Design and Construction of Bipedal Robot System with Dynamixel AX-12A Actuators

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Abstract: The main objective of this research is to design and construct of a practical bipedal robot with obstacle avoidance system by using Arduino microcontroller board and Dynamixel AX-12A servo as actuators. In recent years, robots have been developed to substitute human to carry out some critical tasks in dangerous environment. The purpose of this research project is to design and construct a bipedal robot which is capable of walking and also able to avoid obstacles autonomously. The great challenges in designing a bipedal robot are to choose suitable actuators for each joint and also to ensure the stability of the biped robot during walking. In this project, it is proposed to implement Arduino microcontroller as the main brain to the robot. The project development started with design and construction of a bipedal robot by using SolidWorks and followed by design of electrical and electronic configuration using Proteus ISIS, stability study and controller application. In the early stage, experiments are conducted to interface Arduino microcontroller and Dynamixel servo motors. Then, the bipedal robot is constructed and assembled using Bioloid bipedal robot platform by Robotics. The walking pattern is embedded into the bipedal robot and tested for several trials. Parameters such as servo motor angle of rotation, center of mass and static walking motion are obtained and analysed in terms of the capability to achieve stable forward walking motion. Error analysis and trajectory analysis have been carried out to see the performance of the biped robot walking motion as compared to the actual human walking motion. As conclusion, a practical 12 degree of freedom (DOF) bipedal robot has been designed and constructed by using Dynamixel AX-12A servo motors. The built robot is able to perform walking autonomously. This robot is very practical and suitable to be used in robotics subject in order to learn the basics of humanoid robot.

Keywords: *Bipedal, robot, Arduino, Dynamixel, Humanoid*

Introduction:

There are some researchers who have developed humanoid robots for orthosis and prosthesis research purposes. This can be seen in the development of human orthotics and prosthetics equipment such as motorized leg and arm for neural or muscle impaired patient, biological realistic prosthetics, ankle to foot orthotics tool and much more. Based on an article published in 2009 [1], there is a total of 125000 patients in needs for prosthetic and orthotics services which is deemed to increase throughout the years. Secondly, humanoid robots are also built so that the human body structure and behaviour (biomechanics) can be learned. This leads to simulation of human body for further understanding and cognition study where human ability to analyse sensory information is being discussed for obtaining intuitive and motor techniques. Moreover, human assistance is also made possible with the improving technology on humanoid robots. In this modern era, humanoid robots are being modified into a robot that can perform human tasks such as assisting the sick and elders, doing dangerous task such as fixing electrical cable, space exploration and much more. Theoretically, since humanoid is built in a form of a human body, it can basically do any task human are capable of, with a suitable algorithm. The gaining popularity of humanoid robot in the entertainment field has brought to its development for the same purpose. For example, Ursula is a female robot capable of singing, dancing and interacting with audience at the Universal studios. Ursula has been developed by the Florida Robotics [2]. These robots have realistic expression and gestures that are comparable to human but they do not have cognition or physical anatomy.

By using the measurements, dimension and degrees of freedom (D.O.F) of the robot "Denise" which was developed by Delft University [3], a similar robot was built for research use [4]. The robot has a total of 5 degrees of freedom with 1 degree of freedom at the hip, 2 degrees of freedom at the knee and 2 degrees of freedom at the ankle. Besides, it is made of mainly aluminum material. The main actuator used [4], is the pneumatic muscle or the McKibben muscle which expand its size with the increase of pressure causing the muscle to shorten and produces a force to the pneumatic piston attached to the hip. This in turn collaborates with the interlock system in the knee to remain fixed when the leg swings forward and bent during forward movement. Lastly, the author proposes the use of 16F84A microcontroller which is programmed using C language to control the robot. The microcontroller works simply by detecting the signal given by the sensors mounted on the sole and take appropriate action based on the given programming. On the contrary, Kanagawa Biped Robot-1 Refined or KBR-1R [5] has a total of 12 degrees of freedom with 6 degrees of freedom at the hip, 2 degrees of freedom at the knee and 4 degrees of freedom at the ankle. The author emphasize that the movable angle of KBR-1R is about the same as a human so that it could simulate the movements similar to a human. Besides, the material primarily used in this robot is aluminum. The actuator used in KBR-1R is DC servo motors with the use of timing belts, pulley and harmonic drive gears in the joints to make it smaller. Finally, PC/AT compatible CPU with RT-Linux OS programmed with C language is proposed [5]. The control software has real time module capable of direct communication with the biped robot and non-real time module capable of channeling the input response or output walking pattern to the real time module. Meanwhile, Saika-4 [6] has a total of 30 degrees of freedom with 2 degrees freedom at the head, 14 degrees of freedom at the arm, 12 degrees of freedom at the leg and 2 degrees of freedom at the hand. Since aluminum alloy is light, strong and cheap, it is chosen as the material for the mechanical components while Al-Cu-Mg alloy is used for mechanical pieces and Al-Mg alloy for the outer shell. Each joint has a DC servo motor, harmonic drive reduction gear and rotary optical encoder connected with synchronous belt driver and pulley to reduce the space or weight. The main actuator and microcontroller used is the DC servo motor and IBM PC/AT clone with QNX Realtime Platform OS [6]. The microcontroller functions similar to a generic PC. Furthermore, WABIAN-2 human-like walking robot has a total of 16 degrees of freedom [7]. 2 degrees of freedom is located at the waist, 6 degrees of freedom located at the hip, 2 degrees of freedom located at the knee and 6 degrees of freedom at the ankle. Besides, duralumin is used as the main material in WABIAN-2 construction. Each joint of WABIAN-2 consists of a DC servo motor, harmonic drive gear, a lug belt and two pulleys to allow high reduction ratio and separation between joint axis and motor axis [7]. Lastly, the microcontroller used in this robot is a PC consisting of PCI CPU board.

It can be observed that the biped robot with more than 12 D.O.F for both legs or 6 D.O.F for each leg achieve a much stable walking motion in their experiments. By having such D.O.F configuration also allows better flexibility of the biped robot. Other than that, the summary also shows that majority of the biped robot uses DC Servo motor as their main actuator since it allows adequate torque with high accuracy and high movable angle. Hence, the biped robot proposed in this report uses 6 D.O.F for each leg and DC Servo motor is selected as the main actuator. However, the microcontroller proposed to be used is Arduino which is different from any of the microcontroller used by other researcher shown in the summary. This is to implement new element into this project that is different from other research.

Methodology:

The methodology used in this research paper has been divided into three parts which are mechanical design, electrical and electronic design and stability.

Mechanical Design:

The design of the robot leg has been done by using AutoCAD software. Each leg consist of 6 degrees of freedom where 3 degrees of freedom are located at the hip (roll, pitch and yaw), 1 degree of freedom is located at the knee (pitch) and 2 degrees of freedom are located at the ankle (roll and pitch). The design of the left leg is shown in Fig. 1.

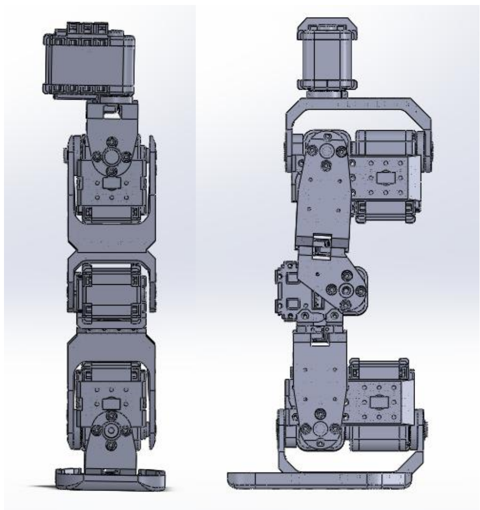


Figure 1: Left Leg CAD Drawing (Front and Lateral view)

2.2 Electrical and Electronic Design

The design of the electrical and electronic circuits have been tested by using Proteus ISIS software. The functionality of each servo motor is tested by using this software before it is tested at the real hardware. The designed hobby servo motor control electrical and electronic configuration in Proteus ISIS together with the Arduino UNO is shown in Fig. 2.

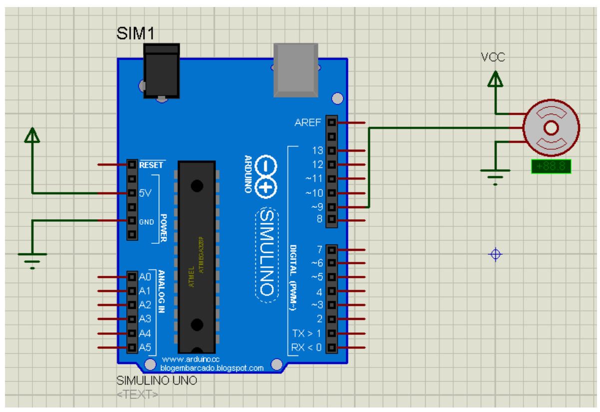
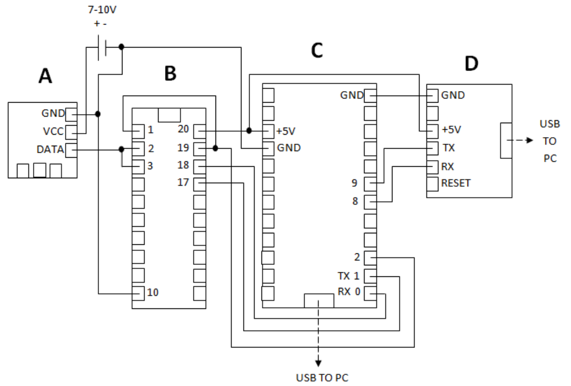


Figure 2: Servo Motor and Arduino Controller in Proteus ISIS

The functionality of the ISIS configuration with the Arduino algorithm is tested in the ISIS simulation and hardware implementation. Besides, positioning experiment is also carried out by taking the angle of the servo motor to check for the error between the desired and actual value. The angle of rotation is measured using a protractor. Average values for multiple measurements are calculated to get a more accurate data and avoid systematical error. Analysis is done to see the accuracy of the servo motor rotation.

Fig. 3 shows the electronic configuration used to build the tri-state buffer board hardware that is required to transfer half-duplex communication between Arduino Uno Rev3 to multiple Dynamixel AX-12A Servo Motors.



- **A.** Dynamixel AX-12A Servo Motor
- **B.** 74LS241N tri-state buffer
- **C.** Arduino Uno Rev3
- **D.** Arduino USB Serial Light Adapter

Figure 3: Tri-state Buffer Board Electronic Configuration

Fig. 4 shows the electronic configuration used to build the power supply protection board hardware. The input header will be connected to the 1000mAh Lipo battery and the output header will be connected to the Dynamixel AX-12A servo motors.

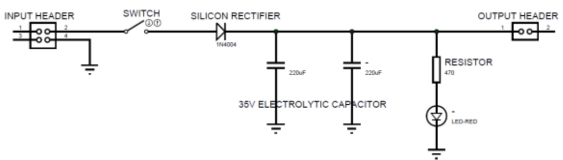


Figure 4: Power Supply Protection Board Electronic Configuration

Stability:

The control criteria for a static walking robot must maintain its center of mass or center of gravity on the ground directly inside of its support polygon. Therefore, by doing so, the robot will have slow walking speed and it can only move on flat surface [8].

On the contrary, with dynamic walking, the center of mass or center of gravity can fall outside of the support polygon but the zero moment point (ZMP) must be inside [8]. This configuration is hard to achieve since it involves complex derivation to make sure that the ZMP is inside of the support polygon. Hence, only static walking is focused in this study.

Static walking defines that the robot will be statically stable which means when the robot is stopped, it is practically stable. For single support phase, its support polygon where the COM lies would directly be the foot surface of that one leg while for double support phase; its support polygon where the COM lies would directly be the minimum convex area containing both foot surfaces [8]. Besides, the walking speed must be low so that the inertial force would be negligible. The static support phase is shown in Fig. 5.

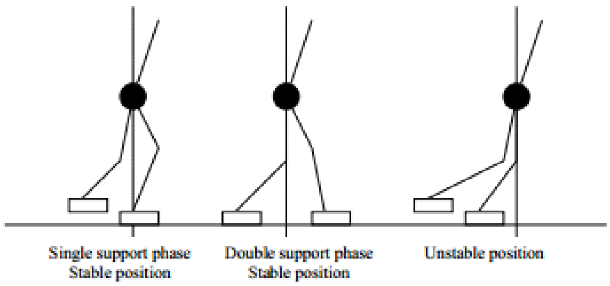


Figure 5: The Static Walking Support Phase

Fig. 6 shows a walking cycle of FOBO robot and is it similar to the walking sequence of static walking that is implemented in this research [9]. The walking cycle can be broken down into right leg and left leg sections. Both of the sections have the same movement but are mirrored about the central axis of the robot. Each sections are separated into up, down and shift motion. During up motion, one of the foot will be lifted and move. Then during the down motion, the lifted foot will be put down since it has reached the required displacement. Lastly, shift is done to move the weight or center of mass to the opposite leg before the foot can set off to up motion. These processes alternate continuously to produce a static walking.

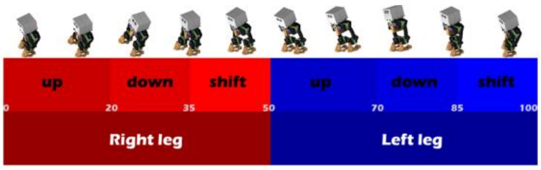


Figure 6: The Static Walking Sequence

Results and Discussion:

The complete hardware of the robot platform is built by using Bioloid plastic frames. It consist of 12 degree of freedom (DOF). Each leg has 6 DOF. The front, side and back view of the final product are shown in Fig. 7 and Fig. 8.

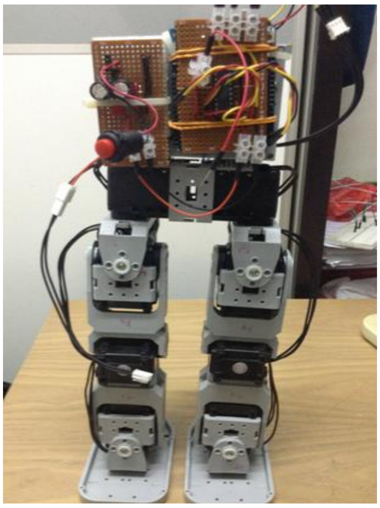


Figure 7: The Front View of The Final Product

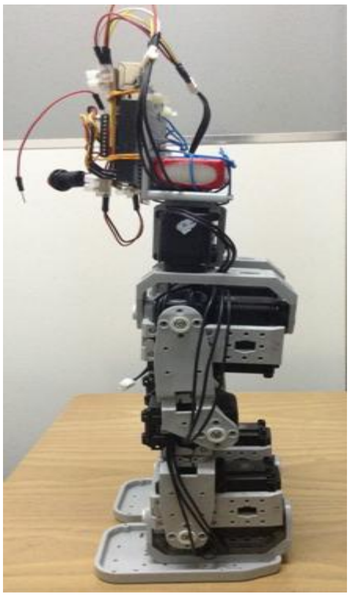


Figure 8: The Side View of The Final Product

4. Conclusion:

As conclusion, a practical 12 degree of freedom (DOF) bipedal robot has been designed and constructed by using Dynamixel AX-12A servo motors. The built robot is able to perform walking autonomously. This robot is very practical and suitable to be used in robotics subject in order to learn the basics of humanoid robot. In the future we will publish about the walking algorithm of the biped robot.

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