SigSent

Autonomous Sentinel and Patrol Robot

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Group 11

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Potential Customers: Knight Scope, iPatrol

Potential Sponsors: Vision Land Service

Significant Contributors: Robotics Club, TI Innovation Lab

Project Narrative

The proposed project will explore a field of robotics, patrol and sentry duty, which has only recently become tractable through modern technological and scientific advancements.

Producing a useful end product will require developing and implementing solutions for multi-terrain travel, efficient power and time management, and simple Human to Robot Interaction (HRI) for both the robot's supervisor and potential intruders.

SigSent will demonstrate a capable platform which could substitute for a human in conducting patrol and sentry duties. These duties include following predefined paths in either smooth or rough terrains, reliably alerting the robot's supervisor to a potential intruder, and instructing a potential intruder on how to proceed.

The security services industry is a prime candidate for growth through human-robot cooperation. The Three Ds of Robotics: Dull, Dirty, and Dangerous, are applicable to security services due to the repetition of tasks, need for assured surveillance, and potential for hostile situations.

Goals & Objectives

The goal of SigSent is to create a robot that is capable of intelligently patrolling a predefined area and reducing the risk of harm to human sentries. SigSent should also enable security professionals to enact a more proactive security policy by freeing security guards from repetitive tasks.

By learning to work in a mixed terrain environment, the robot can effectively perform its job as a sentinel irrespective of the landscape in which it is placed.

By providing a TeleOp functionality to SigSent, operators can manually control the robot or direct it to enter an automatic sentry mode. The SigSent bot will stream a video feed of its perspective, enabling remote surveillance. With multiple SigSent units, a single operator could surveil a much larger area alone. When in sentry or patrol mode, SigSent will also alert the operator upon detecting unknown activity. This will reduce the workload on security guards by freeing them from simultaneous supervision of multiple locations throughout the entirety of their shift. The SigSent robot will also be able to match the speed of an average person jogging so that it may pursue an intruder if deemed necessary. SigSent will be able to deter trespassers with vocal commands, and will also be able to record video of trespassers or events for later action by law enforcement.

In conclusion, SigSent should replace the main duties of a security guard and allow guards to perform higher-level tasks with less occupational hazard.

Requirements Specification

Specification	Value	Units	Rationale	Reference
Sentry Robot Specifications				
Weight	25	kg	OSHA limit of safe weight to lift	[1]
Durability	0.5	m	Survive a 0.5m fall. Internal benchmark to reach.	
Reliability	1	yrs	Based on Life cycle of parts (Servos, motors, etc.)	
Availability	75	%	Robot will need 25% availability for maintenance and repair.	
Speed Characteristics				
Wheel Top speed	12	mph	Average speed of a male human running ranges from 10 to 15 mph	[2]
Rough Terrain Top speed	1	mph	⅓ the normal walking speed of a male human. Internal benchmark to reach.	
Battery Life				
Static Monitoring Span	3	hrs	To be competitively better than our competitors, iPatrol, with a battery life of 1.5 hours	[3]
Walking Lifespan (3mph smooth)	30	mins	For basic, reasonable operation of the sentry bot. Internal benchmark to reach	
Jogging Lifespan (6mph smooth)	10	mins	Internal benchmark to reach	
Running Lifespan (12mph smooth)	3	mins	Internal benchmark to reach	
Rough Terrain Lifespan (1 mph)	15	mins	Internal benchmark to reach	
Accuracy Specifications				
GPS waypoint finding	5	m	Based on standard accuracy of smartphone GPS modules under open sky conditions	[4]
Communication distance	32	m	Based on the signal power limit allowed by FCC regulation for WiFi.	[5] [6]
Bandwidth	5	Mb/s	Based on industry accepted requirements for high definition video streaming.	[7]

Movement specifications

The robot must have certain movement capabilities to be considered a multi-terrain and accessible device. This means the robot must be able to fit in common areas to do its functions. To satisfy this requirement the robot must be able to pass through a standard door size opening of 36 inches. This also includes the ableness to travel across different smooth and rough surfaces/terrain. Our definition of a smooth surface is: “Any continuous surface with no more than a 10 degree incline/decline”. This definition was created with reference from the National Highway Traffic Safety Administration and their road regulations for paved highways. The list of example smooth surfaces are tile, asphalt, and carpet. Our definition of a rough surface is: “Any non-continuous surface with instantaneous raises/lower no greater than 6 inches and a max incline/decline of 15 degrees”. This definition was created with reference from the creation of the smooth surface definition. The list of example rough surfaces are forest, rocks, stairs, and sand.

Security Functionality

Being a sentry bot, this robot will require multiple security capabilities.

- Robot should be able to transmit full quality video to the base station upon request.
- Robot should be able to detect human movement from 10 meters away.
- Robot should be able to sound a siren heard at 60 dB from 10 meters away.
- Robot should be able to reliably operate during night. (at full moon, 0.01 ftcd, lighting)
- Robot should be able to be teleoperated from the base station.
- Robot should be able to have a path programmed into it.

House of Quality

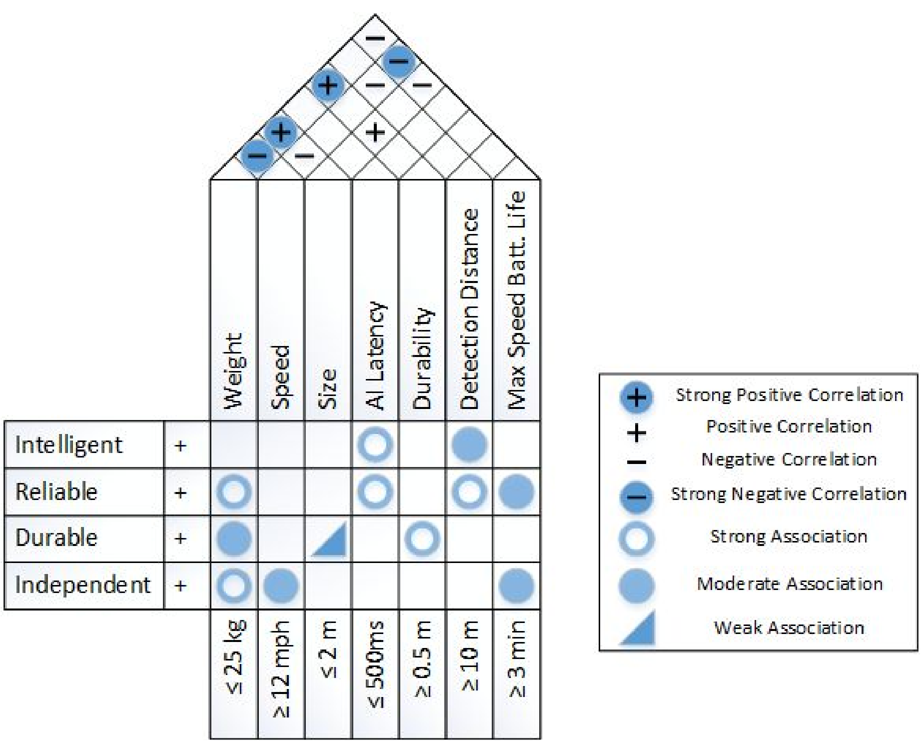


Figure 1: House of Quality (QFD)

Hardware Block Diagram

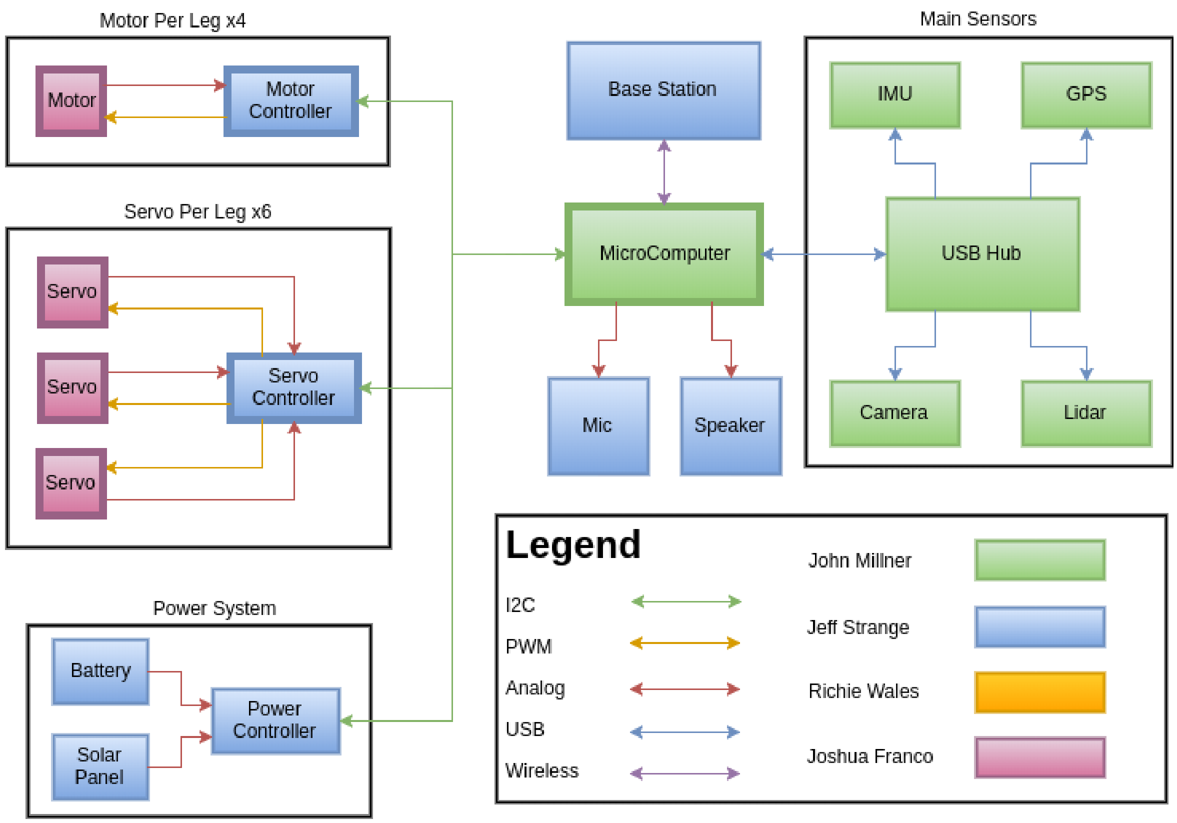


Figure 2: Hardware block diagram without power lines

Hardware Design is split into five main section: wheels, legs, power source, main sensors, and base station.

The Wheels and Legs sections closely mirror each other, in the motor section, we have four high torque brushless motors each connected to an Electronic Speed Controller (ESC) which inputs a PWM and outputs the proper phasing required to drive the DC brushless motor, and with the servo we input a PWM signal and the servo then rotates to a predefined angle attached to that PWM value. There is also a current sensor monitoring the amount of current going to the motor or servo to detect whether or not the motor or servo is completing its desired task. Both the PWM signal and the current sensor output are converted into an I2C Signal which passes through protection circuitry and goes to the microComputer which will input and output data to and from the motors and servos.

In the power source section we have the battery which sends data through a Fuel Gauge which then outputs the status of the battery (voltage, current, coulombs consumed) through the I2C interface, passing through I2C protection circuitry and then to the microComputer which uses the battery data to send alerts or modify its path to be more energy efficient focused.

For the main sensors section we have a USB hub connected to the microComputer which connects most of the sensors together such as the camera, lidar, the wireless network, IMU, and GPS.

The base station section is separate from the robot and acts as a control point for the robot's supervisor to access, control, or receive alerts from the robot - the base station stays in near continuous communication with the robot through a wireless connection.

Software Block Diagram

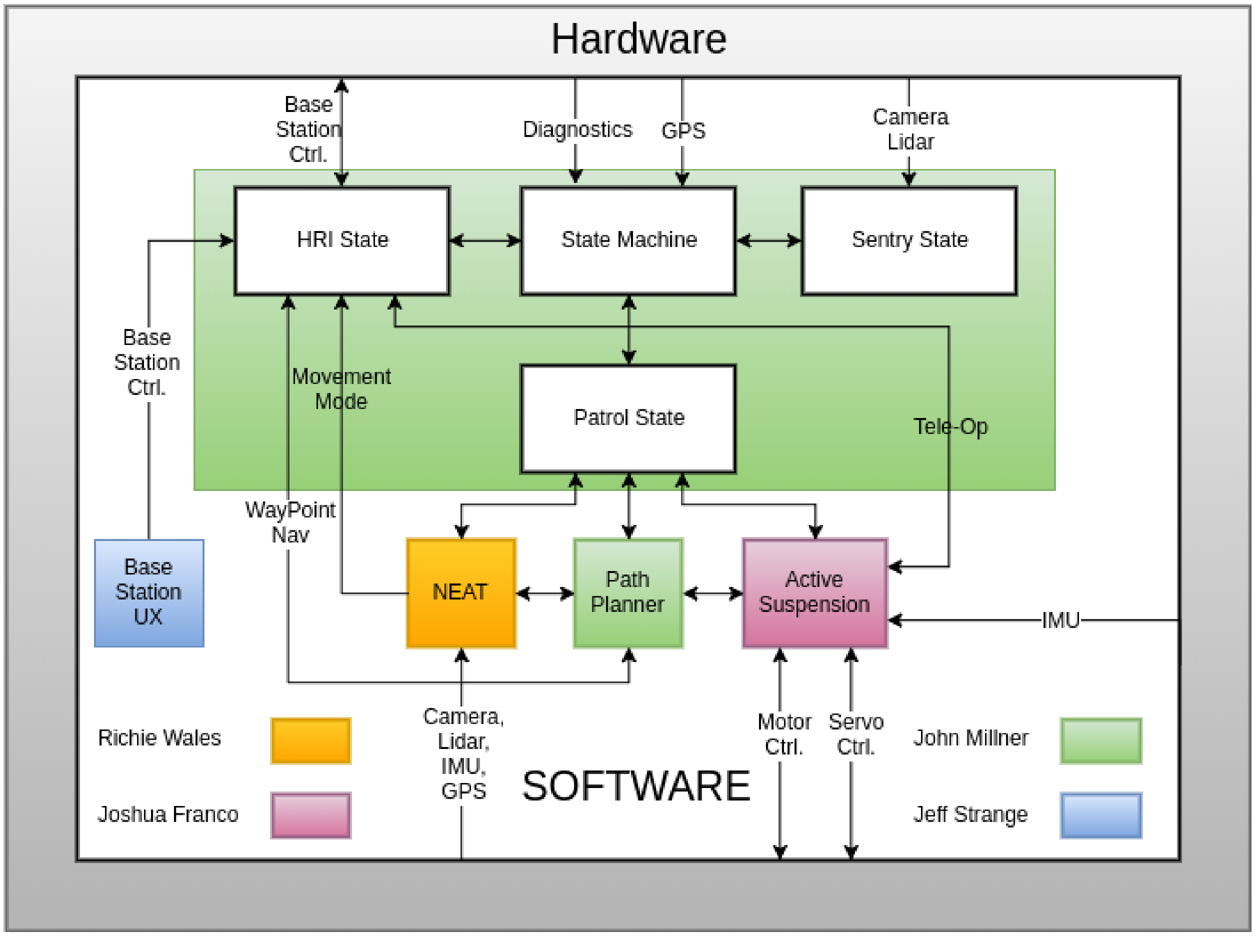


Figure 3: ROS backbone diagram

SigSent will have three states: Sentry State, Patrol (Walk Path) State, and Interface State.

In Sentry State, SigSent stays motionless in a designated spot and stands watch while processing camera and lidar data looking for anomalies and unknown behavior. Upon detection of any unknown behavior the state will send an "ALERT" signal and switch to the Interface State where the base station will be alerted to the unknown behavior.

In the Patrol (Walk Path) State, SigSent walks along a preprogrammed path (a set of GPS waypoints previously programmed) and sends those goals to the path planner which determines the ideal path for SigSent to take depending on priority between time, energy, and risk to robot. Once the path planner determines the ideal path it will send a vector to the Active Suspension Program which will then calculate the ideal values to send to its motors and suspension system based on various sensor data and the output of a NEAT ANN trained to determine which terrain mode the robot should use.

In Interface State, SigSent can send status and telemetry to the base station containing information such as battery percentage, live streaming the camera on SigSent, and viewing the current state of the NEAT ANN. In Interface State the robot can also be programmed with a new GPS waypoint path, teleoperated, or have the operator's voice transferred to output on the robots speaker.

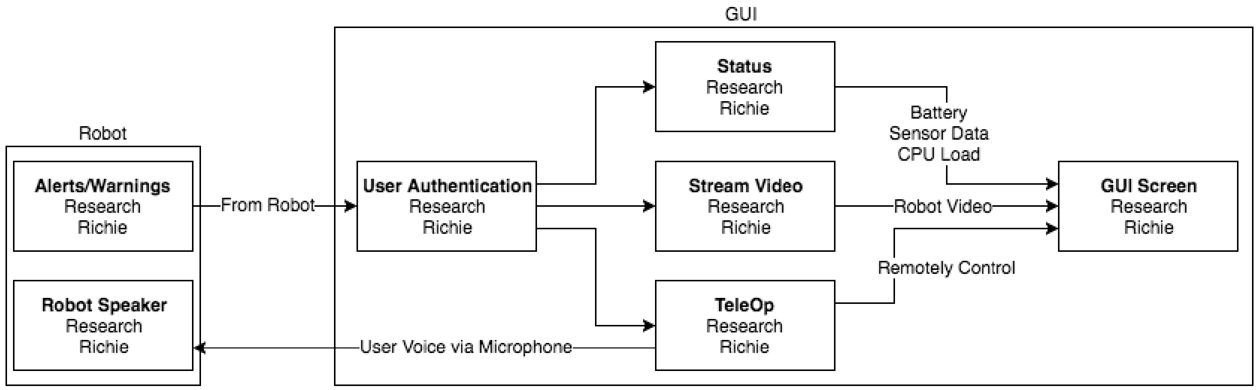


Figure 4: Base Station GUI diagram

A base station will be used to communicate with and remotely operate the robot. Alerts and warnings from the robot encompassing low battery levels and motion detection will always appear on the main screen of the GUI. The GUI is accessed by a single administrator log-in manually created when setting up the system to prevent prying eyes. The user can selectively view the status of the vehicle (including battery levels, raw sensor data, and the current CPU load), watch a streamed video feed from the robot's camera, and remotely control the robot with a Logitech Flight Stick (Extreme 3D Pro Joystick). The TeleOp control also allows for the user to speak into a microphone at the base station that will then project the audio from the robot's attached speaker.

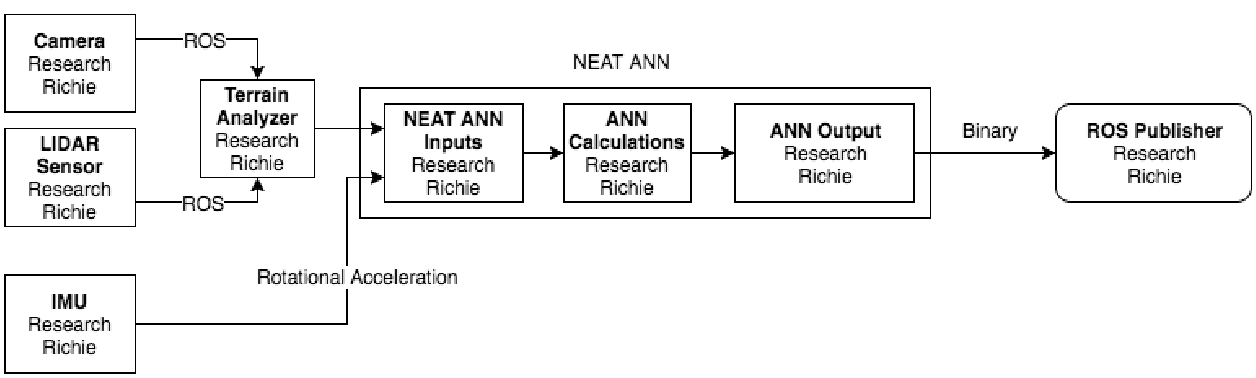


Figure 5: NEAT ANN Diagram

Using the NeuroEvolution of Augmenting Topologies (NEAT) library, the robot will learn to alternate between mobility types based on the environment it is traversing. Throughout the learning phase, NEAT will create Artificial Neural Networks (ANNs) that a Genetic Algorithm (GA) will use and score based on their performances. Each ANN is used in a test environment where sensor values are passed as inputs into the network to receive some desired output values. A camera and LIDAR will be used to identify what kind of terrain the robot is moving over, which is then sent as an input into the network. The IMU will pass its rotational acceleration values as a second input. The output is a binary value of what type of mobility mechanism to engage. The best ANNs are used to create a new population of networks, using popular genetic operators from biology, including crossover and mutation.

Crossover occurs more frequently, moving values from performant networks to create successful offspring. Mutation continues to add diversity to the population so that NEAT properly explores the domain's search space.

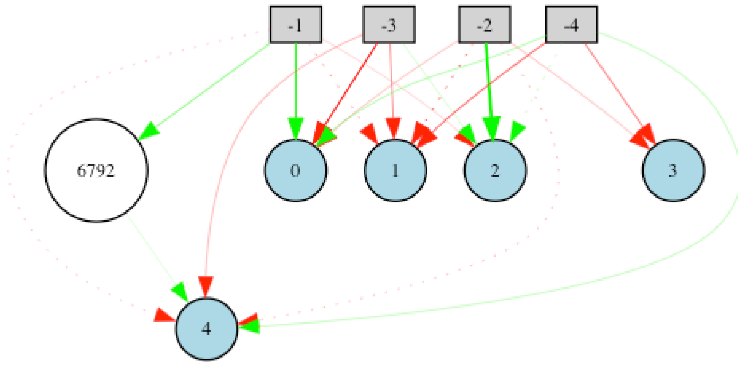
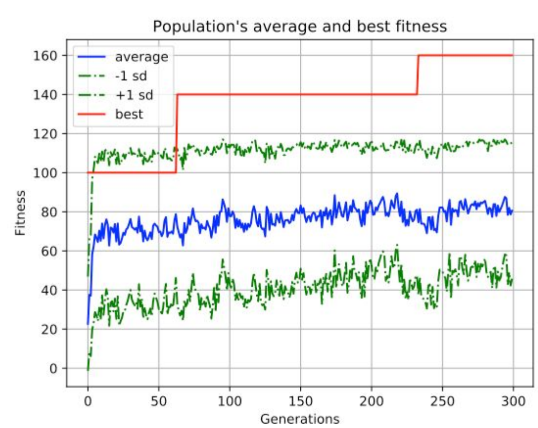


Figure 6: Example generated Neural Network

In the example above, the gray squares are the input nodes and the blue circles are the output nodes. This minimal example was performed in a command-line environment using a 2D grid as the environment, where a robot is an object on the map (with a location designated by its *x* and *y* coordinate on the grid) and has access via "sensors" to its four neighboring cells in each compass direction in a non-toroidal map. The four neighboring cells are inputs into the ANN. Four of the five outputs correspond to the future direction the robot will be headed in, where the node with the highest output value decides what direction the robot takes. The final output node chooses what mobility type the robot will enter prior to moving. If the robot attempts to move onto a cell labeled as being a "rocky" environment, it must have the proper mobility mechanism engaged before it can actually move onto the new cell. A fitness score is assigned based on how far the robot travels, as well as how many unique cells it visits. Based on this fitness, this ANN can be compared to the performances of the other ANNs in the GA's population to decide on what network topologies will continue to proliferate and what search directions should be pruned.

As shown in the graph to the right (Figure 7), the average fitness is steadily growing while the best seen fitness value makes jumps whenever a new, well-performing ANN is discovered. A better ANN results in a better "brain" controlling the robot. Higher fitness values can be achieved by modifying the NEAT parameters to be more optimal for this specific use case. The generation limit should be increased until the fitness levels off at an acceptable value. Additional time should also be considered to account for the GA struggling to break away from suboptimal extrema.

Figure 7: Fitness on the example network



Mechanical Design

The mechanical design of SigSent will be based on the hexapod robot design found common in many commercially available multi-terrain robots today with the addition of motorized wheels to four of its six legs. This allows SigSent to use it's hexapod movement method across rough terrain or move through more traditional wheeled on smoother surfaces efficiently.

Budget

Part Number	Description	Unit Price ($)*	Total Quantity	Total Price ($)*
244000083-0	Motor	18.99	6	113.94
FUTM0043	Servo	22.99	18	413.82
595711	Wheel	1.995	6	11.97
57155K383	Bearing	6.42	6	38.52
92775A106	Shaft Set Screw	0.3476	12	4.1712
91292A015	Motor Screws	0.218	24	5.232
92290A474	servo horn screws	0.78	72	56.16
98511A300	Wheel Screws	0.841	24	20.184
91292A116	Servo Screws	0.0641	72	4.6152
91854A101	Servo Nuts	0.1296	72	9.3312
N/A	Custom 3D Leg Prints	80	1	80
N/A	Custom 3D Abdomen Print	65	1	65
3100	Camera	29.99	1	29.99
3055	Microcontroller	35	1	35
Z50003S-25	Battery	25.38	1	25.38
9192000310-0	ESC	10.53	4	42.12
VN-200	IMU / GPS	2600	1	N/A
GF0876	Speaker	5.02	1	5.02
TS4962IQT	Audio Amplifier	0.99	1	0.99
URG-04LX-UG01	Lidar	1100	1	N/A
	Robot Communications	On-hand	1	N/A
	Basestation Communications	On-hand	1	N/A
	Laptop	On-hand	1	N/A
	Servo Controller Board	50	1	50
	Power Distribution Board	50	1	50
	Logitech Flight Stick	On-hand	1	N/A

	SD Memory Card	On-hand	1	N/A
			Total Cost:	1061.4436

*note discounts and shipping costs not applied

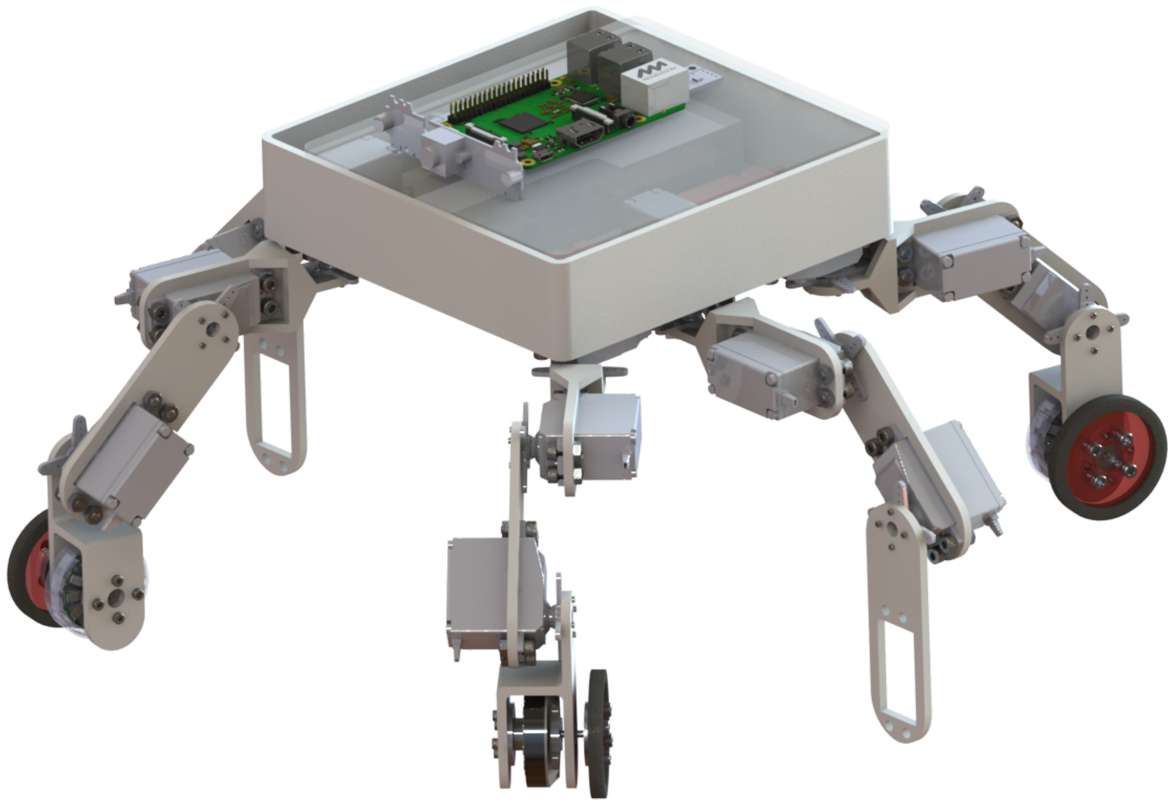
Timeline

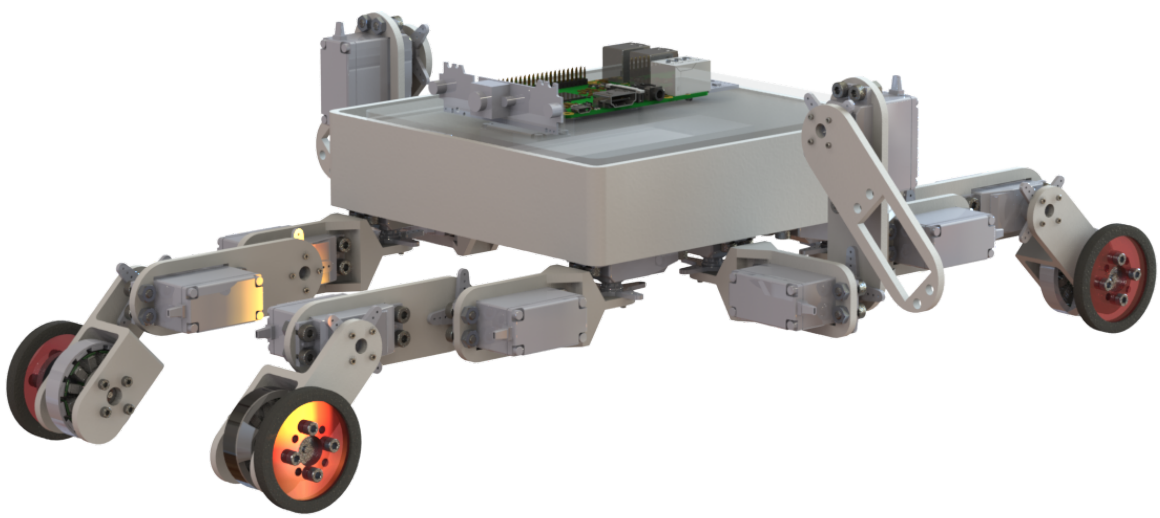
	Due 11/30/2017	John Millner	Josh Franco	Jeff Strange	Richie Wales
Phase 1	Primary Goal	Mechanical Design & Physical Creation	Control System Legs (Sim)	Power System Design	Simulation Creation
	Backup Goal	SImulation Creation	Power System Design	Mech Design & Creation	Control System Legs (Sim)
	Tasks	Complete Laser Cut Design	Kinematic modeling of movement/legs	Confirm sensor selection	Setup VCS
		Create Laser Cut Model	Kinematic modeling of whole body	Calculate power & energy needs	Familiarize with Gazebo
		Sponsorships/Discounts	Input/feedback data for closed loop	Design schematic	Create basic sim environment
		Order Parts	Movement pattern for different terrain	Find Primary Source Components	Move model SDF from Solidworks
		Wire Management	Familiarize with Gazebo	Find Redundant Sources	Add necessary ROS connections to moving parts
		Complete 3D Printed Design	Get necessary inputs for simulation	Create BOM	Follow ROS turtlesim docs
		Create 3D Printed Model		Determine wire routing	Implement code to move robot
		Have Complete Platform		Order Parts	Test/Debug

	Due 1/31/2017	John Millner	Josh Franco	Jeff Strange	Richie Wales
Phase 2	Primary Goal	ROS Integration	Control System Active Suspension on Robot	Communications	Working on ML on Sim
	Backup Goal	Communications	Working on ML on Sim	Control System Active Suspension on Robot	ROS Sensor Integration
	Tasks	Create/find Packages-nodes-publishers for each sensor	Design active suspension implementations	Design Base Station radio system	Research potential computers/MCUs
		Create state machine for different modes	Choose optimal designs for AS	Design robot radio system	Seek NEAT advising (Dr. Wu/Dr. Stanley)
			Input/Feedback from AS included in control	Implement messaging framework from ROS	Run small-scale NEAT tests without all sensors
			Implement AS in control simulation	Implement basestation command line client	Use sensors from John's implementation
				Test connectivity in various environments	Modify parameters and re-run

	Due 2/28/2017	John Millner	Josh Franco	Jeff Strange	Richie Wales
Phase 3	Primary Goal	ROS Path Planning	Polishing Control Systems	Teleop Control	Neat on the Robot
	Backup Goal	Teleop Control	Neat on the Robot	ROS Path Planning	Polishing Control Systems
	Tasks	Create local path planning for legs	Results from Control Sim	Design base station controller	Run NEAT on robot
		Robot must avoid obstacles	Test on different terrains	Design base station GUI	Seek advising on inevitable failures
		robot must path around obstacles on a global goal	Test movement abilities from Sim	Implement video stream	Re-run training until viable result
		robot must be able to move to a GPS Waypoint	Optimize Control Systems	Test, test, test	Train for longer duration (TBD)
		robot must take goal vectors			Save best resulting ANNs

Prototype Renderings





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