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Bipedal Walking Robot - A Developmental Design

Sujan Warnakulasooriya[a], Amin Bagheri[a], Nathan Sherburn[b], Madhavan Shanmugavel[c,*]

[a]*Students,Mechatronics , Monash University, Sunway campus, Malaysia, Jalan Lagoon Seletan, Bandar Sunway, Selengor, 46150, Malaysia*
[b]*Student,Mechatronics, Monash University, Clayton campus, Australia*
[c]*Dr Madhavan Shanmugavel, Lecturer, Mechatronics, School of Engineering, Monash University, Sunway campus, Jalan Lagoon Seletan, Bandar Sunway, Selangor, 46150.*

Abstract

This paper presents developmental design of a simple bipedal walking robot. The robot replicates the walking style of a human particularly walking upright. The robot is built with light-weight Aluminium sheets which act as the structural members and also housing the servos. A controller using EyeBot produces intelligent commands to the servos for walking and kicking. The robot is controlled in open loop utilizing lateral balancing feature for maintaining walking and kicking. This work enables us to realize an insight into design and development of a mechatronic system using the concept of synergetic unison of electronics, mechanical, and computation engineering fields.

Keywords: Bipedal robot; Mechatronics; Walking robot; EyeBot

Nomenclature

m	mass of the robot
l	distance from mass center to joint
c	time taken for motor to bring center of mass directly above it
t	time

Greek symbols

τ	torque of servo motor

Subscripts

j	index

* Corresponding author. Tel.: +603-5514 6250 ; fax: +603-5514 6207 .
E-mail address: madhavan.shanmugavel@monash.edu

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1. Introduction

Walking robot is one of the fascinating and hot topics of research by scientists and engineers. There are different types of robots available based on morphology, functions, applications, locomotion. Each type has its own static and dynamic models. There has been a great deal of interest in legged robots primarily due to their advantages in dealing with certain types of terrain when compared to wheeled robots. Essentially, the flexibility of animal and human legs with multi-links provides a compelling advantages in climbing stairs, for example. It can be said that biped robots are at home in a human environment. But they are the hardest and most challenging to develop and construct. There are many factors contributing this. However, one of the important factors is difficulty in balancing the weight of the robot during walking, running, kicking and other simillar tasks. However the recent advancements in technology, particularly electronics provide relative ease in building the biped robots. There are popular bipedal walking robots available, notably Honda's Asimo [1], Sony's Qrio [2]. A simple bipedal robot called Clyon was developed by Florida University [3].

The current state of the art technology requires that biped robots not only walk in a straight line or simply follow a set of commands produced by static code but rather react in real time to external forces and stimuli. For example, a biped robot may be walking forward and a well programmed closed loop system will be able to protect the robot from falling over when pushed by using sensory information. The robot will need to be able to deal with much more complex stimuli such as a hard push where the only way to maintain stability would be to deviate from its intended course to gain enough of a reaction force to steady itself. The bipedal robots have been designed to take on many different tasks from discerning between walls and corners [4] to reducing the impact force as a foot lands on the ground [5]. There are many different forms of bipedal robots with respect to mechanical design as well as programming methodologies and techniques as evidenced in the references available in [5]. Additionally, many different methods for movement are also being explored (often with a focus on creating natural, continuous movement) [6]. This provides a very wide scope for areas of research including, controlling movement and force, integrating sensory information and creating apparently natural, human like robots. Interestingly, there is a psychological-engineering relationship that comes from the fact that humans prefer to deal with bipedal humanoids which they can relate to [6].

The biped robots are naturally unstable [7], a great deal of effort needs to be spent on ensuring that the control systems behind the brains of the movement are efficient and robust. Safety is also a very big concern particularly when it comes to human-robot interactions or, when robots and humans are occupying the same space. These distinct differences make the design of control systems for biped robots very different from those widely used to deal with classical robots and machinery. One of the basic and important parameter to be met in building a walking robot is balance of mass with respect to its center of gravity. Balancing is similar to mimicking the human while walking. The components for walking lie below the hip and the motion is initiated by activating the joints. There for the structure above the hip can be considered as payload for a simple walking robot.

This paper discusses building a simple bipedal walking robot capable of walking and kicking, while maintains its body balanced. The process of design and developmental activities and the hurdles experienced through various stages are discussed in section 2. The hurdles would include choosing the material and thickness of material, tolerance for assembly, selection of servos for joint actuation and limitations on movements of servo motors and finally the problem with drawing high current by the servos. The section 2.2 discusses selection of servos for joint actuation and limit in movements of servo and the solving the problem of drawing high current by the servos. The section 3 discusses the simple pseudo code of programming sequence for walking and kicking. Finally, the paper ends with conclusion in section 4.

2. Design and development

The design focusses primarily on walking movement using servos. The initial design for the walker featured all servos with a parallel axis of rotation. But, this led to serious problems due to the lack of lateral balance control. An ambitious design using ten separate servo motors was also considered so that the number of degrees of freedom would increase which would allow much more human like movement. This idea was deemed too difficult due to both space and cost requirements. Finally, it is decided to strike a balance between functionality, flexibility and cost. So, a design goal is set to make the robot which is light weight and able to walk while keep the body balanced. The final design

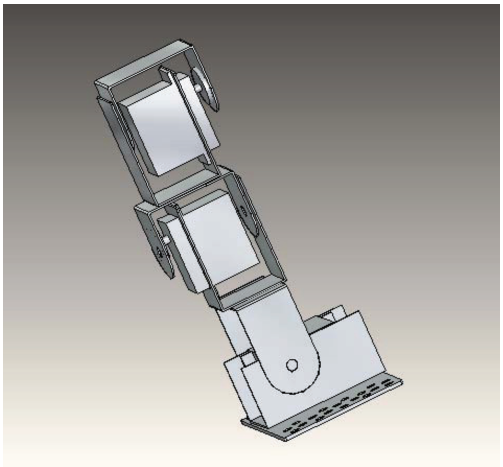

Fig. 1. Leg Assembly

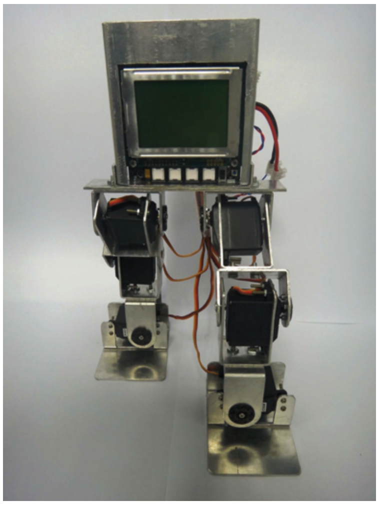

Fig. 2. Walking Robot

of the biped robot consist of two legs with three servos each, and a EyeBot controller [8] which is mounted on the hip. The servos provide an adequate amount of flexibility while walking. This resulted in minimum functionality for walking with the walk sequence being relatively smooth and flexible.

With the final design, two main functions: walking and kicking are considered. Hence only the structures below the hips are considered for design and control. The structure above the hip is used to house the controller: EyeBot. The EyeBot act as the brain of the robot and also the payload to the robot. The motion of the robot is coordinated by the EyeBot. The main structure is built from Aluminium sheet of 2 mm thickness is used. This gives the robot light weight and provides enough strength, flexibility. The sheet is made into of different size of brackets to house the servo motors in high precision. The batteries weigh 0.3 kg and the structure weigh 1.11 kg. Understanding stability control for successful motion is a key component of robot design. Solid Edge was used for the design. Centre of mass of the robot is one of the important key parameter for balanced motion. This is a function of weight distribution, height of the robot and the distance between the legs.

The most significant dynamic equation for the system was that which governed the ankle joints. The knee and hip joint's dynamic equations would be similar but not as critical to the design of the robot as they do not undergo the same magnitude of torque shown in Equation (1).

$$\tau(t) = ml - \frac{tml}{c} \tag{1}$$

where m is the mass of the robot, l is the distance from mass center to joint (tangential to direction of gravity), τ is the torque of the servo motor at ankle joints, c is the time taken for motor to bring center of mass directly above it, and t is the time.

Angular motion is another important parameter to balance and counter-balance the walking and kicking motions. The robot is a six servo biped walker featuring three degrees of freedoms per leg (refer Fig. 1). The servos were placed on the hip, knee and ankle joints to get leg configuration similar to human. The servos on hip and knee have the same axis of rotation (perpendicular to the robot's side surface) while the servo on ankle joint moves the robot right and left. The ankle joint was chosen to rotate in this way in order to balance the robot's centre of gravity from side to side while the hip and knee joints were designed to balance the robot about the forward and backward directions. The algorithmic implementation of speed of the joint movements are controlled by a parabola using the Equation (2):

$$y[j] = (float)(j - steps/2)(j - steps/2) + steps(10) \tag{2}$$

In Equation (2), y is a matrix of wait time values. That is, times that the servo will be told to pause in between every change in angle. The $steps$ value is the number of steps between the initial and final position; more steps means

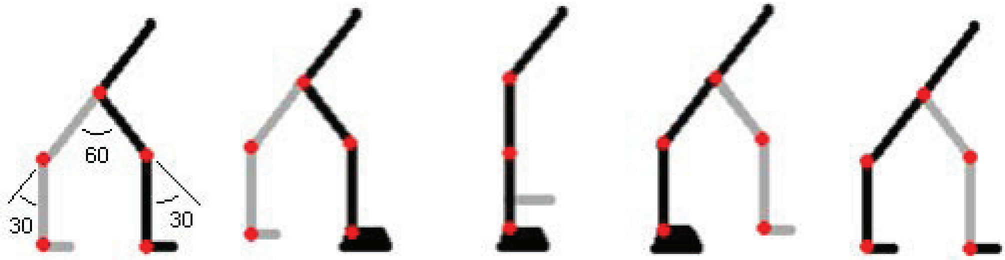

Fig. 3. Walking Motion

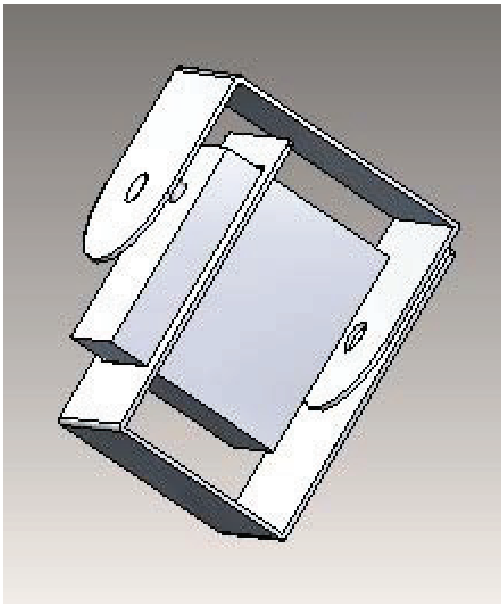

Fig. 4. Knee/Hip Joint

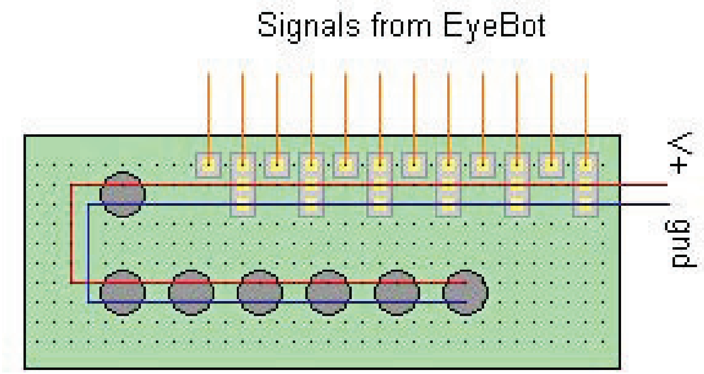

Fig. 5. Power Circuitry

a smoother movement. The final term, $steps(10)$, in this equation raises the turning point of the parabola off the j axis so that every step will have some amount of wait time.

The initial design used 6 high-torque servos and resulted in a quick reaction and fast motion. However, these servos draw more current from the battery lead to significant reduction in battery life as well as current dips when moving. A set of normal servos were used to overcome this problem. Each servo was calibrated for angular movement, and minimum and maximum 80 angular movements of each joint was programmed in EyeBot. The maximum angle of 28.62 degrees and the minimum of 6.66 degrees were found out assuming initial angle is zero. By calculations, the maximum speed was found to be 120 m/hour and the distance per step, 0.15 m/s/step. The sequence of walking motion is depicted in Fig. 3.

2.1. Hardware and Assembly

Initially, 1 mm Aluminium sheet bracket was used. But it was observed that the bracket is not strong enough. Hence, the bracket was fabricated using a 2 mm Aluminium sheet. The tolerance plays a crucial role in deciding further assembly. As shown in Fig. 4, if dimensions of C bracket and Servo C bracket do not match each other. This made the assembly difficult and also cause relative rotation. Therefore, all the parts were designed and made with tolerance of 1 mm and motion of joints were smoother. Bolt and nuts were used to join the parts together which provide a rigid structure to the robot.

2.2. Power circuit

EyeBot was interfaced with the servo motors to rotate the joints. But the servos were rated high torque approximately 20 kg/cm. This produced a significant counter electromagnetic on the EyeBot. Also, they draw a substantial amount of current from the EyeBot. When six servos working simultaneously the proportion of current drawn is too large for EyeBot to handle. This caused a intermittent shut down of the EyeBot often. Sometimes, the EyeBot stop functioning during operation and sometimes it even got restarted.

The problem was identified as the back emf generated by the servo motors and current drawn. As a standard solution, capacitors were used in parallel to counter the back EMF shown in Fig. 5. Thus a capacitor bank of seven capacitors each 1000μF was connected in parallel with the power source input voltage and ground to smoothen the flow of current out of the battery. However, this did not solve the problem fully. The problem was completely eliminated by powering the servos directly but controlled through the EyeBot. A power circuit was built with the Pulse Width Modulation (PWM) signal from the EyeBot 5 control the robot motion solved the problem.

3. Programming

The robot is programmed for walking and kicking in open loop. The following are the pseudocode used for programming.

1. Move robot into starting position
2. Wait for "Go" button to be pressed
3. Read servo values for next position and read value for speed
4. Move servos from current values to new values
5. Repeat step 4 for each of the six sets of servo angles until stopped
6. Once stopped, power down and take care of maintenance operations (i.e. release servo handles etc.)

As mentioned in section 2.1, the EyeBot is programmed with set of rotation for each servo for walking. The initial position of the robot was assumed to have the first set of the sequence of servo operation. That is the robot begin to walk from the second set of sequence of servo rotations. The walking or kicking is triggered by pressing button to execute the walking cycle. This was achieved through a simple *key wait* function. Once the walking motion is triggered and the *Go* button is pressed, the program reads in an array of six angles, each one for one servo motor. A function routine through the angle of rotations of the servo and find the largest in magnitude. The maximum value of rotation is used to calculate the largest time required for movement, and this value is used in a *for loop* that will iterate the servos from one angle through to another.

According to [9], the servos take 0.2 seconds to move 60 degrees. As such, the time taken to move the servos can be calculated off the largest magnitude value obtained previously. In addition to the angular input, the function routine takes an additional argument: desired time of movement of servo. The time difference between time taken for the servos and the desired time needs to be added to the movement in order to meet the total time of the movement. This is a wait time and is not added as one block in the middle of the movement. This time is split equal the largest angle magnitude as calculated before. These time segments are set to be long at the beginning, shorter in the middle and then longer as the movement comes to a rest. That is, the robots movements will start slowly before picking up speed as the movement continues and then finishing the action slowly again. A parabolic wait time segment is used for mimicking the natural movement of legs begin slowly backwards gaining momentum towards middle and ends stamp on the ground quickly.

As can be seen in the Fig. 6, the values of these split times on the parabola begins with large value when x is 0 and then progressively get smaller until x is 1 at which point they begin to get larger again. This is how the time values are calculated. After the values had been read off the parabola, their sum was much larger than the number of seconds we would be requiring the robot to wait for. In order to rectify this, the values were multiplied by a scaling factor.

Once all the wait times had been calculated, a *for loop* was used to move the servos step by step towards their final angles which were also accepted as an array of six angles by the function. This function was then called again for

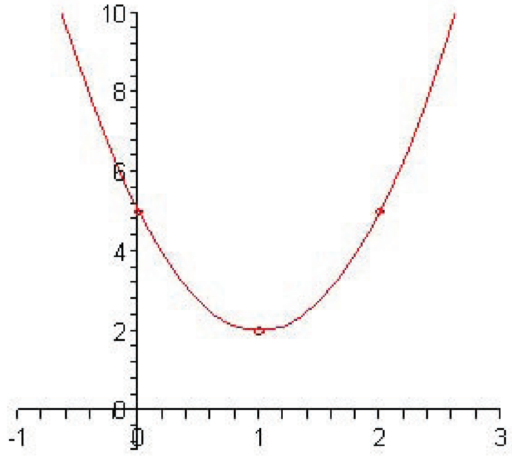

Fig. 6. Wait times

the next set of angles until the last angles of the sequence had been completed at which point, a *while loop* repeated the entire sequence. This loop was infinite until broken by a push button input which would shut down the program, release servo handles and refresh the screen. The programming for robot's kicking action was much easier implement compared to that of the walk cycle. The original code for walking was modified to produce a different sequence of movements whereby one leg was raised back and then quickly thrown forward whilst being offset.

4. Conclusions

A developmental design of a bipedal articulating robot was realized using mechatronics principle of fusion of technologies and engineering. Walking and kicking are the functions that the robot is able to perform while fully maintains its balance. Building this bipedal robot helped us to understand the mechatronics concept of design, function, programming, and its implementation. This simple concept model was build using aluminium sheet, Eyebot controller and servo motors. Practical problems encountered during the project were presented. The robot was designed and controlled using a simple mathematical model which aids movement of the robot more human like. The future work will be focussed on implementing closed loop balancing system for the robot with ineritial measurement devices: accelerometer and gyroscope.

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