# Design and Construction of Mobile Surveillance Robot

David Walters, Molly Harrington, Nicholas Keller, Firas Hassan, and David Mikesell
Ohio Northern University, d-walters@onu.edu, m-harrington@onu.edu, n-keller@onu.edu, f-hassan@onu.edu, d-mikesell@onu.edu

***Abstract* – A cross-disciplinary team of eight students is developing a self-righting mobile surveillance device as an engineering capstone experience. The goal is a robot that can be controlled wirelessly from a location without line of sight, provide live video feedback, and operate for at least a ten-minute time period. Mobility, durability, range, duration of use, and surveillance capabilities are all aspects that were considered during the design of the device.**

*Index Terms* – Capstone, robot, surveillance.

## INTRODUCTION

This project involves the development of a self-righting Mobile Surveillance Robot (MSR). The goal is for the final design to be controlled wirelessly and provide live video feedback to an operator beyond the line-of-sight of the robot The focus criteria for this design mobility, durability, range, duration of use, and surveillance clarity.

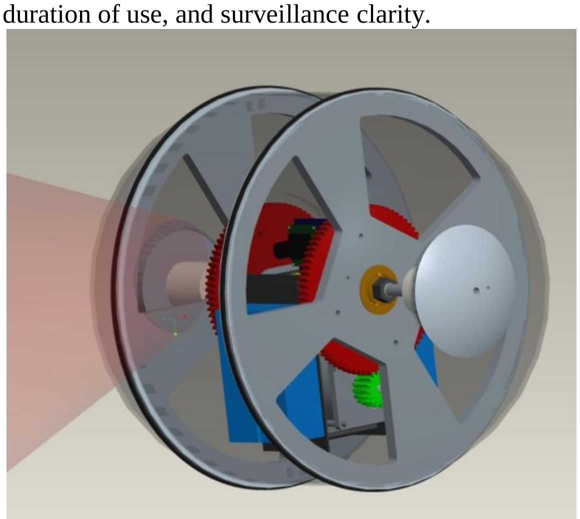

FIGURE 1
MOBILE SURVEILLANCE ROBOT

The robot is being designed and built by a team of eight undergraduate engineering students. Four mechanical engineers are primarily responsible for the structural design and fabrication. Two computer engineers are handling the wireless communication and control and sensor integration. The two electrical engineering students have designed the power distribution and management system.

## CAPABILITIES

To define the desired functionality of the MSR design, the following capabilities were identified. These are general driving concepts of the design used to derive requirements, constraints, or specifications.

- The surveillance robot should be deployable by one person.
- The device should be controlled by the operator while he/she is outside of the room being searched.
- The device should relay live video feed to the operator. The quality of this video should be such that the operator can navigate obstacles and detect the presence of people in the room visually.
- The device should be able to proficiently navigate over flat common household floorings such as tile, carpet (excluding thick shag), hardwood flooring. It should also be capable of ascending a standard handicap access ramp.
- The mobile surveillance robot should be self-righting in the event of being turned on the side, or upside down.

## REQUIREMENTS

Design requirements, both quantitative and qualitative, were established in order to ensure that the MSR possesses the capabilities identified in the capabilities section of this paper. These requirements are listed below.

- The entire device shall be no larger than 18 inches in diameter so that it can easily be carried by one person and has the ability to navigate around a room.
- The device shall have a range of a minimum of 100 feet when an operator is located outside a room.
- The device should have enough torque to be able to climb at least a 5° incline.
- The device will relay live video feed to the controller of the device.
- The device should have the ability to navigate in dark rooms using a night vision camera.
- The device should have a low center of gravity to allow the device to turn upright onto the treads if it falls off of a small step.

### ALTERNATIVE DESIGNS

There were three different designs considered for use: a hanging weight design [1], a "hamster ball" driven design[2], and a dual-tread design[3]. The capabilities and requirements were considered along with several other criteria when generating these design possibilities.

The hanging weight design consisted of a central shaft with a carriage hanging from the shaft as displayed in Figure 2. The carriage would have the ability to rotate around the shaft which would allow for movement forward and backwards. The carriage would also have a small weight inside which would shift side to side to allow the sphere to tilt from side to side while moving forward or backward, and in so doing provide a turning capability.

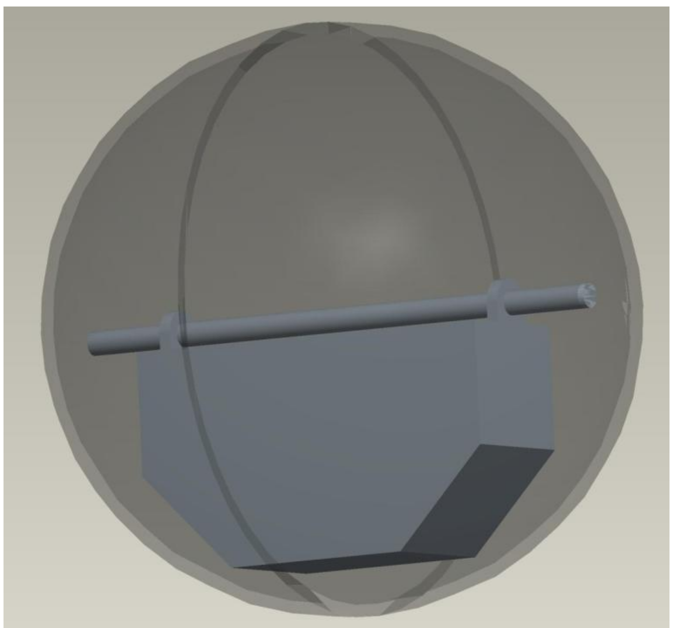

FIGURE 2
HANGING WEIGHT DESIGN

The "hamster ball" design would operate similar to how a hamster is able to move around in a plastic ball. A robot would be contained within a clear plastic sphere with controllable wheel(s) at the bottom that roll along the inside of the sphere. The wheel(s) would be able to rotate so that the sphere could travel in any direction. It would also contain stabilization arms that would keep the robot centered, the wheel(s) in contact with the sphere, and would also protect the components inside the robot if the sphere were to suffer a sudden impact. A sketch for the "hamster ball" design is displayed in Figure 3.

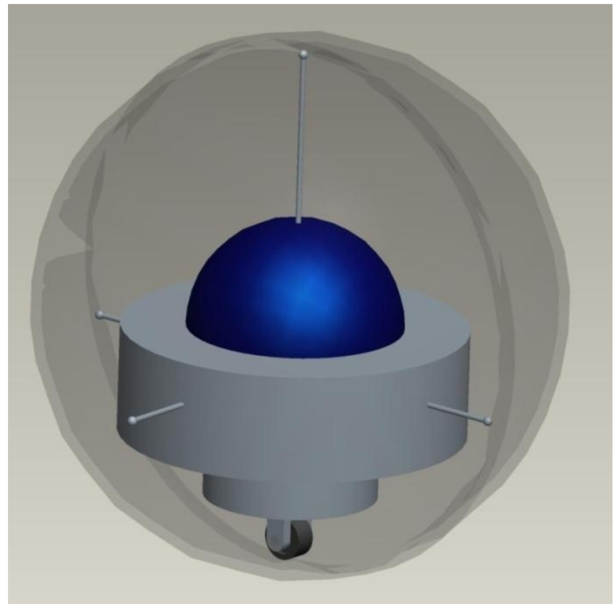

FIGURE 3
HAMSTER BALL DRIVEN DESIGN

The dual-tread design would contain two wheels that have the ability to turn in opposite directions to allow for a zero turn radius. The design would not be perfectly spherical, but would still retain the benefits of a spherical design. A model of the dual-tread design is displayed in Figure 4.

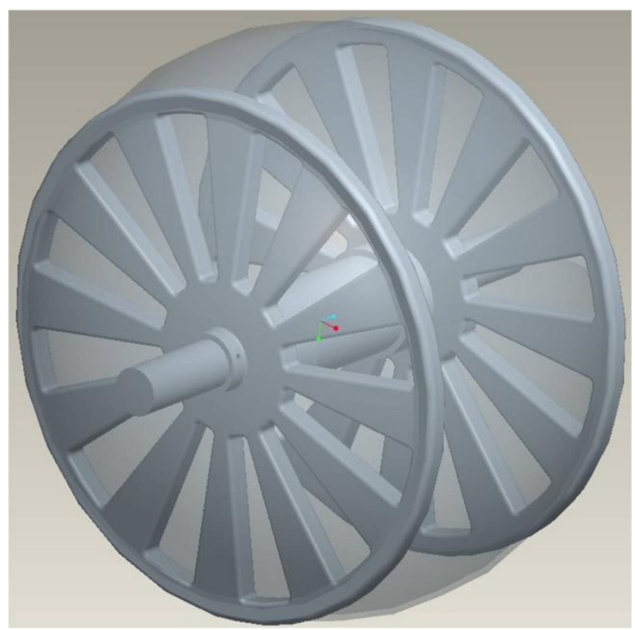

FIGURE 4
DUAL-TREAD DESIGN

All three of these designs were evaluated using a decision matrix that included several design criteria important to the project. The results can be seen in Table 1.

TABLE 1
DECISION MATRIX

| Criteria | Weight | Hanging Carriage | | Hamster Ball | | Dual-Tread Sphere | |
|---|---|---|---|---|---|---|---|
| | | Score | Total | Score | Total | Score | Total |
| Stability | 25 | 0.0 | 0.0 | 0.5 | 12.5 | 1.0 | 25.0 |
| Cost | 10 | 1.0 | 10.0 | 0.3 | 3.3 | 0.0 | 0.0 |
| Durability | 8 | 0.5 | 4.0 | 0.0 | 0.0 | 1.0 | 8.0 |
| Power Use | 6 | 1.0 | 6.0 | 0.0 | 0.0 | 0.5 | 3.0 |
| Feasibility | 10 | 1.0 | 10.0 | 0.0 | 0.0 | 1.0 | 10.0 |
| Mobility | 15 | 0.0 | 0.0 | 0.8 | 11.3 | 1.0 | 15.0 |
| Ease of Assembly | 8 | 1.0 | 8.0 | 0.3 | 2.7 | 0.0 | 0.0 |
| Size | 5 | 0.0 | 0.0 | 0.7 | 3.3 | 1.0 | 5.0 |
| Complexity | 5 | 1.0 | 5.0 | 0.0 | 0.0 | 0.3 | 1.7 |
| Clarity | 8 | 0.3 | 2.7 | 1.0 | 8.0 | 0.0 | 0.0 |
| **Total** | **100** | | **45.7** | | **41.1** | | **67.7** |

The design that was selected based on the specified criteria was the dual-tread design. It was determined that the dual-tread model would be the most stable and the most mobile due to its wheeled design. It should also be easier to insert equipment inside of the dual-tread design, allowing for a smaller size which will benefit the mobility of the robot both in-use and for transportation.

## PROPOSED SYSTEM DESIGN

The design chosen to fulfill the requirements is a dual-tread robot with a capsule shape as shown in Figure 5.

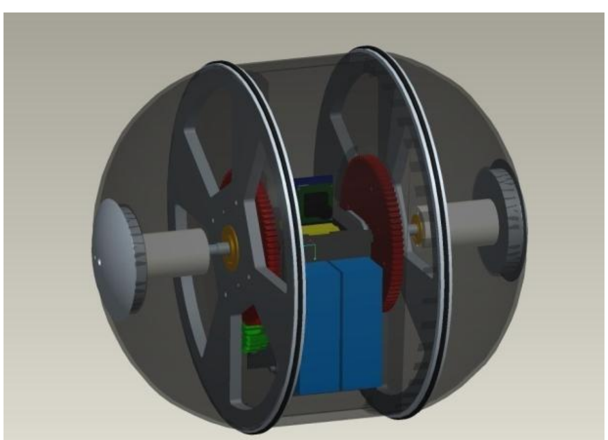

FIGURE 5
DUAL-TREAD ROBOT DESIGN

The middle cylindrical-section of the robot is stationary while the two wheels are domed on the outside and are controlled separately, allowing for a zero-turn radius. The mechanical, controls, data acquisition, and power subsystems are contained within the middle section of the robot.

The elements of the subsystems are mounted in such a way that the center of gravity is well below the geometric center of the robot. The camera and transmitters are mounted closer to the center of the section, on the shaft. This allows for a minimization of interference in the signals due to the motors and power systems. The power subsystem is mounted near the bottom of the containment section to provide stability and to also prohibit interference from the mechanical systems to the power performance.

The different subsystems are hard-mounted to the shaft for strength and stability. The central shaft remains relatively stationary as the wheels rotate around the shaft. The outer shell of MSR is made of polycarbonate to increase strength and durability, while also allowing for optical clarity. Polycarbonate also has a low electrical conductivity, which is beneficial for the power system design.

## DESIGN OF MECHANICAL SUBSYSTEM

The drive train for the Mobile Surveillance Robot consists of two (2) electric motors, four (4) gears, a stationary shaft, and two (2) wheels with bearings. The motors drive the two sets of gears, which are attached to the wheels. The wheels are attached to the stationary central shaft through the use of internal bearings.

The electric motors were selected to meet several specified criterion including maximum voltage, maximum power, minimum torque, minimum rotational speeds, and overall dimensions. The required torque was calculated based on a 10 lb design with traveling up a 5˚ ramp with an acceleration of 2 ft/s$^2$. The required rotational speed was based on a desired speed of 5 ft/s. The desired length was the maximum length possible to mount the motors back to back in the center of the robot.

Based on these criteria, a Portescap B-230013-12A brushless DC motor was chosen for use in the MSR. Table 2 summarizes the desired specifications and the actual specifications of the motor chosen.

Table 2: Motor Specifications [4]

| Criterion | Desired Specification | Motor Specification |
|---|---|---|
| Max. Voltage | 12 V | 12 V |
| Max. Power | 20 W | 28.8 W |
| Min. Torque | 0.75 in-lb | 1.0 in-lb |
| Min. Rotational Speeds | 480 RPM | 2650 RPM |
| Length | < 1.75 in | 1.44 in |
| Diameter | < 1.5 in | 2.22 in |

The diameter and power consumption of the selected motor were larger than desired. However, due to a difficulty meeting all of the desired specifications, it was decided that this motor would be acceptable for the design.

The gears were initially selected based on dimensional requirements of the motor so that the motor would be approximately 3 inches below the center of the shaft. The reason the motor was to be placed at this location was to prevent electromagnetic interference with data collection, transmission, and control signals from the motors. A secondary design requirement was to have a large gear ratio because DC motors generally have a high rotational speed and a low torque which needed to be stepped down for the MSR's desired speed. The two spur gears that were selected had a pressure angle of 20˚and a pitch of 16. The large gear is made of nylon and the pinion in made of steel. The large gear has a pitch diameter of 5 inches with a 0.5 inch bore. The small gear has a pitch diameter of 1 inch with a 0.25 inch bore. The large gear was modified from the stock design. The bore was increased so that it has a clearance fit around the bearing on the shaft, and four small holes were drilled into the wheel to allow it to be attached to the large gear. Also, the hubs on all gears were removed because of width constraints. Figure 6 shows how the motors and gears fit in the MSR assembly.

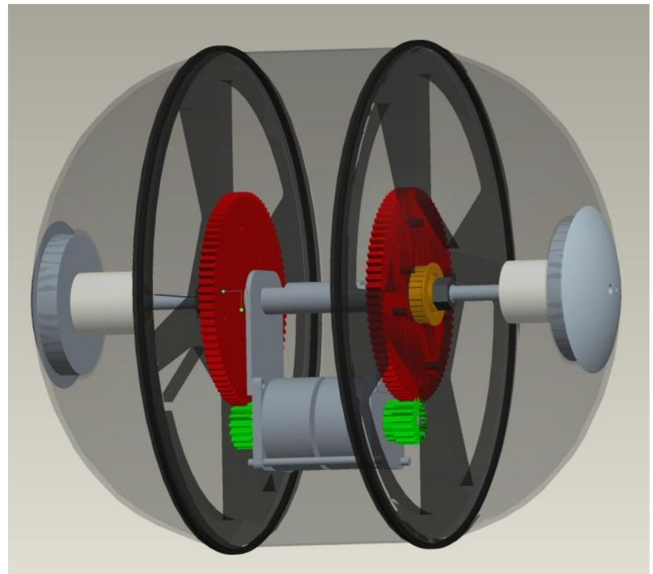

FIGURE 6
MECHANICAL DRIVE SYSTEM

The central shaft supports the two (2) hemispheres and the central cylinder. The wheels are attached to the shaft with bearings. The shaft also serves as a mount for the camera, motors, batteries, and other electronic equipment. The shaft is made from 0.75 inch diameter circular aluminum stock that is approximately 12 inches long. It has six (6) step changes as shown in Figure 7 to facilitate the mounting of the bearings and the camera:

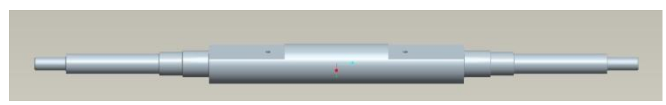

FIGURE 7
SHAFT DESIGN

The two (2) wheels were made from two 12 x 12 x 0.375 inch polycarbonate plates. Polycarbonate was chosen because it is a durable plastic that is permeable to electric signals. The plates were machined to 12 inch diameter wheels with cutouts (spokes) to reduce weight and provide access to the space outside the wheels. A finite element analysis was conducted using ANSYS Workbench® that verified that the wheels would still have a safety factor above 10 when a 10 lb load was apply. The wheels also have a groove on the outer edge to allow a wide o-ring to be attached to provide traction and durability to the wheels. The outer race of the bearing was press-fit onto the 1.375 inch bore of the wheel. The inner race of the wheel's bearing was secured onto the 0.5 inch diameter section of the central shaft by threading the shaft using a nut to fix it in place.

## Design of Controls Subsystem

The design chosen to control the motors of the robot is that similar to a remote control car. The system has one six channel 72MHz computer radio that transmits using pulse position modulation. The radio uses a rechargeable battery pack which eliminates the need for replacement batteries. A six channel FM receiver is used to receive the pulse position modulation signal from the radio and convert the signal to a pulse width modulation. The signal is then sent to the two motor controllers which determine the speed and direction of the motors. The additional channels could be used for future applications. The motor controllers that were selected are capable of handling input voltage of up to 25 volts. They also allow the motor controllers to be connected to a computer by a USB device that allows for the acceleration and deceleration curves to be manipulated, providing optimal performance and power consumption. The motor controllers used are also able to detect when the batteries are below the minimum voltage to operate and will shut down to protect the batteries from damage. The control system is powered by the same battery, and the motor controllers provide power to the receiver which will eliminate the need for extra wires. Figure 8 displays the wiring diagram for the control system.

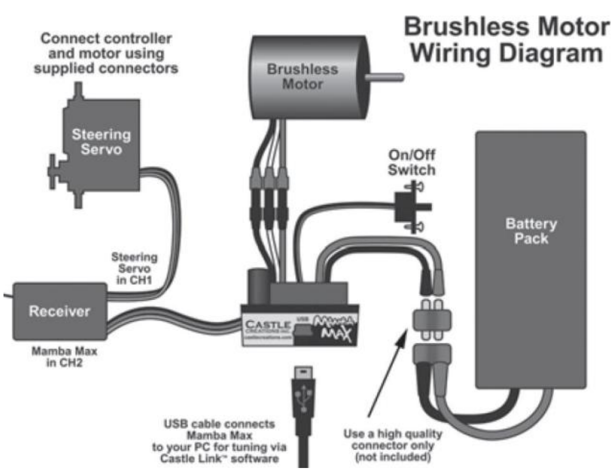


FIGURE 8
WIRING DIAGRAM OF CONTROL SYSTEM [ 5]

A computer is used to interface with the RF transmitter through a National Instruments data acquisition device to send control signals to the robot. Computer software was developed to generate the signal that is sent out by the transmitter to the robot. The system allows for predefined movements to be programmed as well as adjust the sensitivity of the control system. An Xbox controller then can be attached to the computer and used as an analog input to the software so that the robot can be easily driven. Actions can also be assigned to the buttons on the keyboard and controller to perform specific actions.

## Design of Data Acquisition Subsystem

The data acquisition consists of one wireless camera that requires 12 Volts and 0.5 Amps. The camera includes its own transmitter that operates at 2.4GHz. The camera transmits to a receiver that is connected to a display at the base station.

Future expansions of the system would allow the camera feed to be displayed on a computer as well as recorded, either onboard the robot or at the base station. Additional data sensors may be incorporated into the design such as a temperature sensor or a sensor that detects various environmental conditions.

## Design of Power Subsystem

The power system is designed to operate with four batteries. Each of the motors require 12 V and a maximum current of 2.4 A. Two lithium polymer batteries are used to power the two motors. The chosen battery provides 14.8 V and 2.2 Ah, allowing for a 25% contingency in power flow management. A third battery is also connected to the motor subsystem in order to allow for a longer life before charging. Lithium polymer was selected because a large enough voltage and current can be provided while the battery itself is relatively small. The chosen camera also operates at 12 V, so the same type of lithium polymer battery is used. While the camera has a receiver built into it, the robot requires a receiver for the controller. The acquired receiver does not need an additional power source; therefore, no battery is needed.

The decided optimal system design for the power management requires an isolation of two subsystems. This allows for a minimal interaction of the electromagnetic fields and ambiguous current flow. It also allows the design process to focus on the specifics of the current and voltage for each of the elements in the overall object design of the robot.

The first system is designed for the management of the motor control system. This system requires an integration of the controls systems and the power systems, as well as the mechanical motors. The system is designed with three of the four batteries in parallel. This is allowable because the speed controllers can regulate the current supplied to the motor. A voltage regulator is also present to step down the 14.8 V source to the required 12 V. The presence of a second battery allows for the achievement of the optimal current requirement for the desired ten minutes of peak operation. The third battery is present in the case that one of the batteries fail as well as to provide more power to the system overall. The circuit used in this subsystem can be seen below in Figure 9.

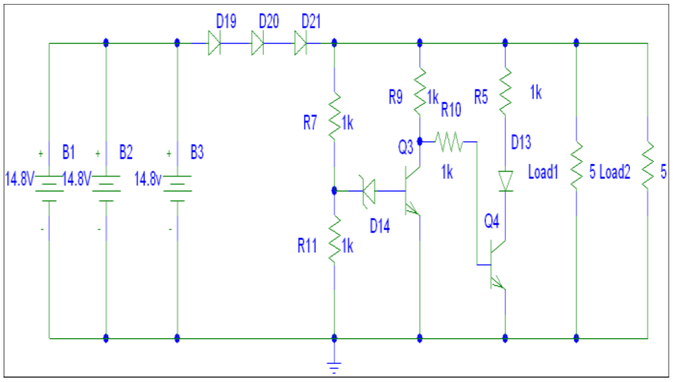


FIGURE 9
MOTOR SUBSYSTEM CIRCUIT

The physical design of the robot allows for the four batteries to be positioned in the lower half of the middle section. This assists in the self-righting ability of the ball. Sufficient distance was maintained between the batteries and the motors to prevent interference with electromagnetic fields. This is important to the operational performance of the robot and prevents the lithium polymer batteries from losing the ability to recharge.

The second system is designed to power the data collection unit. Only one battery is needed for the power requirements over 10 minutes. A transistor acts as a switch to protect the batteries from using all of their charge. The circuit for the camera subsystem is shown below in Figure 10.

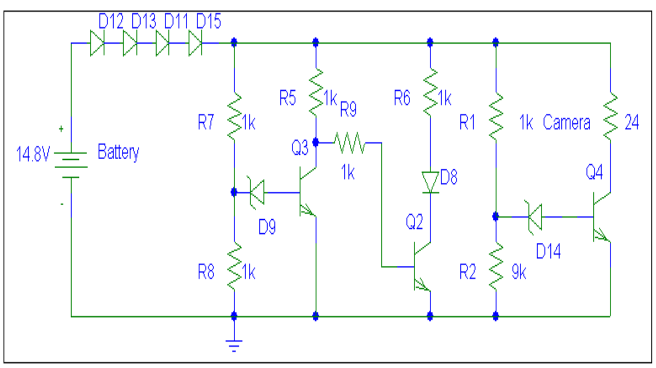


FIGURE 10
CAMERA SUBSYSTEM CIRCUIT

A manual three way switch is present in order to connect to the separate charging circuits for each subsystem. This will isolate the rest of circuit during the charging process. A low battery indicator is also present in both circuits. This low battery indicator consists of two transistors and an LED, which will turn on at a specified voltage. The indicated voltage is set to allow enough power to keep the speed controllers in operation and return the MSR to the user. The LED for the motor subsystem is visible to the camera so the operator of the device knows to bring the MSR back for recharging and data collection.

## CONCLUSION

In this project, several alternative designs were considered and compared based on their ability to meet the requirements established by the design team. The requirements were created in order to assure that the robot was able to be controlled wirelessly from another location without line of sight, provide live video feedback, and have at least ten minutes of full operational capabilities. Other criteria considered in the comparison of the design alternatives were stability, cost, durability, power consumption, feasibility, mobility, manufacturability, size, and surveillance clarity. It was concluded that a dual tread capsule shape design would best fulfill these requirements established by the design team. Once this design was chosen the eight-student design team divided the design into four subsystems to better utilize the specialties of each team member. The subsystems consisted of a mechanical subsystem, created by the four mechanical engineering students on the design team, a control and a data acquisition subsystem, both created by the two computer engineering students on the design team, and a power subsystem created by the two electrical engineering students.

## REFERENCES

[1] Perterdewnl. "Balbot." *YouTube*. 20 June 2007. Web. 11 Oct. 2009. <http://www.youtube.com/watch?v=Be2dYIG7Urs>.

[2] Rusil. "Spherical Autonomic Robot S.A.R." *YouTube*. 28 June 2006. Web. 11 Oct. 2009. <http://www.youtube.com/watch?v=c9Uph7oyV8s>.

[3] Palmisano. "Cyclone RC Robot Kit." *YouTube*. 20 Apr. 2008. Web. 11 Oct. 2009. <http://www.youtube.com/watch?v=GaPTQMg71SI>.

[4] "B-230013-12A Spec Doc." *Portescap*. A Danaher Motion Company. Web. 8 Feb. 2010. hhttp://www.portescap.com/BrushlessSlottedDC>.

[5] *Drivers Ed Guide Instruction Manual for All Castle Creations Car and Truck Brushless Power Systems*. Castle Creations, 2009. Print.