Proceedings of ECTC 2008
2008 ASME Early Career Technical Conference
October 3-4, 2008, Miami, Florida, USA

SIX-LEGGED/WHEELED SECURITY ROBOT

Alfonso Leonardi, Andres Escobar, Juan Villar, and Sabri Tosunoglu
Department of Mechanical Engineering
Florida International University
Miami, Florida, United States

ABSTRACT

The study of the possibility of a new hybrid security robot that can perform both legged and wheeled locomotion in different types of terrain is the main objective of this paper. The robot is capable of adapting to different surfaces and determining the best motion for each case while being able to avoid obstacles and detect any target in a defined area. The Six-legged/Wheeled robot is able to not only detect a target but also to shoot it via a compressed air projectile. Due to its adaptability, it can also be used for many other applications due to its ability to work in different environments and the possibility of the addition of different sensors and servo motors.

INTRODUCTION

Robotics is an engineering field that has been gaining popularity over the last few years. Even though there is an enormous diversity of robots that includes bipeds, humanoids, multi-legged, wheeled, and many others; there are still many issues involving these types of robots.

Bipeds and humanoid robots lack quick response dynamic stability, multi-legged robots are considerably slow for many tasks, and wheeled robots are not able to perform in rough terrains or climb up and down stairs. Even more, most of these robots are only used for research and entertainment fields rather than solving different problems for domestic, industrial, or military applications. For these reasons, a new type of robot will studied.

The Six-Legged/Wheeled Robot will have the ability to perform in different types of surfaces. It will be able to perform efficiently on flat surfaces by using wheeled locomotion and on rough terrain by using legged locomotion. This robot will not have any static stability problems since it has six legs. It will incorporate a target detection system that will allow its use for many applications, such as the security of a defined area.

For this project, many papers related to this area of robotics were studied in order to gain insight and determine the different approaches that could be used to reach the goals. Papers in the multi-legged robot realm present different aspects of enormous significance since they deal with the different types of legged motion, kinematic analysis, force analysis, and many other issues.

Also, papers in the wheeled robots area are very important because they deal with another aspect being implemented in the project. By reviewing all these papers, important information about both the legged locomotion and the wheeled locomotion is gained and can be applied to this project.

DESIGN

The robot's skeleton was purchased from Lynxmotion with the chassis constructed out of Lexan panels interconnected with metal and plastic fasteners. Some modifications to the original platform are made in order to incorporate the wheels and the sensors. The method used to attach the wheels and sensors was by using small plastic sheets that were heated and bent to the desired shapes and angles. These plastic structures were then screwed to the main chassis. Two 2.63'' diameter wheels are added to each side behind the first two legs of the robot. These front two wheels are driven by continuous motion servos controlled by the main processing units. Also, a smaller wheel is added to the back of the robot along the centerline in order to add static stability to the robot when performing the wheeled motion. This rear wheel was acquired from the radio controlled aircraft industry and is widely used as a tail wheel. Figure 1 shows the robot as it was assembled without any modifications.

On top of the platform, along with the robot board and the controller, four sonar sensors were placed covering the front, rear and both sides. These sonar sensors have the function of determining if any obstacle or wall existing in the area covered by the robot. A small elevated platform was added to hold the thermal array sensor that has the function of determining if a detected object is a target. The differentiation of an obstacle or a target deals with if the object has an elevated temperature with respect to its surroundings. This elevated temperature will be used to determine if the object is a living animal or a vehicle that generates heat. Also, a BB gun is added to the robot platform so it can shoot detected targets. This BB gun is mounted on a revolving platform that follows the motion of the thermal array sensor and fires its projectile depending on the results of the thermal sensors survey.

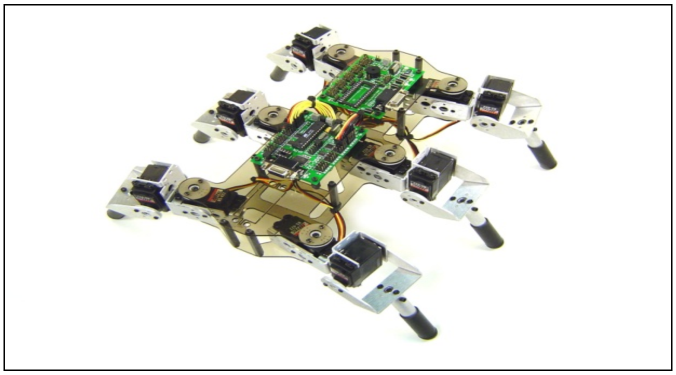

Figure 1 - Six-legged/Wheeled Robot

Each of the six legs of the robot consists of two revolute joints which are actuated by position-controlled servos in order to produce the legged motion. Figure 2 shows the model of each of the legs of the robot.

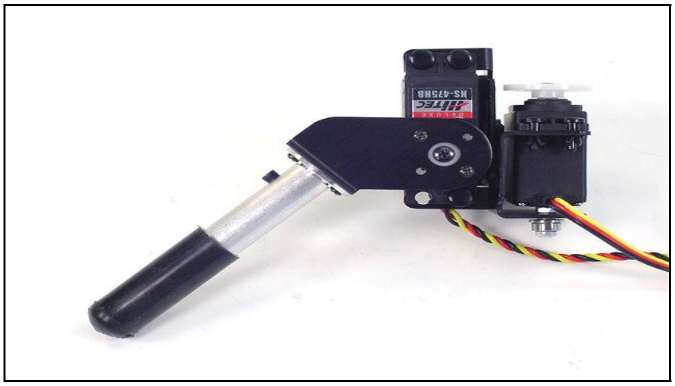

Figure 2 - Two-DOF Leg

Major Components

The sensors used on the robot include four ultrasonic range sensors, a thermal array sensor and whisker type feeling sensors. The sonar is used to detect obstacles; it measures the distance, and it outputs the measured distance by writing into readable data registers. The sonar is placed sufficiently above the ground so that the cone-shaped coverage zone does not give false readings. Figure 3 shows the actual ultrasonic sensors used on the robot. A whisker type sensor is used to determine a change in the surface while performing a mission and will later be explained.

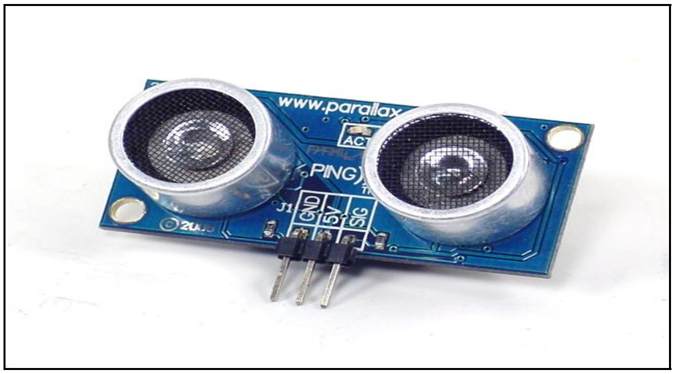

Figure 3 - Ultrasonic Range Sensor

A TPA81 thermal array sensor is used for the detection of targets. The senor measures simultaneously the absolute temperature of 8 adjacent points in its field-of-view with an I2C interface. The measurements are taken and reported in Celsius. In testing it was determined that the sensor can detect a candle flame from up to 2 meters away. Other warm objects like humans can also be detected and thus the robot can be used to detect humans or small animals posing as targets within a small covered area. The TPA81 module also has a servo output that is used to pan the module and build up a thermal image. Figure 4 shows the thermal array sensor used for the project.

In order to control each of the legs, the wheels, and the rotation of the thermal array sensor and the BB gun; ten HS-422 standard servos and six HS-475HB standard servos are used. Theses servos have a range of 180° or 360° and support a voltage of 4.8- 6.0vdc. Their speeds are 0.16s and 0.18s per 60° while the torques 57 oz.-in and 76 oz.-in respectively.

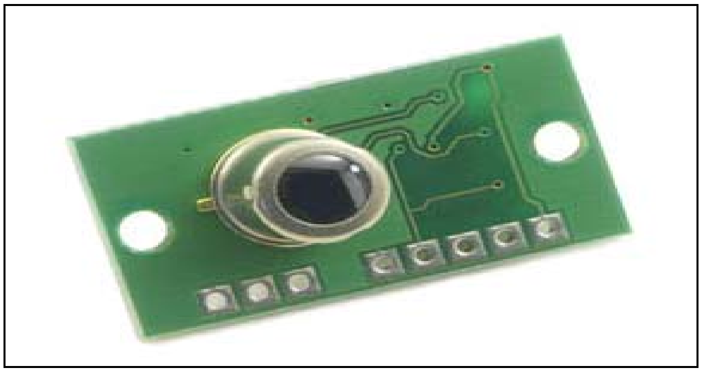

Figure 4 - TPA81 Thermal array sensor

Controller

The electronic hardware of the robot consists of the Bot Board II based with the Basic Atom 28. The Bot Board II supports up to 20 servos plugged in directly, Servo/Logic voltages can connect to A to D inputs with 28 pin Atoms for battery monitoring and the I/O bus with power and ground can be configured for 5vdc. Basic Atom 28 has 14K of program space, 368 bytes of user / system RAM, 256 bytes of user EEPROM, and 33,000 plus instruction per second.

The controller is the SSC-32 Servo controller that has 32 channels of 1uS resolution servo control. This high resolution allows for accurate positioning, and extremely smooth operation. The range is 0.50mS to 2.50mS for a range of about 180°. The motion control can be immediate response, speed controlled, timed motion, or a combination. It includes the Atmel ATMEGA168-20PU microcontroller that operates at 14.75 MHz with 32 outputs, 4 inputs, and an EEPROM of 24LC32P. It supports up to 32 servos plugged in directly and 15 amps per side, 30 amps max while requiring 31mA of current. Figure 5 shows the controller used for this robot.

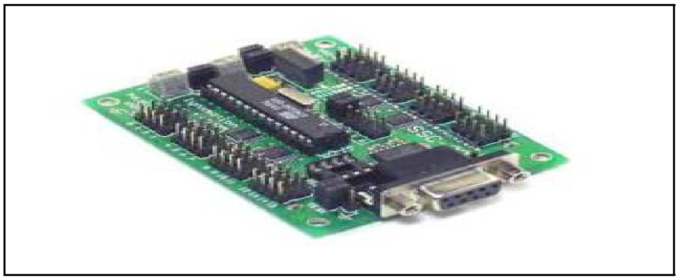

Figure 5 - SSC - 32 Servo Controller

KINEMATIC ANALYSIS

The motion planning of the robot is one of the most important aspects of this project, especially for the six-legged locomotion since this involves dealing with the joint angles and the displacements of the legs. In order to plan the motion of the robot, two options are available.

The first option is the forward or direct kinematics method that determines the displacement of the leg by knowing its length and the joint displacements. The second option is the inverse kinematics method in which the final position of the leg is known and the angle of each joint is then found. For this project, the forward kinematics method is used. Figure 6 shows the variables that characterize the motion of the robot.

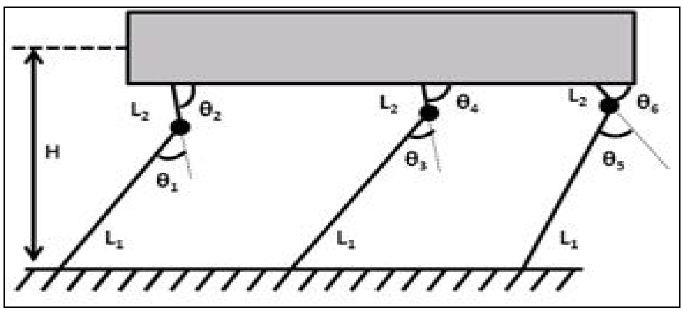

Figure 6 - Kinematic Variables

The following equations are derived from the forward kinematics analysis of the robot. The first two equations correspond to the position of each leg of the robot. By knowing, the lengths and the joints angles, the position of the legs is determined. Then, the rest of the equations correspond to the velocity analysis of the robot which uses the Jacobian matrix to determine the linear velocities of the legs. In this case, partial derivatives of the general position equations (eq.1 and eq.2) are needed. This procedure is used for each of the legs of the robot.

$$X_H - L_2\cos(180° - \theta_2) + L_1\cos(180° - \theta_2 - \theta_1) \quad (1)$$

$$Y_H = L_2\sin(180° - \theta_2) + L_1\sin(180° - \theta_2 - \theta_1) \quad (2)$$

$$V_H = J\omega \quad (3)$$

$$\begin{bmatrix} V_H^x \\ V_H^y \end{bmatrix} = \begin{bmatrix} g_{H1}^x & g_{H2}^x \\ g_{H1}^y & g_{H2}^y \end{bmatrix} \begin{bmatrix} \omega_1 \\ \omega_2 \end{bmatrix} \quad (4)$$

$$g_{H1}^x = \frac{\partial X_H}{\partial \theta_2} \quad (5)$$

$$g_{H1}^y = \frac{\partial Y_H}{\partial \theta_2} \quad (6)$$

$$g_{H2}^x = \frac{\partial X_H}{\partial \theta_1} \quad (7)$$

$$g_{H2}^y = \frac{\partial Y_H}{\partial \theta_1} \quad (8)$$

CONTROL

In order for the robot to be able to decide what means of locomotion is most efficient for the terrain at hand a system of whisker type feeler sensors was employed. A total of six whiskers were used, four of the whiskers are active while the robot is walking on its legs and the two other whiskers are active while the robot is on its wheels. The robot will be initiated in the walking mode due to this being a fail safe mode that allows to robot to move on both smooth and rough terrain.

The way the whisker sensors work is be monitoring the smoothness/roughness of the ground. The four walking whiskers are setup on the four corners of the robot in a position so that at a time where all six legs are on smooth the ground and the robot is level the whiskers are barely touching the ground in the ON position. The program takes a reading from the whiskers while it is walking but at an instant where three of the legs are touching the ground and in theory if the ground is smooth the robot will be level and all four whiskers will be in the ON position. If the condition of all 4 whiskers is activated the robot knows the ground is level and smooth and at this point the robot activates the wheeled locomotion mode. If the robot detects that one or more of the whiskers are in the OFF position and consequently the whisker is in the air, it determines that the robot is still traveling over rough terrain and continues to transport itself via legged locomotion.

The two wheel mode whiskers are set up in a manner so that while the robot is on the wheels on smooth ground the whiskers are barely touching the ground in the ON position. The whiskers are located at the front of the robot so that the tips are pointing to the sides of the robot on the outside of the legs and wheels. This way any differences in elevation of the two front wheels will result in one of the whiskers being in the air. While the robot is moving in the wheel mode the program is constantly checking the wheel mode whiskers. If it detects that one of the whiskers is in the OFF position it knows that the ground is no longer smooth and the wheel is elevated compared to the other wheel. This then alerts the robot that the most effective means of locomotion is with the use of the legs. This cycle is repeated constantly so the robot knows the most efficient means of transportation. Figure 7 shows a diagram of this program.

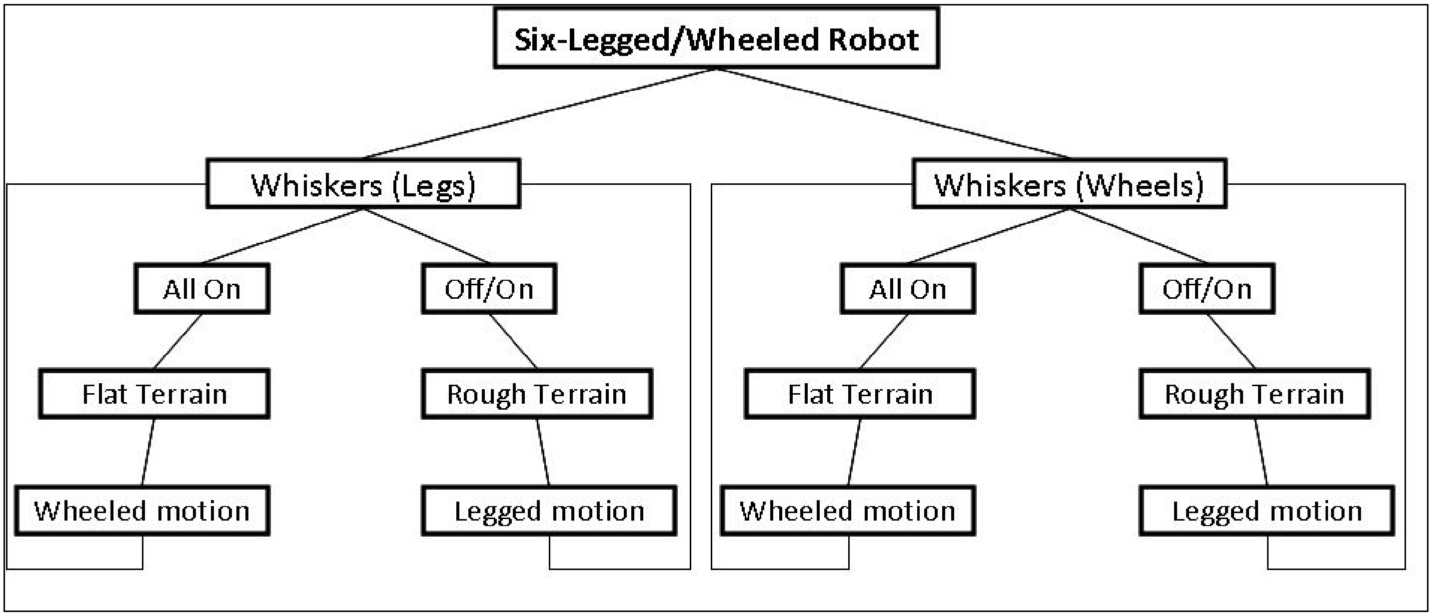

Figure 7 - Surface Detection Program Diagram

Also, for the control and programming of this robot, many conditions are needed to determine the program to be used. For each type of locomotion, a program is developed. For the legged motion, it uses the tripod gait because of its static stability. Figure 8 shows the tripod gait planning.

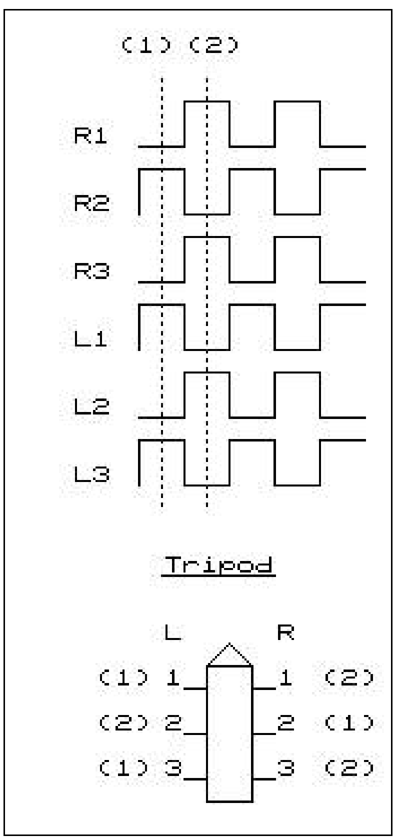

Figure 8 - Tripod Gait Planning

The Tripod Gait is the best-known hexapod gait. A tripod consists of the front and back legs on one side and the middle leg on the opposite side moving together. For each tripod, the legs are lifted, lowered, and moved forwards and backwards in unison. During walking, a hexapod uses its two tripods not unlike a biped stepping from one foot to the other - the weight is simply shifted alternately from one tripod to the other. Since three legs are on the ground at all times, this gait is both statically and dynamically stable. The movement scheme is easily visualized by examining Figure 8; the numbers adjacent to the legs in the body diagram correspond to time points on the graph

For each type of locomotion, the robot has to locate objects in its field of vision and determine if they are simple obstacles or targets. The first step to reach such decision is for the robot to be constantly using the ultrasound sensor for detection of obstacles. If in fact an obstacle is detected within a certain distance, the robot will use the thermal array sensor in order to see if the obstacle detected is a target. The thermal array sensor will provide information about the object, if the object is hot the robot will deem it as a target and then the BB gun on the top of the platform will position and shoot the target. After successfully shooting the target the robot will continue its regular search pattern looking for other obstacles and targets. On the other hand, if the thermal array sensor determines that the object is cold, the robot will treat the object as an obstacle. Therefore the robot will stop, back up, turn, and move forward in order to change its orientation relative to the object. This procedure will constantly be repeated by the robot. A diagram of this procedure is shown in Figure 9.

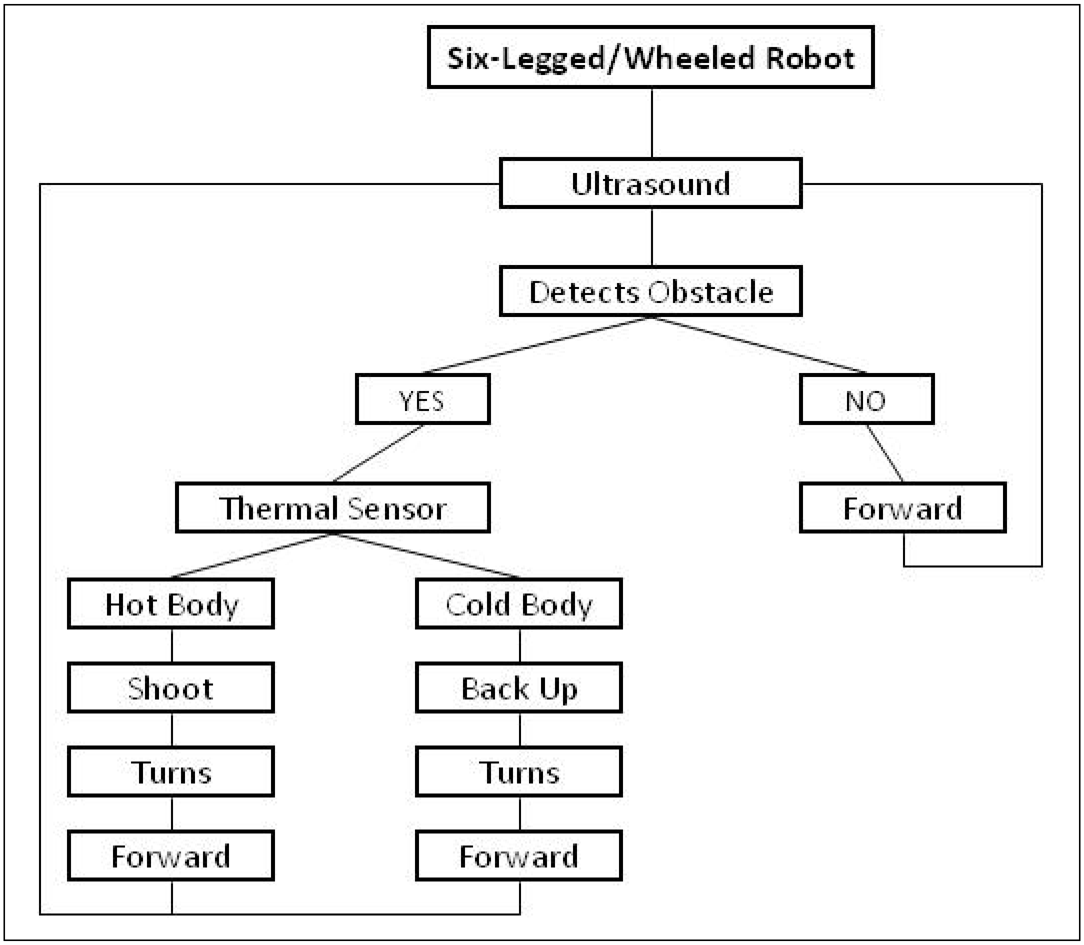

Figure 9 - Detection of Obstacles and Targets Diagram

RESULTS

At this stage, the project is able to perform both types of locomotion. It successfully uses the wheeled locomotion for a fast and efficient mode on flat surfaces, and the tripod gait motion when the robot performs on rough terrain. First, the legged locomotion was tested without using any obstacles until the desired motion was found. Then, the wheeled locomotion was tested producing great results on a flat surface.

After being able to produce both motions successfully, the ultrasonar sensors were incorporated to both of the sub-programs of each of the locomotions. The addition of these sensors to the programs caused many difficulties since the sensors did not provide information about the distance of the obstacle right away. For this reason, many tests were run until the sensors were able to provide the necessary information. In both the legged and the wheeled locomotion, the robot is able to determine and avoid obstacles by changing direction and continuing its motion.

For the purpose of this project, an ultrasound sensor was placed at the bottom-front of the robot in order to determine the type of surface. If the distance read by the sensor is constant while the robot is performing the wheeled locomotion, then the robot will continue in this motion.

However, if there are changes in the distance to the ground, the robot will infer that it is on rough terrain and it will automatically change to the legged locomotion. The same procedure is used when the robot is performing the legged locomotion; if the distance read from the sensor does not change, then the robot will go back to the wheeled locomotion.

This system replaced the original idea of using the whiskers for the surface detection system because of time issues. This system produced many challenges, but at the end, the robot was able to change the locomotion every time it was needed.

This type of hybrid robot proves to be very effective when used in unknown environments in which changes of surface can occur. However, the target detection system was not included in the prototype of this project for reasons pertaining to time, complexity and cost. Figure 10 shows the robot performing the legged locomotion on a rough terrain. Figure 11 shows the robot performing the wheeled locomotion on a flat surface. The figures also present all the changes made to the body of the robot.

Figure 10 - Final Robot Assembly (Legged Motion)

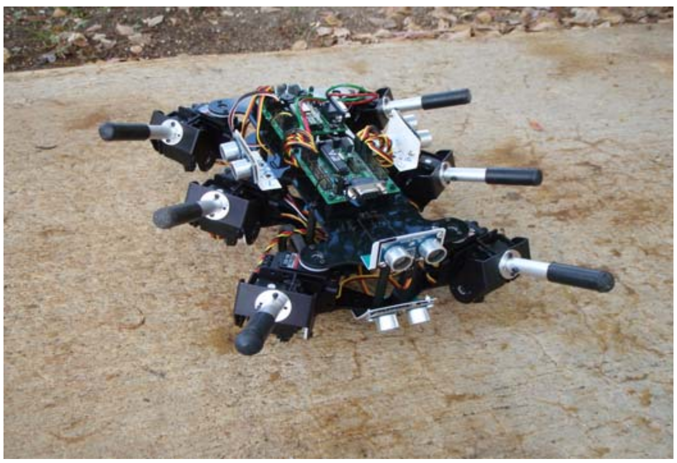

Figure 11 - Final Robot Assembly (Wheeled Motion)

FUTURE ENDEAVOURS

In order for the effectiveness of the robot to be increased for future real world use, a number of improvements have been considered. The main objectives of these improvements deal with enhancing the robots features/capabilities as well as simplifying its components with the aim in increasing reliability. The most significant addition to the robot would be an on board GPS tracking system that would be able to communicate with an external computer. The main advantage of a system like this would be that the operator would be able to simplify the programming of the robot to work in different areas. At the current time the operator needs to specify a home point/base for the robot and the dimensions and shape of the area the robot needs to patrol. With a GPS system the operator would be able to simply either draw a boundary on a digital map or physically with the use of a hand held GPS mark the perimeter of the area to be patrolled. In the case of drawing the perimeter on a digital map the computer would then automatically transmit to the robot the coordinates of this drawn boundary.

Another improvement that has been considered for the robot deals with the addition of a visual camera that can wirelessly broadcast an image of its surroundings to an operator. Even though the robot is able to operate autonomously, the ability for the operator to see what the robot sees, or at least be able to at later time review footage of its mission would be very valuable for safety and political reasons. In order to improve the versatility of the robot, a tank style track system could be adapted instead of using traditional wheels. The advantage of a tank style track over traditional wheels is that both are capable of achieving high speeds but the tank tracks are able to achieve high speeds over semi rough terrain due to their increased footprint and traction. To increase the reliability of the robot the ideal scenario would be to decrease the number of individual components. At its current state the robot utilizes six whisker style feel sensors in order to determine the type of terrain it is traveling over. The most viable option for this goal would be to implement a laser measuring system that could be mounted to the underside of the robot. This system would be capable of measuring the distance to a number of points around the robot in order to determine the characteristics of the surrounding terrain.

CONCLUSION

The Six-Legged/Wheeled Robot was designed with the main objective of having a robot that was able to transport itself over various terrain types swiftly and efficiently. Over rough terrain the robot uses a legged locomotion mode that allows it to craw over varied and unsteady terrain. This method is slow but a sure means of transportation over rough terrain. The second means of transportation was wheeled locomotion. Wheeled locomotion has the advantage of allowing rapid and precise transportation. Because of the two separate continuous servo motors used the robot is able to make quick turns in any direction to avoid obstacles. Overall these two functions were successfully implemented and executed. The secondary aspect of the robot deals with its ability to act as a security force. With the use of its ultrasound sensors and thermal array the robot is able to autonomously explore a predefined area looking for obstacles and targets. Because the robot is designed to operate in hostile areas it is equipped with a weapon that is able to inflict terminal injuries on living beings that may pose a security threat to its mission. In order to further advance the functionality of the robot a number of improvements have been considered and studied. With the improvements of a GPS navigation system, improved wheeled locomotion via the use of tank tracks, a video camera and improved ground characteristic recognition sensors The Six-Legged/Wheeled Robot will be a major addition to any units armed forces.

REFERENCES

[1] Salermo, A., and Angeles, J., 2007, “A New Family of Two-Wheeled Mobile Robots: Modeling and Controllability,” IEEE Transactions on Robotics, Vol. 23, No. 1.

[2] Wenjie Chen, L., and Yeo, S., 1998, “Adaptive Gait Planning for Multi-Legged Robots with an Adjustment of Center-of Gravity.” Robotica (1999) volume 17, pp. 391–403.

[3] Angeles, J., 2005, "An Innovative Drive for Wheeled Mobile Robots." IEEE/ASME Transactions on Mechatronics, Vol. 10, No. 1.
[4] Larin, V., 2005, "Control of Wheeled Robots." *International Applied Mechanics*, *Vol. 41*, *No. 4*.
[5] Silva, M., and Machado, J., 2007, "Kinematics and Dynamic Performance Analysis of Artificial Legged Sytems." Robotica (2008) volume 26, pp. 19–39.
[6] Rizzi, A., and Mason, M., 2003, "Legless Locomotion for Legged Robots." The Robotics Institute, Carnegi Mellon University.
[7] Go, Y., and Yin, X., and Bowling, A., 2006, "Navigability of Multi-Legged Robots." IEEE/ASME Transactions on Mechatronics, Vol. 11, No. 1.
[8] Erden, M., and Leblebicioglu, K., 2007, "Torque Distribution In A Six-Legged Robot" IEEE Transactions on Robotics, Vol. 23, No. 1.