Design and Development of a Biped Robot

Vishnu Vardhan Madadi, and Sabri Tosunoglu, *Member, ASME*

***Abstract*—Many researchers have been encouraged to investigate the design, posture and stability of biped robots in order to replicate the anthropoid gait. This paper addresses the design and development of a bipedal robot. It presents a combination of the design considerations and simplicity of design to provide a test bed for autonomous biped robots. Kinematic models of the biped robot are also developed and simulated prior to experimentally verifying the performance of the system. Overall, a low cost, open system biped robot is the underlying objective on which new gait algorithms and controllers will be developed to further the research in the field of humanoid robots.**

I. INTRODUCTION

FOR the wide range of potential applications foreseen in robotics, research in the area of biped robots has been actively pursued. The legged robot forms, which utilize discreet footholds rather than continuous support such as wheels or tracks, have been of particular interest. By taking advantage of the strategic footholds in the terrain, legs increase traction and decrease energy consumption [1].

Although a number of biped walking prototypes has been built over the years, several issues still hinder active use of biped robots in our every day applications. The bipedal structure is inherently unstable and prone to falls. They have an instability problem even for level ground locomotion. Efficient and robust legged locomotion has always been an interesting but difficult problem to address, given the high degree of uncertainty and complex dynamics that arise in traversing unstructured terrain [2]. Despite bipedal locomotion being a great challenge in autonomous and mobile robotics, Sony and Honda have made progress in these areas by developing Qrio and Asimo, respectively, as illustrated in fig. 1 [3], [4]. These robots demonstrate the ability to walk, identify some structures, shake hands and execute other predetermined objectives. Walking robots have potential applications that will eventually exceed the capabilities of humans with respect to physical abilities [5].

This paper presents the design, and development of a biped robot. The objective is to build a platform that can be used to investigate walking states and generate gaits using different control techniques. Designed models are simulated in a real time physical environment to assess constraint parameters. Current work is focused on developing static stable gaits on level and inclined surfaces using an inertial guidance unit.

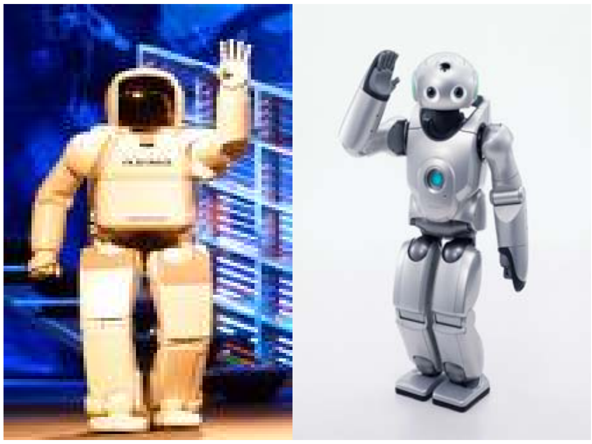

Fig. 1. Honda's Asimo (L) and Sony's Qrio Robot (R)

This paper is organized as follows: An outline of the mechanical design of the developed biped robot is given in Section 2. The hardware and sensor system used to build the mechanical structure is described in Section 3. In Section 4, gait development of the system and its prospects are explained. Finally, Section 5 contains conclusions and future work.

II. MECHANICAL DESIGN

Determination of appropriate design parameters to achieve reliable and stable gaits in biped robots is demanding due to the numerous parameters influencing its locomotion. Several biped robot designs have been proposed earlier, each with its own strengths and weaknesses. This work presents the next generation of the biped robot under development at Florida International University (FIU) [6].

The fundamental principle of the design is to obtain a low cost system that upholds necessary standards to be compatible for research on bipedal robots. All components designed and employed in this system comply with standards maintained in the market.

Observing and analyzing the anthropoid gait under different circumstances was the approach taken in designing the biped robot. An empirical structure of the human form is chosen as the fundamental mechanical design. Allocation of the number of joints and their location were specified with respect to the anthropomorphic framework. The designed model is a non-holonomic system as the number of controllable degrees of freedom (DOF) is less than the number of degrees of freedom the anthropoid structure

---

Manuscript received January 31, 2007.

V. V. Madadi is with the Department of Mechanical Engineering, Florida International University, Miami, FL 33174 USA (phone: 305-297-4533; e-mail: vmada001@ fiu.edu).

S. Tosunoglu is with the Department of Mechanical Engineering, Florida International University, Miami, FL 33174 USA (phone: 305-348-1091; e-mail: tosun@fiu.edu).

Proceedings of the 7th IEEE International Symposium on Computational Intelligence in Robotics and Automation,
IEEE CIRA 2007, Jacksonville, Florida, June 20-23, 2007.

possesses. Even with a fewer number of joints in comparison to the human structure, it is capable of executing essential tasks for research in biped locomotion.

The joint structure of the designed robot has ten degrees of freedom. Servos are mounted on the biped robot to serve as actuators for the system. On each leg, two servos are attached to the hip, one to the knee and two to the ankle. The adapted structure is found in some robot designs as it provides reasonably good mobility. The mechanical design of the bipedal robot is modular, making it easy to change and replace parts.

The servos used are pre-programmed to have a standalone rotation of 140º. They are capable of a 180º rotation when programmed with a digital servo programmer (DSP-1). The range of motion of a few joints is limited when assembled owing to the outcome of the final design of the biped robot.

The ankle joint has 2-DOF, which allows it motion in the sagittal and the lateral plane. The range of motion in the sagittal plane is between +90º and -50º and +40º and -70º in the lateral plane. The mobility for the knee joint is +140º in the sagittal plane. The hip joint designed is similar to the ankle. Like the ankle joint it is capable of mobility in the sagittal and lateral plane. In this case, the range of motion is from +70º to -70º for movement in the sagittal plane, and between +40º and -70º for lateral plane. Stable and reliable motion is achieved with the above set of values.

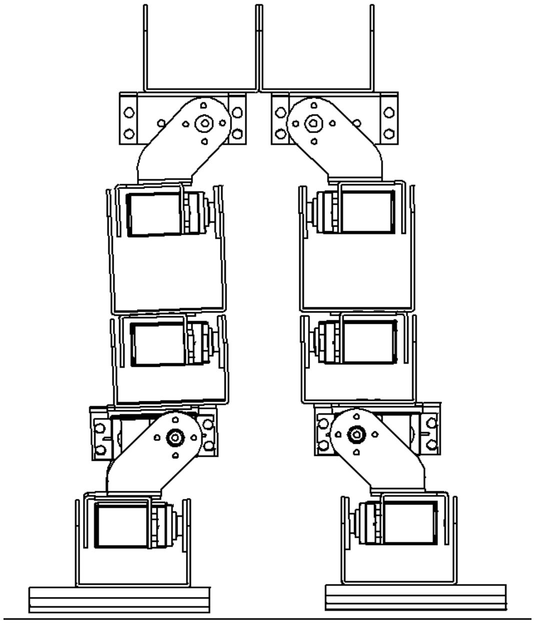

Fig. 2. CAD Model – Front View

The appropriate size and shape of the foot is another important design aspect. Powered biped robots typically use flat feet so that their ankles can effectively apply torque to propel the robot to move forward in the stance phase, and to facilitate its stability control [7]. Larger feet provide a greater support area increasing the stability of the biped robot. This slows down the gait speed and performance considerably as it experiences extreme difficulty in foot interference and clearance. The foot size designed here is capable of achieving a decent speed and is relatively smaller than the previous bipeds developed at FIU [6]. It is equipped with a rubber padding to absorb shock while walking. Force and other tactile sensors could be placed in this layered structure at the sole for feedback concerning ground conditions.

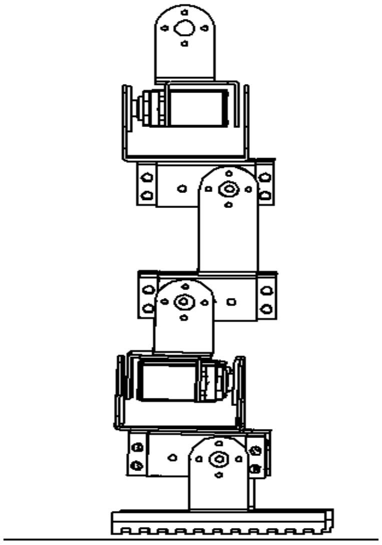

Fig. 3. Side View

.

This biped robot is designed and assembled to provide a platform for research in biped locomotion and also to further research in the field of humanoid robots. The design structure is easy to modify or alter to accommodate the interest of the researcher and the manner of testing it has to undergo. The result is a low maintenance platform. The weight of the complete robot structure is below 1 kg (without supply batteries) and it stands 1 ft tall with the control board mounted on it.

III. HARDWARE

A fully functional biped robot is assembled with a combination of mechanical links, electronic actuators and sensors to execute a desired task. A Processing Unit (PU), chiefly comprising of embedded processor, systematically controls all components of the biped robot. Such micro controllers are the core of many robots. They have considerable processing power packed on one chip, allowing considerable freedom for programmers.

A. *Actuators*

Selection of actuators is a critical factor in the design process of a biped robot. The weight of the actuator contributes a significant sum to the total weight of the biped robot which has a direct bearing on balance issues. Considering that the objective of the design was a low cost platform, DC servomotors were chosen as the actuator type. These motors are small, affordable and are extremely powerful for their size. These servos are compact in size and their entire control circuitry, motors, set of gears are cased providing a good option for smaller robot designs.

The servomotor constitutes of motors, gears, control circuits and a potentiometer that is connected to the output shaft. The potentiometer allows the control circuitry to monitor the current angle of the servomotor. If the shaft is at the correct angle, then the motor shuts off. If the circuit finds that the angle is not correct, it will turn the motor in the correct direction until the angle is correct. The output shaft of the servo is capable of traveling somewhere around 180 degrees. The range of motion varies by manufacturer. A normal servo is used to control an angular motion of between 0 and 180 degrees.

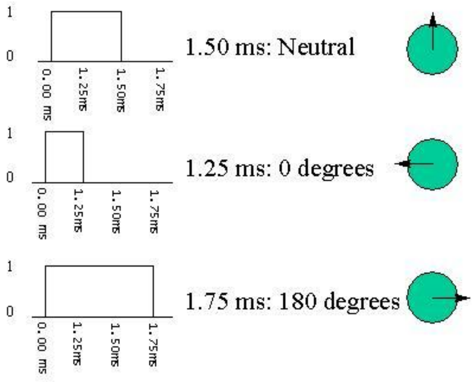

Fig. 4. Pulse Width Modulation in Servos [8]

The amount of power applied to the motor is directly proportional to the distance it needs to rotate. This is called proportional control. The control wire is used to communicate the angle. The angle is determined by the duration of a pulse that is applied to the control wire. This is called Pulse Width Modulation (PWM).

B. *Sensors*

Robotics has matured into a system integration engineering field defined as “the intelligent connection of the perception to action” [9].

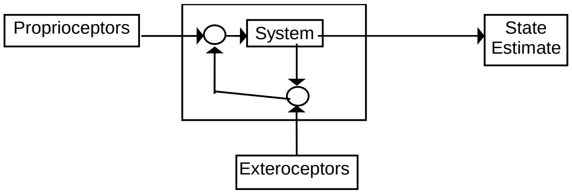

Fig. 5. Incorporation of sensors in the robotic system

Most robotic systems use sensors which can be broadly classified under proprioceptors and exteroceptors. Proprioceptors are used for the measurement of the robot’s internal parameters; while exteroceptors for the measurement of its environmental or external parameters.

Data from multiple sensors may be further fused depending upon the system’s requirements. Finally, at the perception level, the model is analyzed to infer the system and environment state, and to assess the robotic system’s actions. This process is shown in fig. 5.

1) *Proprioceptors*

Proprioceptors are sensors measuring both kinematic and dynamic parameters of the robot. Based on these measurements, the control system activates the actuators to exert torque so that the designed mechanical structure executes the defined task. The usual kinematic parameters are the joint positions, velocities, and accelerations. Dynamic parameters such as forces, torques and inertia are also important to monitor for the proper control of the robotic manipulators.

This system uses an Inertial Measurement Unit (IMU) which measures the robot’s kinematic parameters. It uses a single IC triple axis accelerometer from Freescale MMA7260Q and combines it with three iMEMs gyroscopes. The unit consists of roll, pitch, and yaw gyro sensors and includes three tilt axis sensors. All measurements are transmitted over a simple TTL level serial connection via the 4-pin header on board.

Fig. 6. IMU 6 Degrees of Freedom v2 with Bluetooth/ADXRS150 [10]

The gyroscopes are capable of reading a maximum rate of 150 degree/s. Three temperature readings from ADXRS in the form of 2.5V outputs are used for error correction. They are used to calibrate the drift associated with a gyro unit. Individual channels are turned on/off, depending on requirements and sensitivity can be varied on each accelerometer. Unused channels are turned off to increase the output frequency.

2) *Exteroceptors*

Exteroceptors are sensors that measure the positional or intensity interaction of the robot with its environment. Exteroceptors can be broadly classified under Contact Sensors and Remote Sensors.

Contact sensors are used to detect the positive contact between two mating parts and/or to measure the interaction forces and torques which appear while the system is operating. Other types of contact sensors are tactile sensors which measure a multitude of parameters of the touched object surface. Tactile sensing is defined as the continuous sensing of variable contact forces over an area within which there is a spatial resolution. Tactile sensing is more complex than touch sensing, which, usually is a simple vectorial force/torque measurement at a single point.

Remote sensors detect objects without any form of physical contact. These sensors are generally used in enclosed areas dealing with applications such as object approaching or avoidance and other robotic operations. Range sensors measure the distance from the system to objects in their operational area. A common principle used to estimate the range is by measuring the time elapsed between the transmission and return of a pulse.

C. Micro Controllers

Micro controllers maintain a relationship between the actuators and their consequential movements using measurements made by sensors. It maintains a model of the environment using exteroceptor sensor data. The sequence of steps required to execute a task are planned and controlled in response to the task being performed. It is capable of being programmed to adapt the robot's actions in response to changes in the external environment.

Fig. 7. BASIC Stamp 2 Module [11]

A 16-pin DIP (Dual Inline Package) module micro-controller, shown in fig. 8, is used with a Basic Stamp 2 processor, shown in fig. 7. It is able to control and monitor switches, timers, motors, sensors, relays, valves, and more. The micro-controller used in this system enables the user to act as a guiding system, in which the user leads the robot through the motions to be performed or it allows the user to write a program to specify motion and sensing.

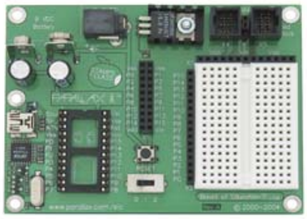

Fig. 8. Board of Education Development Board [12]

Each higher level task is accomplished by decomposing them into a sequence of lower level commands based on the strategic model of the task. At the servo system, where actuators control the mechanism parameters using feedback of internal sensory data, paths are modified on the basis of external sensory data

IV. GAIT DEVELOPMENT

The most popular approach to humanoid walking has been to observe human leg positions over time [13]. This trajectory-based approach has been called "kinematic obsession" because of its extensive use in robotics [14].

Human motion when reviewed can be broken down into a sequence of stable or near-stable states. The speed of transition and/or shift in balance extremities from one state to another would result in the gait being static or dynamic. Static walking assumes that the robot is statically stable at all moments during the gait. It implies that, at any time, if the motion of the system comes to a halt then the robot will indefinitely stay in a stable position. Gait development for this biped robot was approached by developing statically stable gaits. Much of the work was initially done intuitively by trial and error.

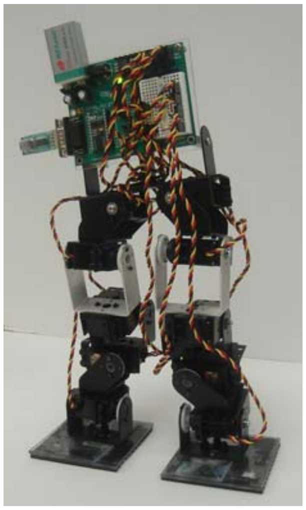

Fig. 9. Prototype Biped Robot

A walking gait encompasses a sequence of strides. A simple walking gait which is explained below is split into four stages. The initial state where the biped robot is balanced and ready to walk is labeled as stage 1. Stage 2 comprises of the shift in center of gravity to its left or right based on its first stride. The process of the system completing its first stride is stage 3. Shifting its center of gravity back to the center is labeled as stage 4. A simple walking gait is achieved when the above cycle is repeated. Even without a torso, only a minor shift in center of gravity of the system is required.

The ankle joint plays a major role while turning the system in any direction. Unlike most systems, the biped is capable of making an acute or obtuse angle turn depending on its needs instead of an ineffectual 90 degree turn. The design of the ankle joints allows the biped robot to turn while walking, rather than halting and turning, which makes the system more time efficient and bears a closer resemblance to the human walk. The present biped system shown in fig. 9 is capable of efficient, realistic and reasonably fast walking on flat surfaces.

The current work will be expanded to develop gaits for the system to climb inclined surfaces. Data from the proprioceptors and exteroceptors will then be analyzed to obtain information regarding the robot's internal and external parameters. The IMU provides the measurement and orientation of the biped robot. Force and other tactile sensors on the sole of the biped robot combined with the data from the IMU will be used to detect inclined surfaces. Actuator control of the mechanism will then be modified and altered based on the feedback provided by internal sensory data, and paths are modified as well based on external sensory data.

V. CONCLUSION

In this paper a low cost, open system biped robot has been presented. The main goal of this work has been to develop a functioning biped robot. The entire unit was experimentally observed to verify the range of mobility and constraints in design. The hardware used to build this system is inexpensive and easy to obtain. The design structure adapted allows easy and quick replacements of parts when required.

The initial results in gait development for the system on flat surfaces has provided robust locomotion. Subsequent to gait development on flat surfaces, more complex problems such as navigation on irregular surfaces will be undertaken. Gait development for inclined or uneven surfaces will also be addressed which requires modification of the periodic walking cycles that have been developed so far.

REFERENCES

[1] M.H. Raibert, "Legged Robots That Balance", Cambridge, MA: MIT Press, 1986.

[2] R. Cory. (2007, Jan) [Online]. Available: http://web.mit.edu/recory/www/research.html

[3] Sony.Net, "QRIO," Sony Corporation, Tokyo, Japan, "Sony Corporation. Sony Global," January, 2007 [Online]. Available: http://www.sony.net/SonyInfo/QRIO/top_nf.html.

[4] American Honda Motor Co., Inc. Corporate Affairs and Communications. Technical Information: ASIMO, January 2003. January 9, 2007 Available: http://asimo.honda.com/index.asp?bhcp=1

[5] K. Berns, and R. Dillmann, "Climbing and Walking Robots (CLAWAR)," *Biology to Industrial Applications 4th International Conference* 2001.

[6] A. Senior, and S. Tosunoglu, "Robust Bipedal Walking: The Clyon Project," *The 8th Florida Conference on Recent Advances in Robotics*, Gainesville, Florida, May 2005.

[7] Tao Geng, Bernd Porr and Florentin Wörgötter, "Self-stabilized Biped Walking under Control of A Novel Reflexive Network", Computational Neuroscience, University of Stirling, Stirling, UK.

[8] Seattle Robotics Society, Standard Technologies of the Seattle Robotics Society, "What is a Servo?" (2007, Jan 24) [Online]. Available: http://www.seattlerobotics.org/guide/servos.html, 2007

[9] M. E. Petriu, University of Ottawa, (2007, Jan 17) [Online]. Available: http://www.site.uottawa.ca/~petriu/CEG4392-IntroRobotics-Sensors.pdf

[10] Inertial Measurement Unit ADXRS150, Spark Fun Electronics Boulder, CO, (2007, Jan 17) [Online]. Available: http://www.sparkfun.com/commerce/product_info.php?products_id=8189

[11] BASIC Stamp 2 Interpreter Chip (DIP), Retrieved: Parallax Corporation, Rocklin, CA, (2007, Jan 17) [Online]. Available: http://www.parallax.com/detail.asp?product_id=BS2-IC

[12] Board of Education Development Board (USB), Parallax Corporation, Rocklin, CA. (2007, Jan 17) [Online]. Available: http://www.parallax.com/detail.asp?product_id=28850

[13] Vukobratovic, M., Borovac, B., Surla, D., and Stokic, D., "Biped Locomotion: Dynamics, Stability, Control, and Applications", Berlin: Springer-Verlag, 1990.

[14] Collins, S. H., Wisse, M., Ruina, A., "A 3-D Passive Dynamic Walking Robot with Two Legs and Knees", *The International Journal of Robotics Research*, 2001, pp. 607-615.

[15] Christine Chevallereau, Gabriel Abba, Yannick Aoustin, Franck Plestan, Westervelt E. R., Carlos Canudas-de-Wit, and Grizzle .J. W., "Rabbit: A Testbed for Advanced Control Theory", *IEEE Control Systems Magazine*, 0272-1708, 2003.

[16] Miguel Albero, Francisco Blanes, Gines Benet, José Simó, Pascual Pérez, "YABIRO, A New approach to small Biped Robots", *5th IFAC/EURON Symposium on Intelligent Autonomous Vehicles*, July 5-7, 2004.

[17] K. Hirai, M. Hirose, Y. Haikawa, and T. Takenake "The development of Honda humanoid robot," in *Proceedings. IEEE International Conference in Robotics and Automation*, Leuven, Belgium, May 1998, pp. 1321–1326.

[18] T. McGeer, "Passive dynamic walking," *International Journal Robotics Research*, vol. 9, no. 2, pp. 62–82, 1990.

[19] T. McGeer, "Stability and control of two-dimensional biped walking," Center for Systems Science, Simon Fraser University, Burnaby, B.C., Canada, Tech. Rep. 1, 1988.

[20] P.H. Channon, S. Hopkins, and Pham, "Optimal walking motions for a biped walking robot," *Robotica*, vol. 10, no. 2, pp. 165–172, 1990.

[21] C. Chevallereau and P. Sardain, "Design and actuation optimization of a 4 axes biped robot for walking and running," in *Proceedings IEEE International Conference in Robotics and Automation*, San Francisco, CA, Apr. 2000, pp. 3365–3370.

[22] F. Plestan, J.W. Grizzle, E.R. Westervelt, and G. Abba., "Stable walking of a 7-DOF biped robot," to be published, *IEEE Transactions in Robotics and Automation*.