Robot will fall down while walking.

When the robot is in the standing straight position as shown in Fig. 9, all the servo motors are at initial orientation. This position is when the robot has the highest amount of stability.

During the sway right position, the whole body of the Biped Robot is tilted to the right side. The foot motor on the right side is responsible for this movement. When the axis of the right foot motor rotates 15 degrees clockwise, the biped robot sways to the right side. At this position, the right foot is on the ground but the left foot is slightly lifted above the ground. The lifting of the left foot is essential because for the next movement the left leg needs to move forward. If both feet are on the ground, the left leg can't be brought forward. Even though the Biped Robot is tilted to the right side, there is still enough stability to avoid the Biped Robot from falling to the right side.

When the left leg is forward, as shown in Fig. 10, four servo motors are responsible for this motion. They are left hip motor, left knee motor, right hip motor and right knee motor. All axes of the four servo motors will be rotated 10 degrees anti-clockwise to achieve this movement. The left leg will be moved forward and right leg will be moved backwards. The overall motion of the Biped Robot will be forward. From here, the Biped Robot will go back to standing straight position before continuing to other movements.

During the sway left position, the whole body of the Biped Robot is tilted to the left side. The foot motor on the left side is responsible for this movement. When the axis of the left foot motor rotates 15 degrees anti-clockwise, the biped robot sways to the left side. At this position, the left foot is on the ground but the right foot is slightly lifted above the ground. The lifting of the right foot is essential because for the next movement the right leg needs to move forward. If both feet are on the ground, the right leg can't be brought forward. Even though the Biped Robot is tilted to the left side, there is still enough stability to avoid the Biped Robot from falling to the left side.

When the right leg is forward, as shown in Fig. 11, four servo motors are responsible for this motion. They are right hip motor, right knee motor, left hip motor and left knee motor. All axes of the four servo motors will be rotated 10 degrees clockwise to achieve this movement. The right leg will be moved forward and left leg will be moved backwards. The overall motion of the Biped Robot will be forward. From here, the Biped Robot will go back to standing straight position before continuing to other movements.

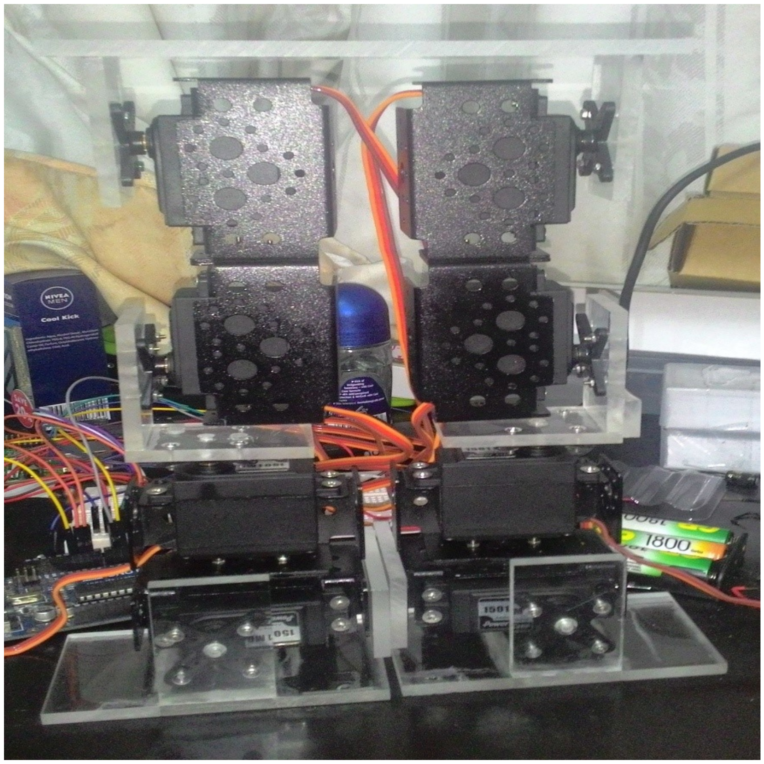

Fig. 9. Standing straight

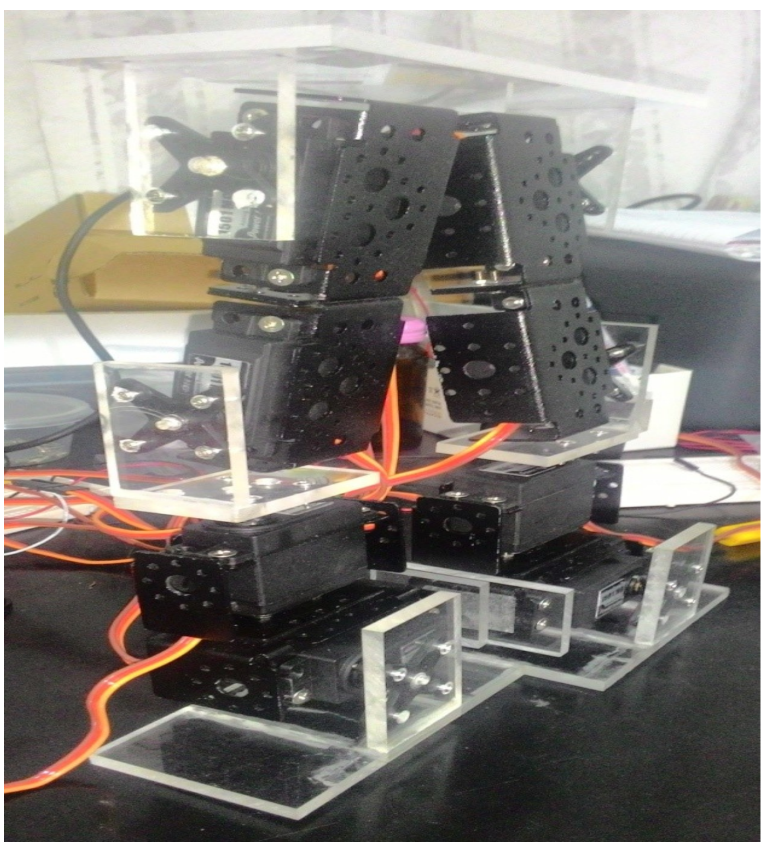

Fig. 10. Left leg forward

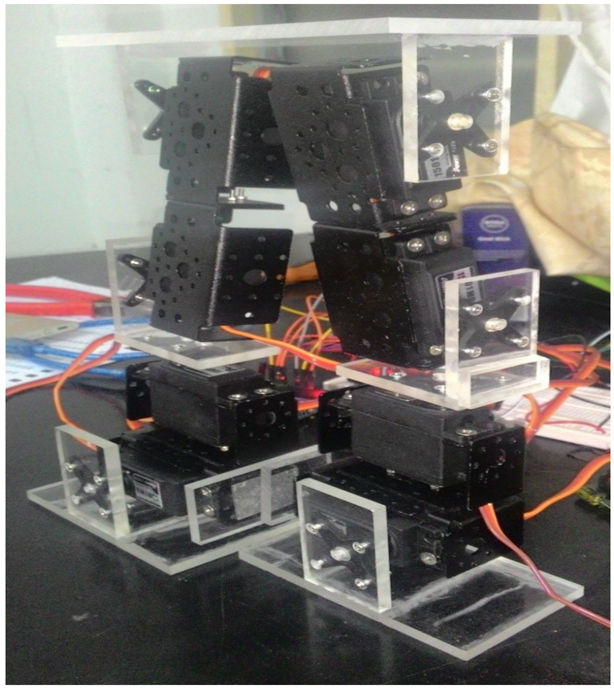

Fig. 11. Right leg forward

CONCLUSION AND RECOMMENDATIONS

At the beginning of the project, the objective was to design and construct a Biped Robot structure with certain number of joints for walking and turning motion. Using the Arduino microcontroller and servo motors, the objective had been achieved. The Biped Robot managed to achieve two-legged locomotion. Next, the performance analysis of the Biped Robot motion had been made. Furthermore, the forward kinematics calculation of the Biped Robot had been made. The analysis and calculation prove that Arduino microcontroller is the best controller for the Biped Robot. Apart from those three objectives, another achievement had been made. Arduino and Raspberry have managed to work together. Using the digital input and output pins, the two microcontrollers managed to communicate between them.

This Biped Robot can only walk on flat surface. On uneven surface, the Biped Robot cant walk. Future research should be made to create a Biped Robot that can walk on uneven surface and climb stairs. This type of Biped Robot technology could be integrated into the prosthetic leg technology. In this project, the communication between the two microcontrollers was made possible by connecting the digital I/O pins. Even though the communication was good in this method, the two microcontrollers need to be always connected by a connecting wire. The two microcontrollers can't be fixed too far from each other. In the future, further research should be made to enable the microcontrollers communicate with each other using wireless connection. Through this method, even two separate robots can communicate remotely with each other. speculate on its rapid development in the near future.

Declaration of Conflicting Interests

There are no associated conflicts pf interest.

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