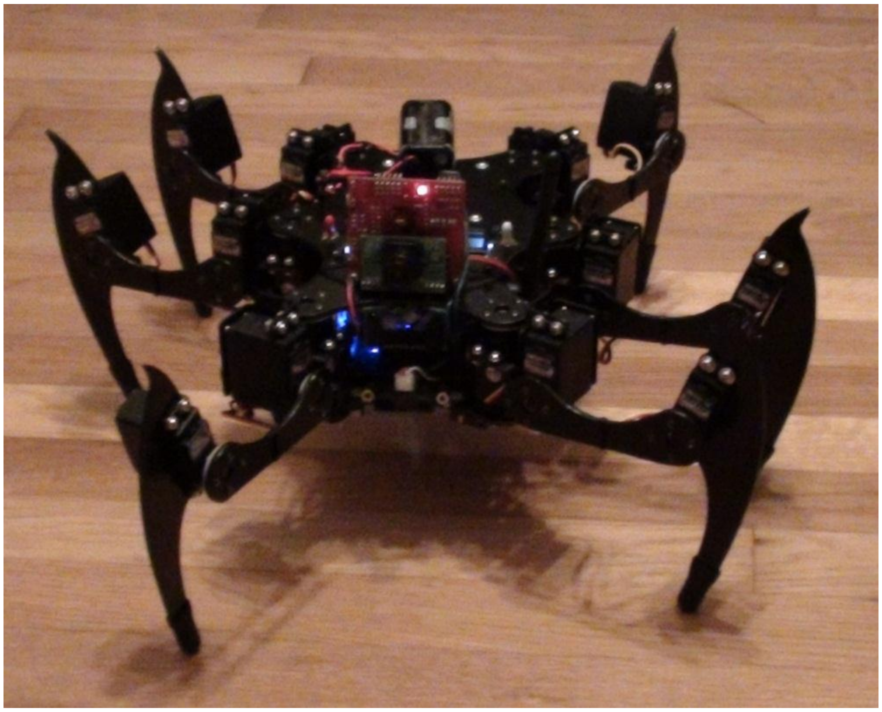
S.P.D.R.

Security Patrol and Defense Robot

Joshua Weaver

December 6, 2010



University of Florida
Department of Electrical and Computer Engineering
EEL 5666C – IMDL – Final Report
Instructors: A. Antonio Arroyo, Eric M. Schwartz
TAs: Mike Pridgen, Thomas Vermeer, Devin Hughes,
Ryan Stevens, Tim Martin

Table of Contents

Abstract

Given the high demand for systems to provide security for businesses and home use, many methods have been created over the past few years to automate security patrol. Some systems are stationary while others still rely on multiple people to perform the patrols while using cameras and computers to assist. This paper describes the Security Patrol and Defense Robot (SPDR), a 6-legged hexapod robot that is capable of performing basic patrol throughout a building while it attempts to detect any motion. SPDR is capable of connecting to a computer or to an Android phone to transmit status data or warnings when motion has been detected. The robot has basic object avoidance to maneuver around objects within a building. SPDR is designed as a 6-legged hexapod to allow for better mobility in tight spaces along with move controlled motion of each leg.

Executive Summary

SPDR, a six-legged hexapod, was created with the main objective to patrol, detect motion, and warn an owner of any intruders. The hexapod is also capable of communicating with an Android phone, where a special application allows control over the hexapod. When turned on, SPDR waits for its owner to send the patrol command via the Android application. When active, the hexapod begins a random walking pattern. Once forty-five seconds has passed, SPDR will go into scan mode. During this mode the robot will drop down to the ground while stretching its legs out and, with the body in a low profile, SPDR is then able to attempt to detect motion with no obstructions. If any motion is detected, a warning message is sent to the Android phone to warn the user of a possible intruder. After thirty seconds, SPDR leaves scan mode and returns to patrol mode.

SPDR is capable of detecting motion using either a Passive Infrared Motion Sensor (PIR) or a CMUCam2. The PIR motion sensor simply attempts to detect any infrared movement and returns data when motion is detected. The CMUCam2 uses frame differencing to detect whether an object (no need for infrared) has moved across the view of the camera. Frame differencing is performed by loading an image into the buffer of the camera, and then comparing subsequent images to this buffer to detect changes. Comparisons are made using a histogram that looks for a specific desired threshold of image differences.

Two Infrared Range sensors and two bump sensors control the object avoidance behaviors that allow SPDR to avoid objects while it walks randomly in patrol mode. Once an object is detected close enough to the front of the hexapod, the robot will begin to randomly rotate in place. If no object is detected via the IR sensors, yet the bump sensors are triggered, SPDR will back up slightly and then turn in the opposite direction of the triggered bump sensor.

A major aspect of SPDR is the control scheme required for a 6-legged hexapod. There are various methods of allowing the robot to move using different walking gaits. SPDR is capable of fully employing a simple wave gait and a tripod gait which require a certain amount of steps. Steps are performed by sending servo position and speed data to an SSC-32 Servo Controller.

Introduction

Break-ins are an unfortunate part of everyday life. Both private and commercial property owners are concerned with keeping their property, as well as themselves, safe from intruders. In order to feel secure about their holding when they are unable to physically monitor the situation themselves, most owners turn to various types of security measures. The first and most common of these implementations is a security alarm or perimeter barrier. This approach can be overcome by intruders and so there are some issues with its ability to protect. A second and much more expensive option is the use of a human security force. This option is a less faulty method but runs the risk of corruption and life loss of said force. This option also consumes a large amount monetarily, so only well-to-do companies or homes can typically afford such a force.

This report introduces and details a moderately inexpensive and reliable third option in the design and implementation of a Security Patrol and Defense Robot (SPDR). SPDR is the main objective of a project for the Intelligent and Machine Design Lab. SPDR's main directive is to detect and warn a property owner of possible intruders. Detection is performed through a process in which SPDR will continuously watch for movement through the use of a passive infrared motion sensor and visual camera. After patrolling for a set amount of time, SPDR then use its motion sensors to scan the room. Once the likelihood of an intruder is confirmed, SPDR will then alert the property owner of the situation.

Using IR sensors, SPDR can keep itself away from walls or other objects that may move into its path, while bump sensors allow the system to detect collisions with objects. SPDR also has Bluetooth capabilities for the ability to warn the user of any detected movement.

Integrated System

SPDR uses the Pridgen Vermeer Robotics ATXMega128A1 (PVR) Microcontroller board for control of all connected components. Components consist of a sensor suite, actuators, a servo controller, batteries, and a LCD screen for feedback. The block diagram in Figure 1 shows the interface connections of all components.

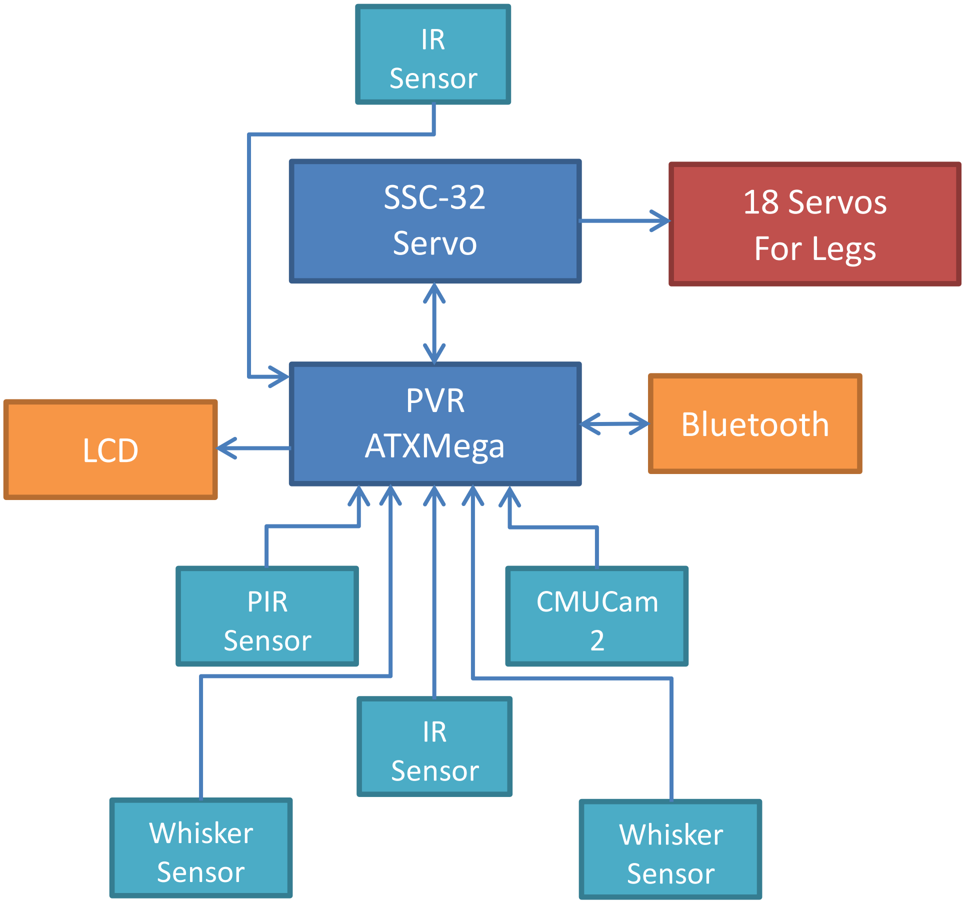


Figure 1 SPDR Block Diagram

Mobile Platform

Balsa wood is used for SPDR's platform to reduce price and weight, which allows for better mobility and flexibility of the system. The system has two primary sections: the body and the legs. The body of SPDR is made of two identical frames that are sandwiched together using standoffs. The primary processing electronics such as the PVR board are housed within the body frame to give them protection from the outside environment. The majority of the body frame is rectangular, except for pairs of appendages located at the front, back, and either side. The frame takes on a symmetrical design if split from front to back.

The legs of the system take a cue from most insect legs and have three main components: the coxa, femur, and tibia (as seen in Figure 2). The legs come in pairs and connect to each of the appendages on the body frame via the coxa, where two servos are used to create the joint. The femur is the connecting leg for the coxa and the tibia. One side of the femur connects to the two servo joint of the coxa and the other side connects to a third servo creating a joint between the femur and tibia. The tibia is the ground contact leg that allows the SPDR to walk along a surface.

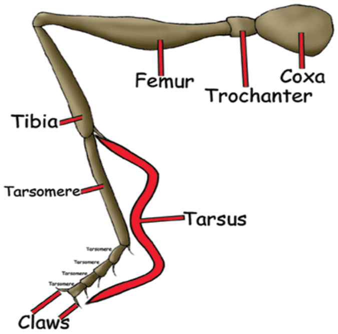


Figure 2 Insect's Leg

The creation of the body and legs was performed by modeling all parts in SolidWorks and is further discussed in the Actuation Section. Once the parts were modeled, they were cut from balsa wood and the robot was assembled.

Actuation

SPDR uses 12 Hitec HS-485HB and 6 Hitec HS-645MG servos (Figure 3) for motion control. The servos are given a six volt supply which results in a speed of .18 seconds per 60 degrees with no load. Each servo is also capable of producing up to 6.0 kg.cm of torque. Each leg of SPDR is designed to use three servos. Two servos are combined using brackets and are connected to the body at six different points to create different coxa. One of the servos allow for horizontal movement of the leg while the other allows for vertical motion. The latter servo is also connected to the femur. On the far end of the femur, the connecting joint to the tibia, a servo is used to make the connection and allows for inward and outward movement. The third servo can also serve as extra vertical extension for the legs.

Figure 3 Hitec HS-485 Servo

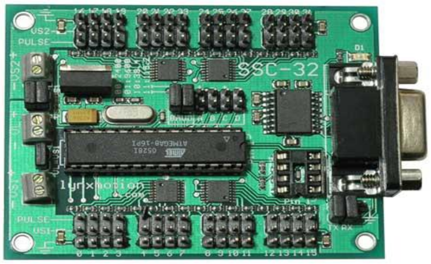


Figure 4 SSC-32 Servo Controller

Each servo connects to the SSC-32 servo controller (Figure 4) for smoother control and accurate positioning. The controller also allows for better timing of each move to allow for better sequencing of leg positions. The servo controller is connected to the PVR board via a standard TTL serial line. The combination of different commands allow SPDR to move forwards, backwards, side to side, turn, stand up, or lie low. The servo controller requires two different power lines for control. A six volt line is used for powering the servos while a nine volt line is used to power the logic controller that allows the board to function.

Mechanical actuation of the system is one of the special components of SPDR's functions. Instead of most standard wheeled designs, SPDR takes on a different design of a legged hexapod to allow for better mobility. Instead of performing coding and electronic work that has been performed before, the mechanical design and function of each leg was pursued to advance to a better understanding of mechanics. For correct balance of each leg special care was taken when sketching and scaling the components for the legs and body. SolidWorks was used to model each component and then the body components were cut out of balsa wood (Figure 5).

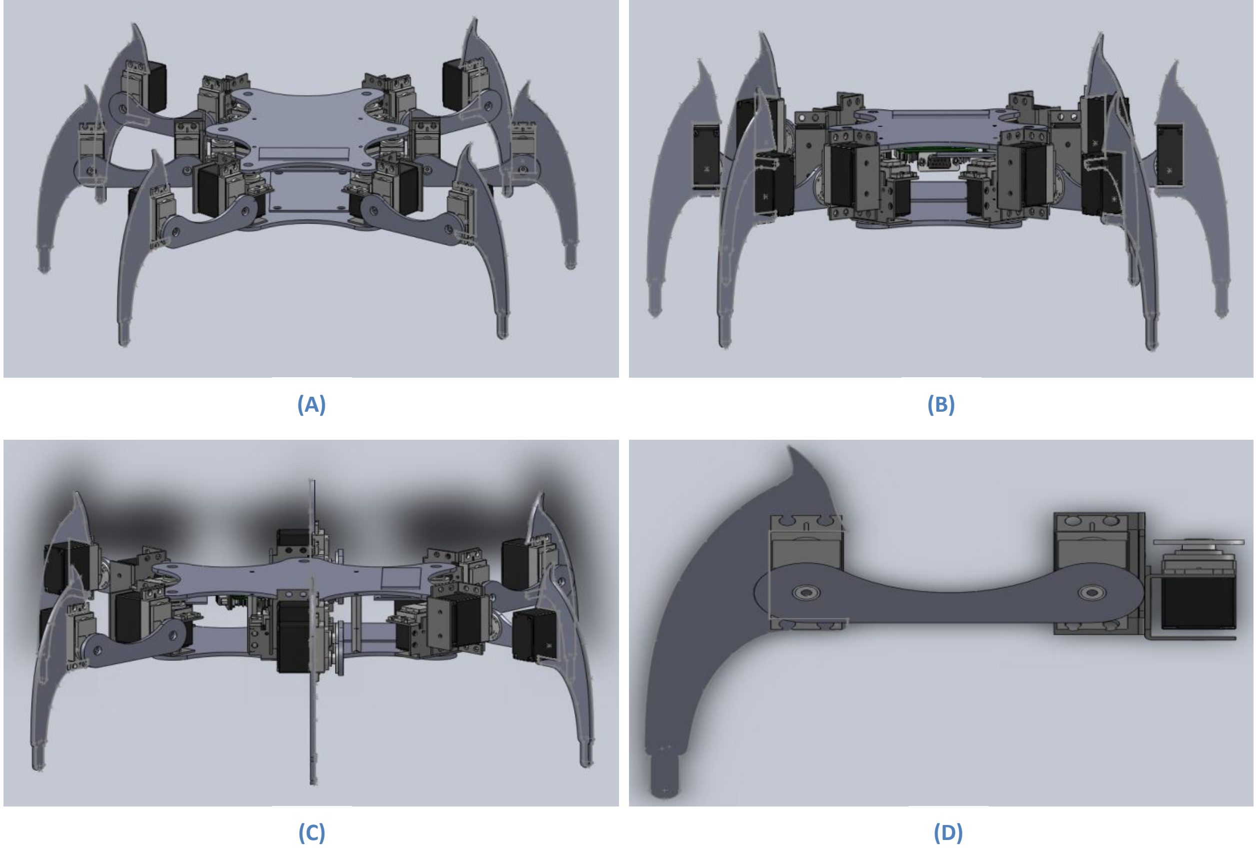

(A)
(B)
(C)
(D)

Figure 5 SolidWorks SPDR design. (A) Front View. (B) Back View. (C) Side View. (D) Close up of right leg.

As the body of SPDR was put together, actuator control was tested constantly to confirm there were no complications. Balance was tested to confirm that the robot was capable to handle free standing position while also confirming that each servo could handle holding the body weight. Servos for each leg were then put through a calisthenics test to check the capable range of each leg and characterize range and their resulting values. From here, basic routines were created for standard control of each leg, which then developed into movement routines for controlling each actuator in a certain matter for directional control.

Sensors

Two short range analog IR sensors (Sharp GP2Y0A21YK0F), as shown in Figure 6, are mounted to the body frame in the front and back of SPDR to assist in object avoidance. Each IR sensor value is read and, dependent on the direction SPDR is currently moving, will react to avoid any objects that are detected. The sensors are capable of accurately detecting objects between 10 cm to 71 cm in front or behind the robot. Object avoidance begins to occur if an object is detected within 12 cm.

For collision detection, SPDR uses two bump whiskers that are located at each corner of the front of the body. The bump sensors are a made of a simple SPDT switch, pull up resistor, and a rubber attachment. Collision detection is used to protect the legs from objects that may have been overlooked by IR sensors or during turns where IR sensors are not greatly used. The whiskers protrude slightly ahead of each leg (front and back) in hopes to detect a collision before the object comes close enough to the legs.

Figure 6 GP2Y0A21YK0F IR Sensor

Two sensors are used to perform the primary sensing that SPDR needs to perform its main directive: a Passive Infrared Motion Sensor (Sparkfun SEN-08630 PIR Sensor) and a CMUCam2 as seen in Figure and Figure 7 CMUCam2 respectively. The PIR sensor is able to detect an infrared source created from the temperature of a human or creature. An analog value is read into the PVR board that warns of possible motion detection. If the signal shows detection for a given amount of time, SPDR assumes that the source is real and then SPDR sends a message to the owner to warn them of the intrusion. The motion sensor is only capable of reaching up to 6 feet, so a more capable sensor, the CMUCam2, was added to the motion detectin scheme.

Figure 7 PIR Motion Sensor

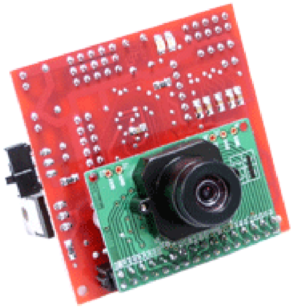
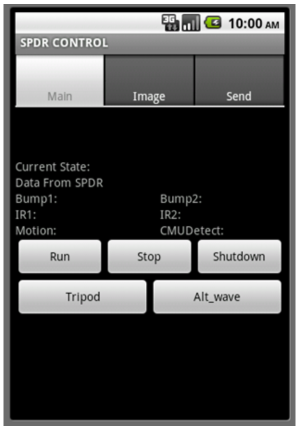


Figure 7 CMUCam2

The CMUCam2 is the first special sensor of SPDR and is used for motion detection. The hexapod uses the frame differencing ability of the camera to detect motion. During the scan mode of the robot, a snapshot image is captured and loaded to the camera's buffer. After the image is loaded, multiple images are checked against the stored image for the rest of the scan mode. The device is connected to the PVR board via the RS232 channel.

A final component of the sensor suite, and another of the special components of SPDR, is Bluetooth communications which are controlled via a BlueSMiRF RP-SMA (Sparkfun WRL-00158) device and antenna combination. The Bluetooth device is connected to the PVR board via standard TTL serial line and allows the Microcontroller to communicate to external devices as a serial device. This allows simple connection to Smartphones such as devices with the Android OS. A basic downloadable application is then used to start, end, and receive updates during SPDR's security patrol.

Figure 9 BlueSMiRF



Current State:
Data From SPDR
Bump1:
Bump2:
IR1:
IR2:
Motion:
CMUDetect:

Figure 9 Android Phone

When developing the software for the Bluetooth component of SPDR, trial runs were made using a standard laptop to confirm communication. Some issues were discovered when connecting to the PVR board due to the use of the drawn out RS-232 lines versus a required TTL line source. Distance tests have shown that the antenna does give the desired effect of reaching throughout an entire 2000 sq/ft house.

The following table summarizes the list of sensors being used on the robot. There are a few extra sensors on the robot that are not used for this project.

Sensor	**Number**	**Task**
IR Sensors	2	Object Avoidance
Bumper Whiskers	2	Object Avoidance
PIR Sensor	1	Motion Detection
CMUCam2	1	Motion Detection and Image Capture
BlueSMiRF RP-SMA Bluetooth	1	Data Communication and Control

Behaviors

Various behaviors have been created for SPDR to allow for complete control of its purpose: object avoidance, patrol, and scan behaviors. The object avoidance code is a simple routine that takes in IR and whisker sensor values to allow SPDR to avoid obstacles. During the routine, a function is called to collect IR and whisker sensor values into respective arrays. Then an evaluation function checks the arrays to decide on whether any special changes should be made to the current direction SPDR is moving. While checking the different sensors, the whiskers are made to supersede IR sensors as object collision is more important to handle immediately.

The object avoidance splits into three different types of moves dependent on which sensors are triggered. Any whisker sensor detections force the robot to immediately stop, move in reverse, and then slightly rotate in the opposite direction of where the sensor was located for a short time. For example, if the front right sensor is bumped, SPDR will back up, then turn slightly left and begin moving forward again. SPDR works on the paradigm that IR sensing is used to state that there is no way to move any further in the current direction. Once an IR value reaches threshold, SPDR will turn randomly away from the object and begin moving straight again.

The basic patrol behavior is a general behavior that runs for as long as SPDR is still being told to be on patrol. Basic patrol requires object avoidance to perform its routine. The premise behind basic patrol is for SPDR to move around on patrol for a set period of time. The basic patrol does not control turns itself, but uses object avoidance to give it the random patrol that it requires.

Once patrol time has completed, the robot will switch into the scan behavior. Scan behavior requires SPDR to drop itself to the floor and lay out its legs. This allows the motion detection sensors to be unobstructed while performing their detection algorithms. After another set amount of time, SPDR will lift itself and begin forward movement again.

Experimental Layout and Results

SPDR went through multiple changes throughout the design process. During the planning stage, the design changed back and forth between a hexapod and wheeled design due to money restrictions. The hexapod design was finally decided upon due to its difficulty and more interesting design. Time was spent sketching out different designs, taking into account different moments, center of mass, and mechanical placements. A final design was made that closely resembles the design on a hexapod known as Phoenix.

It was first desired for the design to be capable to climb up stairs and self-balance, but due to time constraints a more directed focus on using the system for random patrolling and scanning for motion was created. Originally the system contained two analog IR sensors, two digital IR sensors, four bumper whiskers, and a PIR motion sensor. However, when tests were performed on each sensor's capability it was first found that the digital IR sensors were not sensitive enough to be useful for object avoidance. Object avoidance was able to be performed using just the front analog IR sensor and the front two bump whiskers. This leaves the back analog IR sensor and the back two bump whiskers for future additions to the object avoidance behavior.

The final design of SPDR added the CMUCam2 for better motion detection. During early tests, it was found that the PIR Motion sensor wasn't capable enough to detect motion at far enough ranges. The CMUCam2 was added to allow for better range and detection of motion. The camera was also added so a raw image of whatever triggered the motion detection could be given to the owner of the robot. It has been set for future additions to display the detected image through the Android application.

Conclusion

Before joining IMDL, I had experience with working with robotic and embedded engineering. I have worked on creating and testing various behaviors with robots, but have never had to design and build a complete robot on my own. I found this to be an exciting adventure. Though it was more challenging given the mechanical design and being out of my comfort zone, I chose to create a hexapod in hopes of creating a design I had always wanted to do and would learn a great deal from. I feel that my biggest limitation was time, given how much I wanted to do and how little time I had to complete it. My biggest difficulty during the entire project was the modeling of my robot’s design in SolidWorks since I had no experience with it.

For future work, I plan on changing control of my robot to inverse kinematics rather than sequenced gaits. I also plan on adding in more advanced behaviors to allow better maneuverability over objects, thus increasing the capabilities of the hexapod.

Documentation

- PVR Board
- ATXMega - http://www.atmel.com/dyn/resources/prod_documents/doc8067.pdf
- SSC-32 Servo Controller - http://www.lynxmotion.com/images/html/build136.htm
- CMUCam2 - http://www.seattlerobotics.com/CMUcam2_manual.pdf
- BlueSMiRF - http://www.rovingnetworks.com/documents/RN-41.pdf
- GP2Y0A21YK0F IR Sensor - http://www.pololu.com/file/0J85/gp2y0a21yk0f.pdf

Appendices

The code consists of many files that can be found at the following site.

https://sites.google.com/site/epsilonorionrobotics/spdr