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Procedia Engineering 41 (2012) 8 – 14

Engineering Procedia

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International Symposium on Robotics and Intelligent Sensors 2012 (IRIS 2012)

The Locomotion of Bipedal Walking Robot with Six Degree of Freedom

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Abstract

A bipedal walking robot is a type of humanoid robot which mimics like human being and can be programmed to perform some tasks as required. In this paper, a prototype robot is built to provide a test bed for the physical locomotion that is used to control the robot movements such as moving forward, backward, turn left and right, get up from front and back, rollover from left and right. The paper also describes how the bipedal robot is built; how the movement steps are obtained and the detection when it falls down. The movement of the robot also can be controlled by using a remote controller. This bipedal robot can assist human to carry out the tasks or activities in hazardous environment. This could eliminate human's risk of injury or life casualty.

Keywords: Bipedal Robot, Accelerometer; Center of Mass, Self-Balancing

Nomenclature

$\vec{P}CoM$ = Position of Com of the robot

m_i = mass of *i*th part of the robot

$\vec{P}_i$ = Position of the center of mass of part *i* of the robot

$\vec{g}$ = gravititional acceleration vector $[0\ 0\ -9.82]^T$

$\vec{P}GCoM$ = Position of the ground projection of the CoM

1. Introduction

As of the 21st century, from automated industrial lines to simple daily use of electronics devices, the mobile robot has become a hobby for those robot fanatics. Robots have been designed by the hobbyists for fun games soccer robot [1], sumo robot [2], etc. Robots have been also of much help in the industries and it was invented with the purpose of helping human beings. There are many types of robot such as hexapod [3-5], quadrupeds [6-8], wheeled robots [9-11], etc.

The bipedal walking robot imitate human characteristics was selected to simulate the human movements. Bipedal robots will operate in a human environment with much greater efficiency than any other type of robot yet devised [12]. It is capable to complete tasks which are too difficult or dangerous for human. Such dangerous applications are in the environmental conditions like fire rescue operations, toxic gases or chemicals, explosives such as land mines or assist humans in complicated tasks which they are unable to perform.

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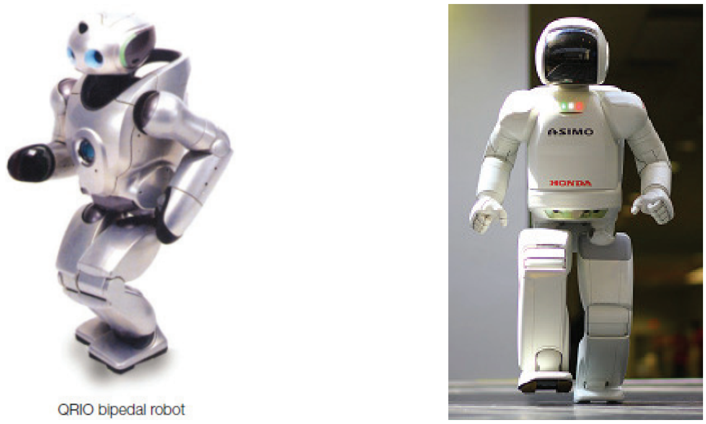
doi:10.1016/j.proeng.2012.07.136

There are many bipedal walking robots that have been created in the last 20 years. The recent developments are Sony Qrio [13] and Honda Asimo [14] as shown in Fig. 1.

2. Biped Specification

There are six TowerPro SG-5010 servo motors (Operating Speed: 0.20sec/60˚ (4.8V), 0.16sec/60˚ (6.0V), Stall Torque: 5.2kg*cm (4.8V), 6.5kg*cm (6.0V), Rotational Range: 180˚) used in the project for this bipedal robot, featuring three degrees of freedom (DOF) on each leg. The robot structure is made from aluminium sheet brackets with 1 mm thickness. Hardware fasteners such as standoff (M3 size), screws and nuts are used to support and assembled all the components together including the electrical hardware.

Acceleration sensor (±3g), two axes with the sensitivity (440 mV/g) to detect the robot when fall down and able to get up automatically. The robot locomotion can move forward, backward, turn left and right, get up from front and back, rollover from left and right. The robot power supplied by a 7.4VDC Lithium Polymer (Li-Po) battery pack. A remote controller is to control the robot movements with the power supply of a 9VDC alkaline battery.



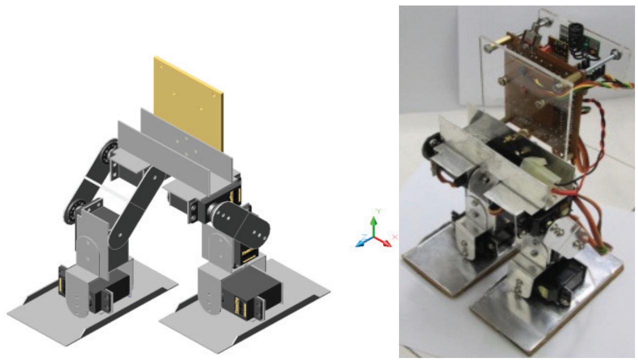
(a) (b)

Fig. 1. (a).Sony Qrio [2] and (b).Honda Asimo [3].

3. Mechanical Hardware Structure

Bracket design is easy to dismantle part by part; it does not require dismantling the whole subsystem to check the faulty or misalignment components. Time consumption has been reduced during the adjustment on the servo horn with the servo motor positioning offset.

The mechanical design drawings have been created as in three dimension (3D) mode by using the AutoCAD software. The process of shaping the brackets basically involved cutting, bending, drilling, and filing in order to form the shape of each component. The completed bipedal robot design outlook and the complete physical assembled mechanical structure are shown in Fig. 2.



(a) (b)

Fig. 2. (a). Bipedal robot design outlook and (b). completed mechanical and electronics structure.

The bipedal robot locomotion is different from human, it perform the leg movements according to the sequence of the servo motors and positioning accurately in order to walk stably, whereas human is flexible in any angle with any speed desired [15]. Table 1 shows the human working angle and the manually physical tested bipedal walking robot working angle.

Table 1. Human versus bipedal walking robot working angle range.

Joints	Locomotion	Human Working Angle [15]	Bipedal Walking Robot Working Angle
Hip	Yaw	-45° to 45°	NA
	Roll	-45° to 20°	NA
	Pitch	-125° to 15°	-45° to 90°
Knee	Pitch	-0° to 130°	-90° to 90°
Ankle	Pitch	-45° to 20°	NA
	Roll	-20° to 30°	-75° to 45°

4. Center of Mass (CoM) and Ground Projection Center of Mass (GCoM)

4.1. Center of Mass (CoM)

The center gravitational forces which acts on all parts of the robot. According to Wollherr [16], the summation of all the forces to a single virtue force acting at the center of mass (CoM) of the robot which can be calculated as follow [16]:

$$\vec{P}CoM = \frac{\sum_i m_i \vec{P}_i}{\sum_i m_i} \tag{1}$$

4.2. Ground Projection of Mass (GCoM)

The Ground Projection Center of Mass (GCoM) is the center of mass on the ground plane acting upon to the Center of Mass (CoM). It can be calculated as follow [16]:

$$\sum_i \left[\left(\vec{P}GCoM - \vec{P}_i \right) \times m_i \vec{g} \right] = 0 \tag{2}$$

The Center of Mass (CoM) and the Ground Projection of Mass acting on the bipedal walking robot are shown in Fig. 3.

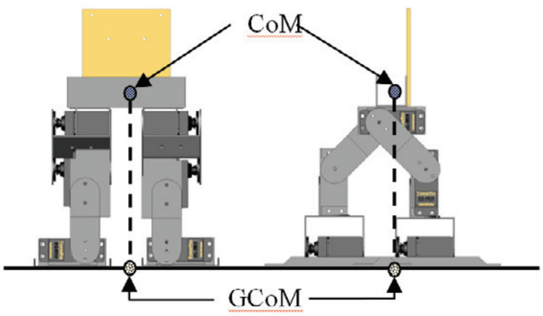


Fig. 3. The Center of Mass (CoM) and Ground Projection Center of Mass (GCoM) of the bipedal walking robot.

5. Electronic Hardware Structure

5.1 The Operational Circuit

It is the main circuit board that being used to operate the robot movements. The circuit board is attached onto the back of the robot structure. The Microchip PIC16F877A microcontroller is the central processing unit that interfaces and communicates with other devices such as the servo motor (TowerPro SG-5010), decoder (Princeton PT2272), accelerometer sensor (Freescale MMA7341L) and a radio frequency receiver module (Cytron RF-RX-315).

5.2. The Accelerometer Sensor Circuit

The accelerometer sensor circuit is applied on this robot to sense the gravitational force, g. The sensor is typically requires a supply voltage of 3.3 V thus a voltage regulator is needed to step down the voltage from the main circuit board from 5 V to 3.3 V. The accelerometer sensor used is manufactured by Freescale Semiconductor which has the characteristic of low power and low profile capacitive micro-machined accelerometer. This sensor consists of signal conditioning, self-test, single pole low pass filter, temperature compensation, and optional g-select for 2 sensitivities (±3g and ±11g). In this circuit, the sensitivity of ±3g is selected due to the smaller sensitivity range but yet it could provide better responsive feedback when the robot falls down.

5.3. The Remote Controller Circuit

The remote controller is used to transmit the data from one location to another. It is used to request the movements of the servo motor from the microcontroller after the data has been transmitted. There are six push button switches in total to control the robot movements. The switches are labeled as forward, backward, left, right, kick and getup from front accordingly. This remote controller circuit consists of two main components which are the transmitter module (Cytron RF-TX-315) and the encoder (Princeton PT2262). The encoder is used to reduce the code collision and for the security purposes. Whereas, the transmitter is used to transmit the data bit with the set of address at the encoder and transmit through the air. The finish assembled of remote controller is shown in Fig. 4 below.

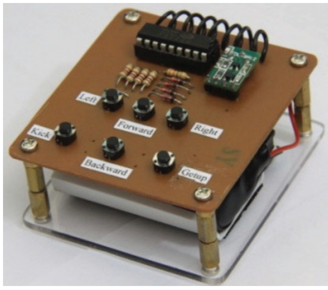


Fig. 4. Remote controller.

6. Software Development

The software (PicBasic Pro Compiler) of the program are used to execute the activities to perform its task, such activities are requesting the robot to move forward, backward, left, right, kick, rollover from left and right, get up from front and back. The overall operational flow chart is shown in Fig. 5 for the program activities.

7. Results and Discussions

7.1 Acceleration Sensor

The physical data test result of Z-axis and Y-axis is tabulated in Table. 2. The Y-axis and Z-axis voltages are measured by using digital multi-meter. The Z-axis is used to detect the robot falling to the front or back. While the Y-axis is to detect the robot falling to the left or right side. With these data provided, it can be used to set the data range to execute the program commands such as get up from front and back, rollover from left and right.

The physical voltages tested from the accelerometer sensor are in the form of analog signal. The analog data needs to be converted to digital form by the microcontroller; therefore the values obtained are not in voltages but in the data form instead. For example Z-axis 1.56 V (analog) and the digital form of data Z-axis value is 79 as observed in the serial communicator in the PicBasic Pro. In addition, the analog to digital converter is shown in Fig. 6.

Table 2. Acceleration and angular for the robot posture.

Bipedal Walking Robot Posture	Accelerometer Sensor, Z and Y axis				Acceleration, g	Angular, (°)
	Practical Tested		Practical Tested			
	Z-axis value	Z-axis voltage, (V)	Y-axis value	Y-axis voltage, (V)		
Vertical	79	1.56	83	1.53	≈ 0 (X and Y-axis)	≈ 0 (X and Y-axis)
Fall to front	59	1.13	83	1.60	-1.182 (Z-axis)	77.69 (Z-axis)
Fall to back	99	1.89	83	1.56	0.545 (Z-axis)	48.59 (Z-axis)
Fall to left	78	1.50	61	1.18	-1.068 (Y-axis)	52.70 (Y-axis)
Fall to right	81	1.59	104	1.99	0.772 (Y-axis)	> 90 (Y-axis)

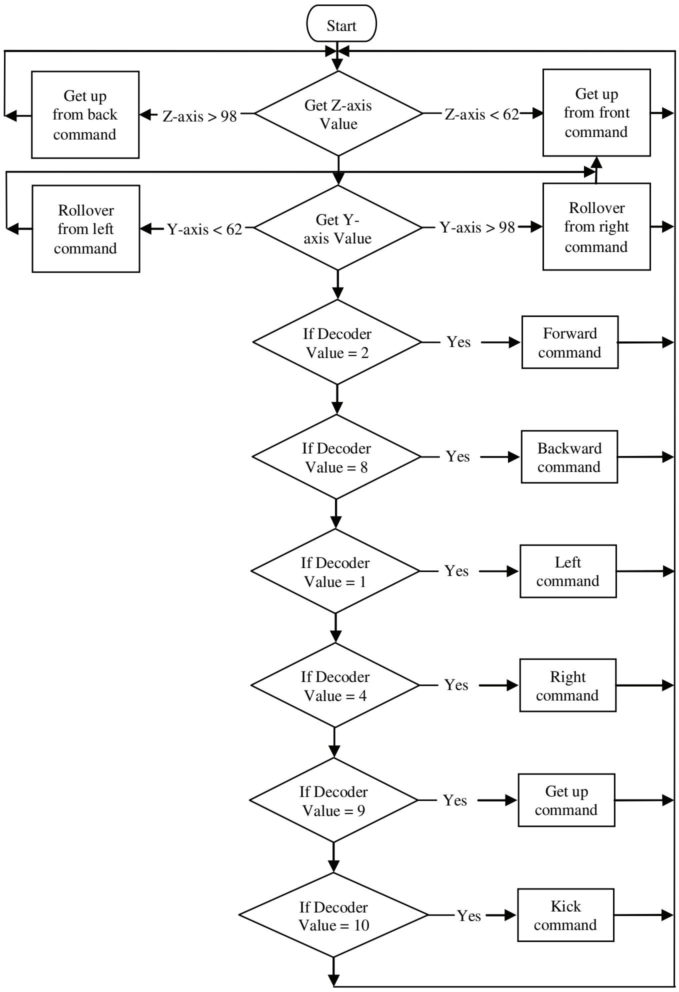


Fig. 5. Overall operational flow chart.

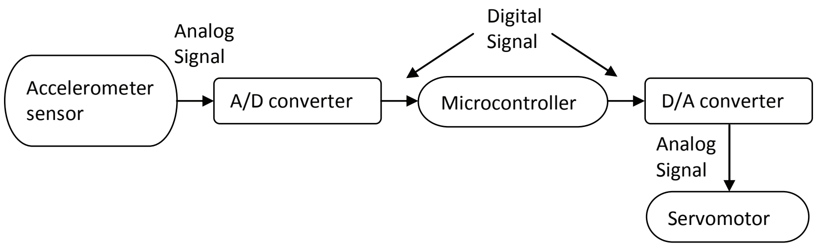


Fig. 6. Microcontroller control hardware.

7.2. The Locomotion Steps Sequence

The capability of the servo motor position has been tested by trial and error in order to get the correct posture of the locomotion such as moving forward, backward, left and right, get up from front and back, rollover from left and right and kick. The values of the data are then to be applied in the application to perform the locomotion. At first, the assembly of the bipedal walking robot is completed. Input the trial and error values in the program, and the value which is the best for the position is determined.

The connection between the servo motors and the relevant output ports of the microcontroller are as follow:

i) Servo Motor 1 = Right Hip = Portb.5
ii) Servo Motor 2 = Right Knee = Portb.6
iii) Servo Motor 3 = Right Ankle = Portb.7
iv) Servo Motor 4 = Left Hip = Portb.2
v) Servo Motor 5 = Left Knee = Portb.3
vi) Servo Motor 6 = Left Ankle = Portb.4

Fig. 7 shows the locomotion steps sequence for the get up from front locomotion together with the angle of the relevant servo motors. During Step 1, only servo motor 1 corresponding to the right knee (Portb.6) is moving followed by servo motor 5 corresponding to left knee (Portb.3) during Step 2. Same applied to Step 3 and 4. The purpose of letting only one servo motor to move at a time to let the robot to get into balanced stable position for Step 5 and 6 as well as to preserve the battery life. There are two servo motors rotating at the same time during Step 5 and 6 for stability reason. All the initial value of the servo motors has been set to 150° in PicBasic Pro Compiler for neutral position which is the midrange position.

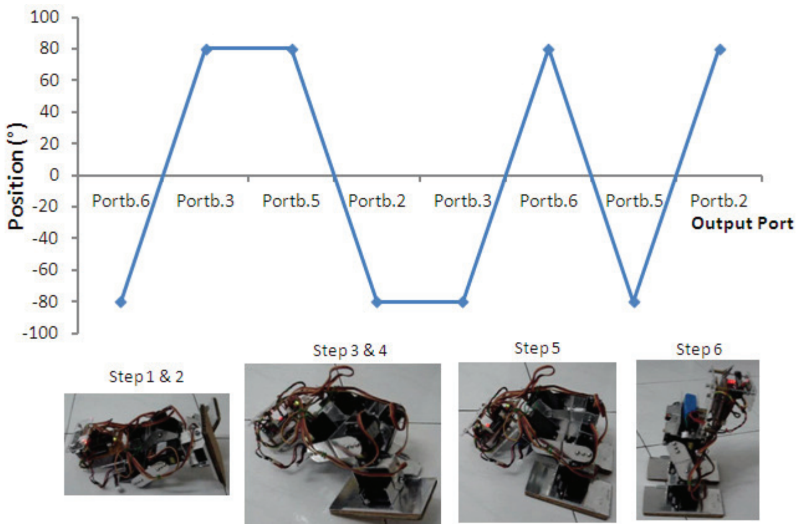


Fig. 7. Locomotion steps sequence for get up from front locomotion.

The servo motors position and the step sequences for all other movements are shown in Fig. 8.

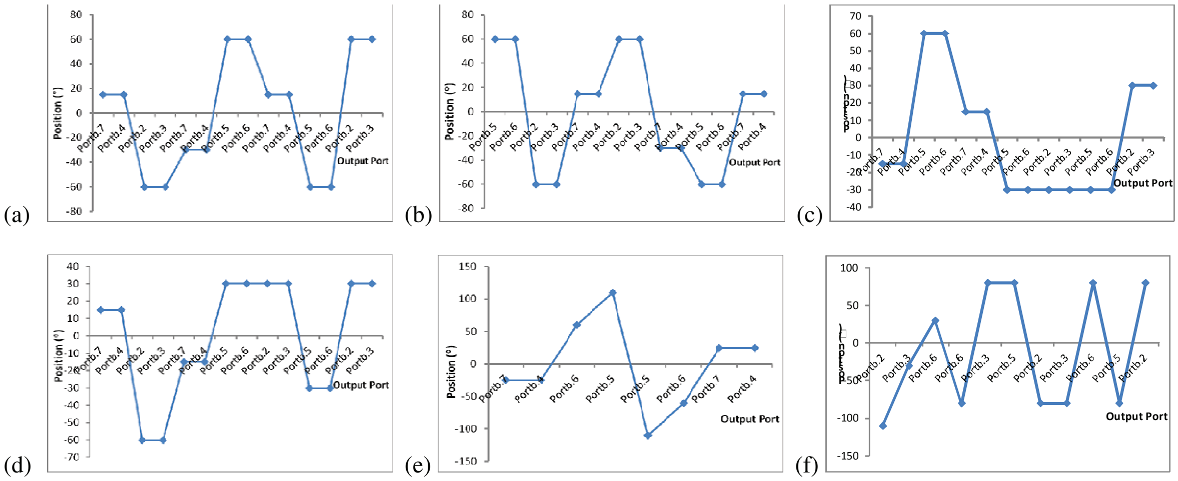


Fig. 8. The servo motors position and the step sequences for all other movements. (a). move forward (b). move backward (c). turn right (d). turn left (e). kick (f). rollover from right. Other locomotion that can be performed by the robot are rollover from left and get up from back.

8. Conclusion

A prototype six degree of freedom bipedal walking robot is successfully built. The locomotion, i.e. move forward, backward, turn left and right, kick, get up from front and back, rollover from left and right are successfully achieved without tumbling over. The work carried out during the experiments of the walking procedure and sequences of movements are the steps which make the locomotion robot successful. Finally, the “Bipedal Walking Robot” is not only able to perform its locomotion with the help of the servomotor; it also can automatically stand up when falls down and able to be controlled wirelessly by using a remote control.

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