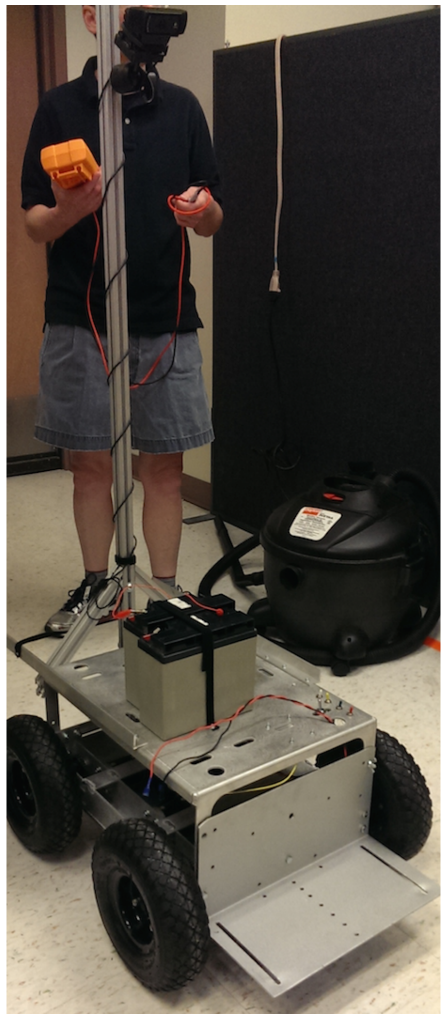
College of Engineering and Applied Science
UNIVERSITY OF COLORADO DENVER | ANSCHUTZ MEDICAL CAMPUS

2015 Intelligent Ground Vehicle Competition
"Sparky"



I hereby certify as the faculty advisor that the design and engineering of the vehicle to be entered in the 2015 Intelligent Ground Vehicle Competition by the current student team has been significant and equivalent to what might be awarded credit in a senior design course.

Wendell Chun, Department of Electrical Engineering

Table of Contents

Introduction

The Robot:

Sparky is a first generation robot built and designed by the current student robotics club members at the University of Colorado -Denver. The team is comprised of undergraduate and graduate Electrical Engineering students. University of Colorado at Denver has a long history of robotics and competing in IGVC. Between 1992 and 2000, the university placed in the top four at each year's IGVC event, including first place showings in 1998, 1999, and 2001. Since 2004 though the robotics team has been more scattered rarely having a consistent team or entering any competitions. In 2014 a new team formed with the goal of building an obstacle avoiding robot from scratch and entering it in IGVC. Six team members from last year have remained and started a beginners robotics club to recruit new members. This year there is a total of nine members with three new additions since last year working on the intelligent ground vehicle, Sparky. The team has also been fortunate to have the guidance and advice from a new faculty member who has spent his career in the robotics field, Wendell Chun. The robotics team has formed with the goal of learning through collaboration and building a lasting platform that future UCD students can build on and learn from. The following report will describe how the team has gone about building the first generation robot through hardware, software, and intelligent design.

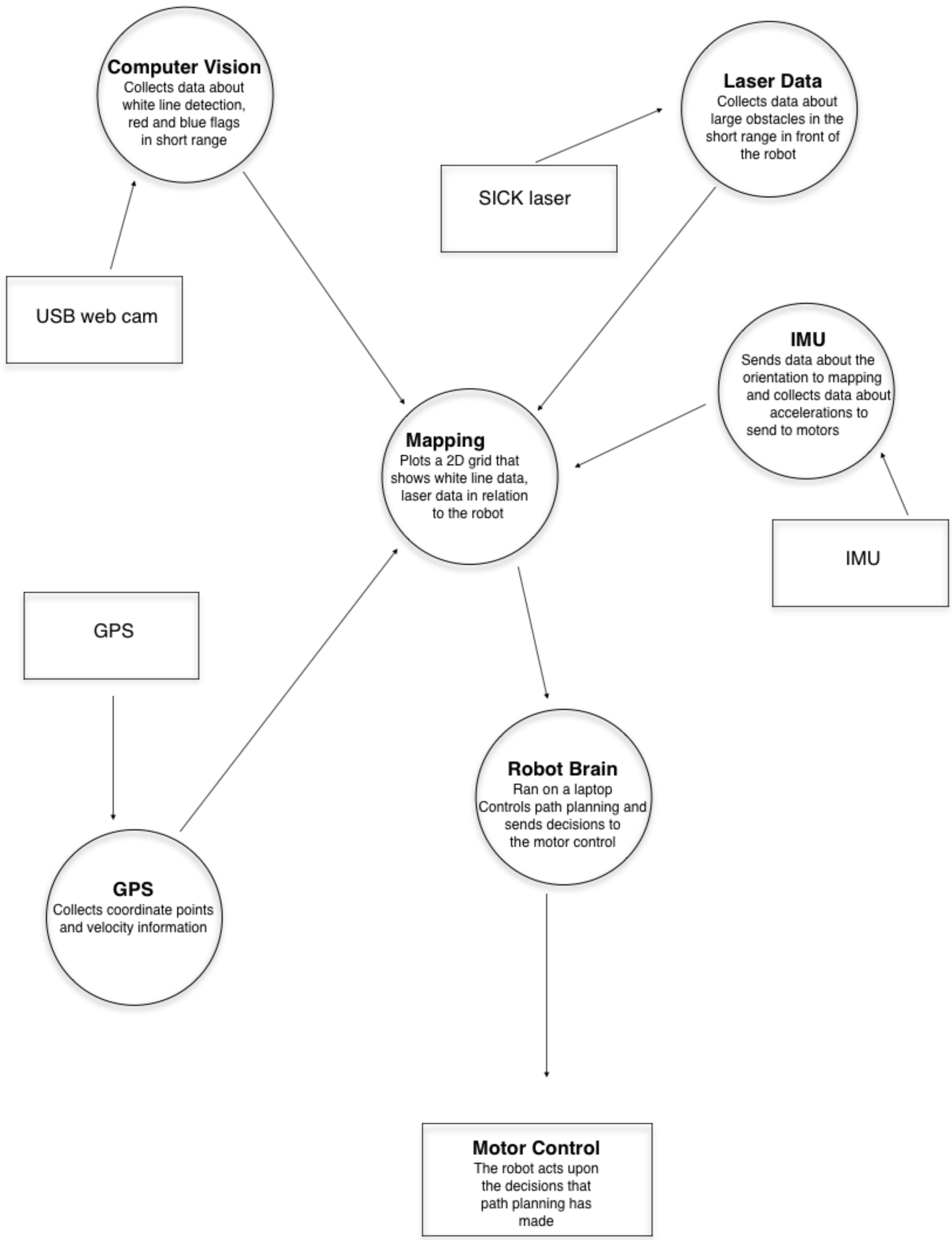
The Team Members:

Name	Year	Role	Time on Robotics
Julian Abbot-Whitley	Sophmore Undergraduate	Mapping Lead, path planning	One year
Nick Burton	Sophmore Undergraduate	Computer Vision	One year
Nse Ekpoudom	Senior Undergraduate	Computer Vision, Laser Data, Mapping	Two years
Chris Haddad	Sophmore Undergraduate	Physical Design, Computer Vision	One year
Kimberly Hoskins	Junior Undergraduate	Mapping, Path planning	Two years
Mike Morgan	Junior Undergraduate	Computer Vision, GPS Lead	Two years
Ethan Steenson	Senior Undergraduate	Physical Design Lead	Two years
Kyle Townsend	Junior Undergraduate	Physical Design	Two years
Diane Willams	Graduate	Team Lead	Multiple Years

Team Advisor:

Wendell Chun	Lecturer in the Electrical Engineering Department	Team Advisor	One year

Robot Hierarchy:



Hardware
Chassis:
The team was granted a funding opportunity in 2014 and was able to use it to purchase a chassis off of SuperDroid robots. The model purchased was the 4WD All Terrain Heavy Duty Robot Platform. The robot was built with the following hardware pieces:

Chassis, Motors			
	4WD All Terrain Heavy Duty Robot Platform - IG52 DB Options: Four IG52-04 24VDC 285 RPM Gear Motors with Encoder, 10 inch tires, Sabertooth Dual 25A Motor Driver, Spektrum DX5eTransmitter with AR600 Receiver	SuperDroid Robotics	TP-170-052
	ATR Upper Deck and Sensor Mount	SuperDroid Robotics	TD-130-000

The robot chassis was expanded upon in order to house the electrical components. A rod was built on top to carry the GPS and camera. A mount was added to the front for the SICK laser and another to the back that is used to strap on the computer that will run the system processes for the robot.

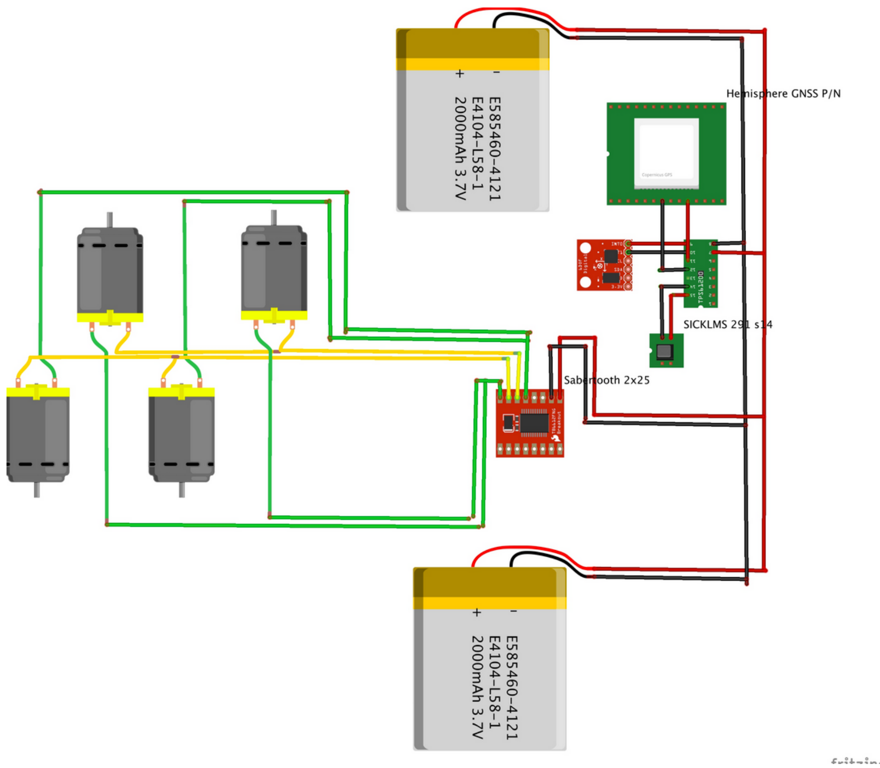
Electrical:

Power needed to be supplied to the robot, the camera, GPS unit, encoder and IMU. The power systems currently used are:

Power				
	Mastech HIGH CURRENT SWITCHING Single-Output DC POWER SUPPLY 50V 20A HY5020E 1000W	Amazon	Mastech	
	Isolated DC/DC Converters 960W 24V 4	Mouser	Mean Well	SD-1000L-24

The team is also using independent power sources. For example the computer will run entirely on its own battery performance. Other processes will be running on independent power supply of their own

A frizzing schematic of the robots electrical system is provided below:



Safety:

The robot has a 1 x 1 Channel 200M Toggle Mode Remote Switch DC 6V / 9V / 12V / 24V With Magnetic Mount Antenna. This will allow the robot to be shut down at any time wirelessly. There is also and emergency stop button located on the robot that will allow the systems to be shut down if hit. The 200m receiver/transmitter with magnetic antenna mount was purchased from RF Control systems online.

Software:

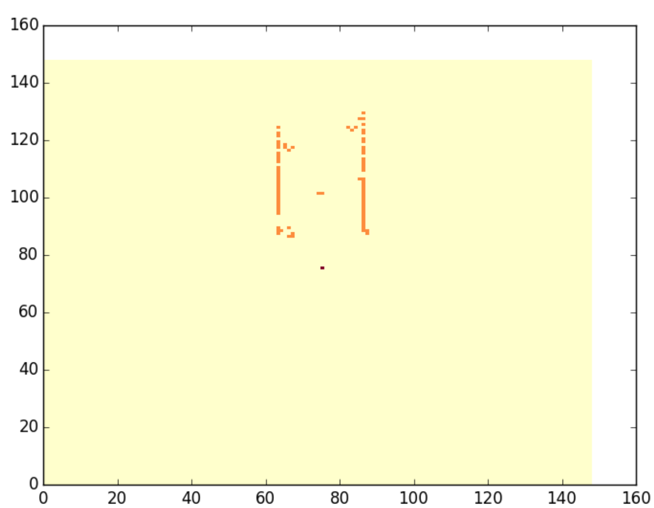
Mapping Team:

The mapping teams main goal to assist the robot was to pipe in various sensory inputs from multiple peripheral devices that would then be used to create a map. This map would be used to plot objects and white lines on a 2D grid based off of the position of the robot.

Creating an Occupancy Grid:

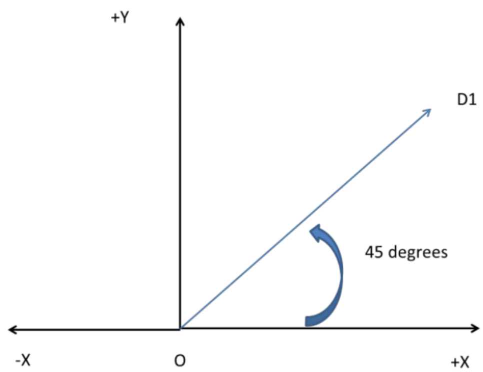
The grid that was created piped in data from the SICK Laser, Computer Vision, and GPS to create a 2D representation of the obstacles and white lines in reference of the position of the robot. The code was written mostly in python. Data coming in was organized and accessed using HDF files tools in python. This helped keep this data organized, readable, and easy to implement. The figures shown below represent how the map interprets real world data into a 2D grid:

Obstacles scanned by the SICK laser

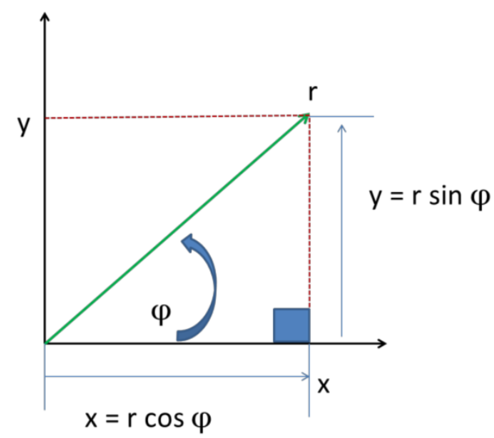


Graphical representation of those obstacles in reference to the robots location

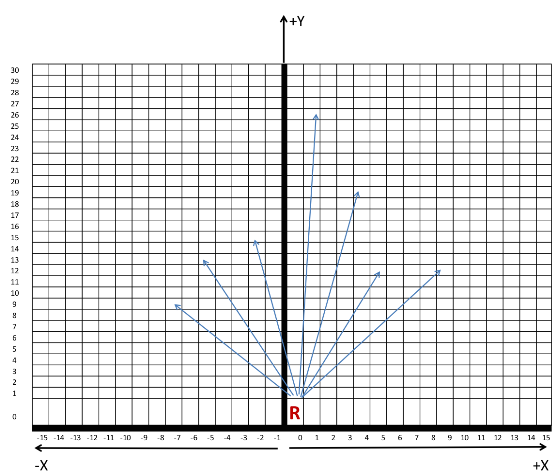
Gathering Laser Data:
The team is a SICK LMS291 S14 Laser Range Finder. The process of implementing this started by writing code in C to gather data from a sweep range of 45 degrees to 135 degrees. The sensor returns the measured distance information. This information is in two dimensional polar coordinates, (r,ϕ). The laser scan was completed in two dimensions. We have a known distance vector, corresponding to r, and know scan angle, corresponding to ϕ. The frequency of our laser is operating at about 40 Hz. The laser sweeps across an obstacle field and records the data that is then sent to mapping team and plotted on an occupancy grid. Below shows this process using graphical images.



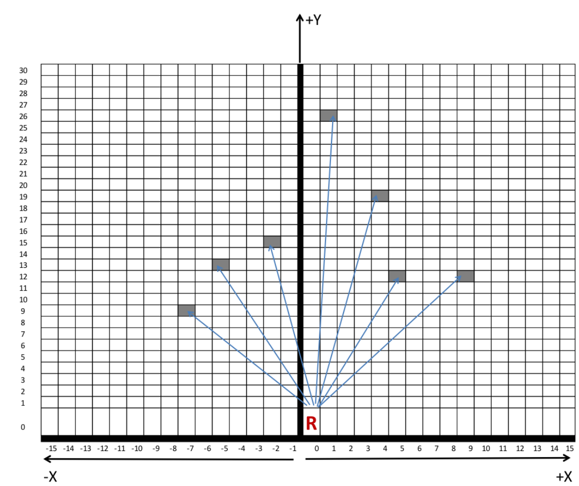
Laser distance measurement D1



Laser distance measurement D1



Map depicting robot position and laser distance measurements



Map with detected obstacles marked in gray

Computer Vision:
To capture the video image that will later be used to gather data by computer vision software the team is using a Logitech HD Pro Webcam C920. The camera is mounted on the robot and takes a short range image. Using computer visions libraries implemented in C++ the computer vision team detects white lines and red and blue flags in the robots path. This information is sent to the map and plotted in relation to the robot. The line and flag detection algorithms are very similar, due to their similar feature sets of color, edges, and distinct shapes.
The team had to take in many varying conditions in order to program this successfully. The robot's operating environment is outdoors, primarily on a grass-covered surface. This forces us to consider how

different lighting conditions will affect the color representation in our images. Conditions may vary from bright direct sunlight to cloudy, overcast days. There may also be varying degrees of shade and shadows cast by other objects. One of the robot's operating constraints is that it must operate in varying degrees of light, depending on the time of day and weather conditions.
Color is a quality constructed by the human visual brain system and not necessarily a property of an object. A color model is an abstract mathematical model describing the way colors are represented numerically. There are many color models used to display color in a digital image. The initial focus considered two color models: RGB (red, green, blue) and HSV (hue, saturation, value). RGB color values vary depending on lighting conditions, whereas the HSV color model is better at handling lighting differences. In the RGB color space, a white line appears as we normally think of the color white. It is the brightest intensity in each of the color planes and the composite RGB image.

Color White Representation			
RGB	Red: 255	Green: 255	Blue: 255
HSV	Hue: 0 degrees	Saturation: 0 %	Value: 100 %

After testing images taken from several different times of day, lighting, and weather conditions, it was discovered that the filtering threshold values change due to different lighting conditions. On sunny days, an image with no shadow cast on a white line generates pixels in the ranges of 240-255. On cloudy days, where the lighting is flat, there is less contrast in an image. White pixel values will go as low as 150. Low intensity values for white pixels also occur in situations when the line is in shade.

These circumstances led to the use of an adaptive threshold. It was observed that the color white will be the brightest pixels in a gray scale image, no matter the outdoor lighting conditions. After experimentation with the data set, an acceptable percentage value of 5% of the highest intensity pixels in a gray scale image provided a consistent threshold for retaining white line pixels.

The total pixel count is multiplied by the acceptable percentage value to establish a target count. The adaptive threshold algorithm then counts down from the highest histogram bin intensity values, totaling the pixel count. When the pixel count total matches the target count, the current bin number is used as the threshold for determining white vs. non-white pixels.

All pixel values less than or equal to the threshold value are set to zero, and all pixels greater the threshold value are set to a maximum intensity of 255.

Dilation was then used to fill in the gaps in the image, and erosion removed most of the noise created by the dilation step.

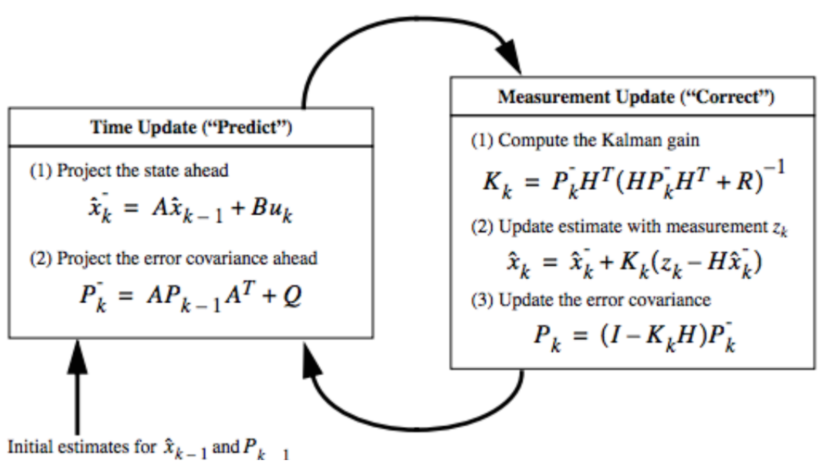
All of this was used in the process of lane detection and obstacle avoidance for the robot.

Path Planning

Using the information gathered by the map the team plans to use the following weeks implementing a path planning algorithm. One major problem identified throughout the development process was a need to utilize noisy sensor data for creating accurate state estimations. The Kalman Filter is a recursive solution to the linear filtering problem, which is ideal for stochastic estimation from noisy sensor measurements. The main application of the Kalman filter was to enable a system that would handle the errors associated with GPS measurements resulting from Ionospheric delays, atmospheric delays, Tropospheric delay, and multipath interference. With the Kalman Filter, these errors were minimized by use of several equations that function as a predictor-corrector estimator to minimize the estimated error covariance.

The Kalman filter uses a form of feedback control whereby an estimate is made at some point in time, which is then corrected using the feedback from the noisy measurement device. The equations for the Kalman filter fall within two categories, time update equations and measurement update equations. "The time update equations are responsible for projecting forward (in time) the current state and error covariance estimates to obtain the *a priori* estimates for the next time step. The measurement update equations are responsible for the feedback—i.e. for incorporating a new measurement into the *a priori* estimate to obtain an improved *a posteriori* estimate." (*cs.unc.edu).* After each time and measurement update pair, a new *a posteriori* estimate is generated, using the previous estimates, thus creating a recursive system that conditions the current estimate on all prior measurements. Figure n.1 contains a diagram of the filter operation along with the necessary predictive and measurement update equations.

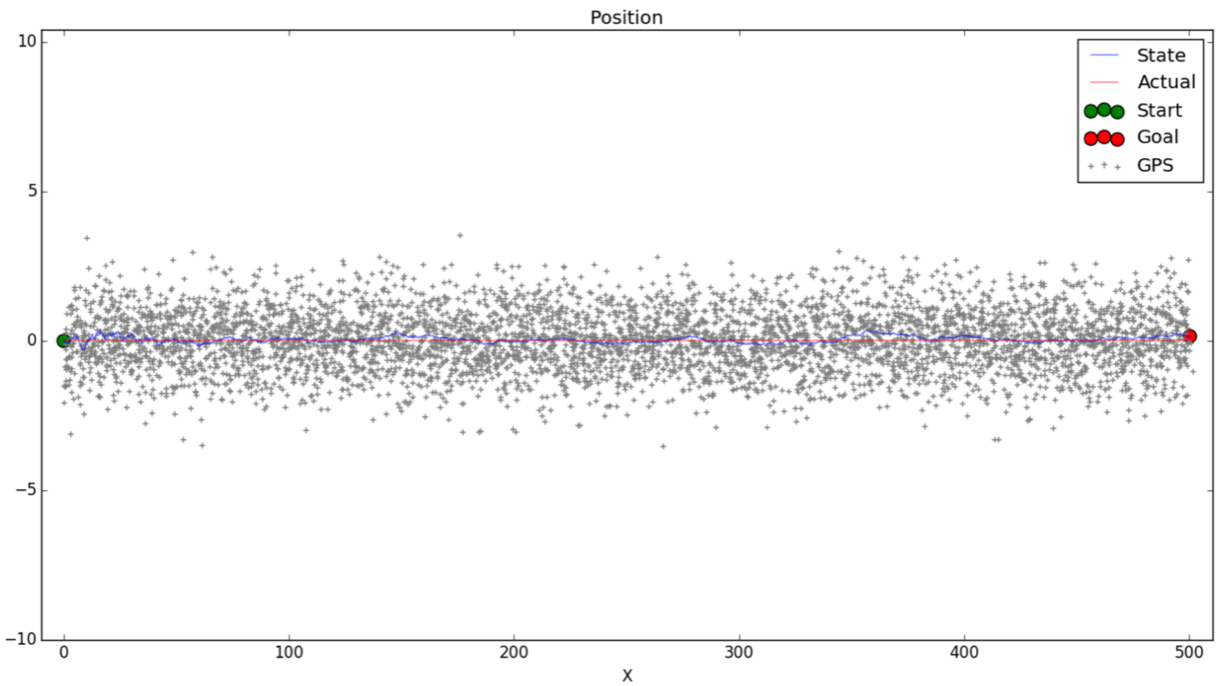
Figure n.1



cs.unc.edu

Figure n.2 contains a simulation of a GPS unit traversing an arbitrary x-axis with an various alterations in acceleration. While traveling a distance of 500 units, the GPS noise measurements can be seen as a cloudy haze that surrounds the actual course of travel, (shown in red), while the blue line reflects the Filtered path created by the system.

Figure n.2



Using these strategies along with other algorithms the team hopes to come up with an implementable system that allows the robot to make a decision 30 times a second.

Cost:

System	Description	Vendor	Manufacturer	Model	Price	Total
IMU	Inertial measurment unit, case type screw down	YEI Technology	YEI Technology	3 Space USB/RS232	166.00	166.00
Vision	Vista Explorer 60-Inch Lightweight Tripod with Tripod Bag	Amazon			19.99	19.99
	AmazonBasics USB 2.0 A-Male to A-Female Extension Cable (9.8 Feet/3.0 Meters)	Amazon			5.79	5.79
	Logitech HD Pro Webcam C920, 1080p Widescreen Video Calling and Recording	Amazon	Logitech	Logitech HD Pro Webcam C920, 1080p	59.99	59.99
GPS	Hemisphere GNSS P/N 940-2093-000 A101 Smart Antenna Kit	Subsea Technologies, Inc	Hemisphere	940-2093-000 A101	1,500.00	1,500.0
	Hemisphere GNSS P/N 051-0129-002 3m A100/A300 Power/Data Cable (single DB9 connector)	Subsea Technologies, Inc	Hemisphere	051-0129-002 3m A100/A300	275.00	275.00
Power	Mastech HIGH CURRENT SWITCHING Single-Output DC POWER SUPPLY 50V 20A HY5020E 1000W	Amazon	Mastech		274.99	274.99
	Isolated DC/DC Converters 960W 24V 40A 19-72Vin	Mouser	Mean Well	SD-1000L-24	358.00	358.00
Chassis, Motors	4WD All Terrain Heavy Duty Robot Platform - IG52 DB Options: Four IG52-04 24VDC 285 RPM Gear Motors with Encoder, 10 inch tires, Sabertooth Dual 25A Motor Driver, Spektrum DX5eTransmitter with AR600 Receiver	SuperDroid Robotics	SuperDroid Robotics	TP-170-052	1,540.67	1,540.6
	ATR Upper Deck and Sensor Mount	SuperDroid Robotics	SuperDroid Robotics	TD-130-000	112.00	112.00
						4,312.4

Conclusion:
As a rookie robotics team relatively new to the subject of robotics, the team has come together with the goals of creating and understanding concepts in the robotic industry. While “Sparky” the obstacle avoiding robot still has more work needed to be fully functional, the team looks forward to continuing and completing these goal and more in the time going forward.

Acknowledgements:
The team would like to thank the University of Colorado for funding and making this possible. Wendell Chun has been invaluable to the robotics club’s progress and improvement.