Autonomous Sentry Robot

Group 9
Brian Dodge - EE
Nicholas Musco - EE
Trevor Roman - CpE

Motivation

- We wanted to do a project that applied and expanded our knowledge of robotics and computer vision.
- Since we are two electrical and one computer engineering students, we wanted to do a project that had both hardware and software components and a robot was a perfect choice.
- We thought it would be an interesting idea to have an autonomous mobile security system for your home.

Goals and Objectives

- **Autonomous Control** - must be able to perform its tasks without user control
- **Remote Control** - user must be able to take control of the robot and perform the same tasks manually
- **Mapping and Localization** - must map an enclosed area and determine its position in that area
- **Object Avoidance** - must be able to dynamically avoid obstacles and react to its environment
- **Motion Detection -** must be able to detect motion with high precision
- **User Alerts -** must send easily accessible alerts to the user in real time if motion is detected

Specifications

Form Factor

Requirement ID	Requirement Description
FF1	The chassis must be low profile, no more than 1ft high, and 1.5ft wide.

Sensors

Requirement ID	Requirement Description
S1	The robot’s sensors must be able to detect obstacles that are 2cm away.

Power

Requirement ID	Requirement Description
PW1	The robot must be able to operate for at least 2 hours on a full charge.

Specifications

Processing

Requirement ID	Requirement Description
P1	The robot must reliably operate, react, and make decisions within 1-3 seconds.
P2	The robot must have 75% certainty of detections before alerting its user.
P3	The user must receive alert notifications from ASR within 5 seconds of detection.

Design Constraints

- Low Cost
- Low Power
- Lightweight
- Small Form Factor
- Less Time

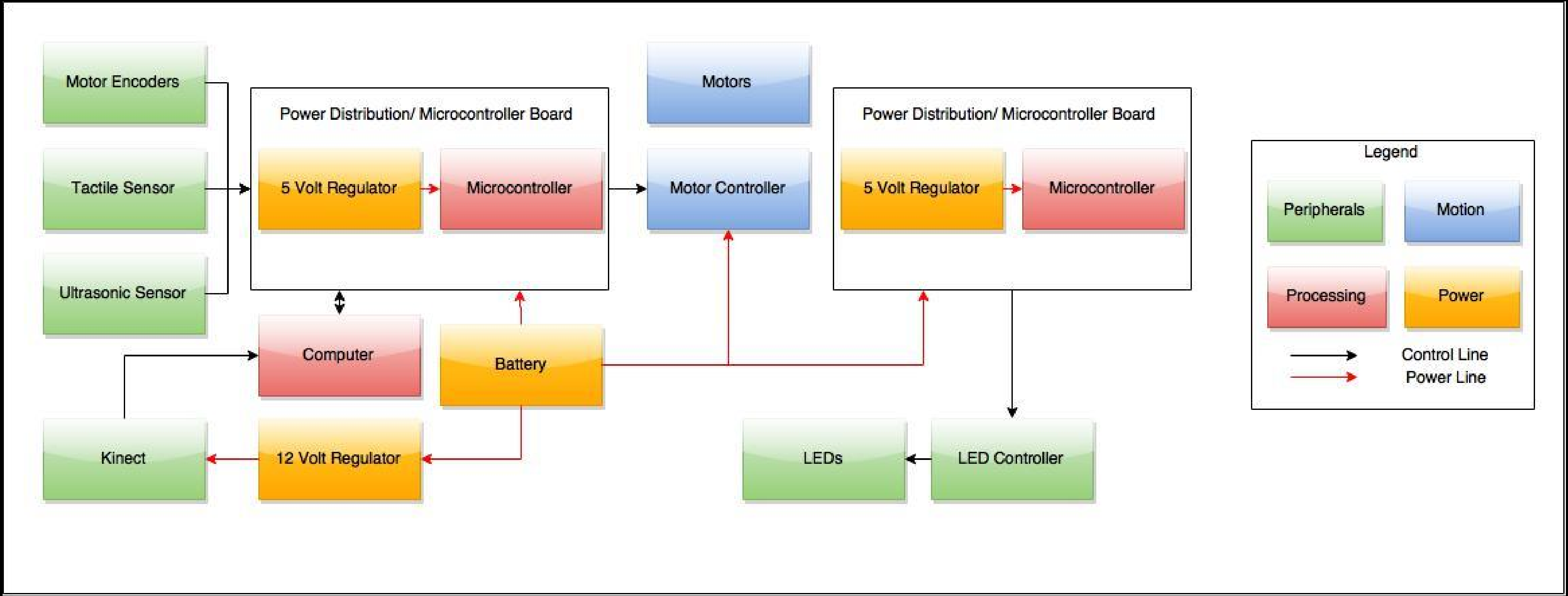
Related Standards

Standard Number	Scope	Title
IEEE 802.11n-2009	WiFi	IEEE Standard for Information technology -Telecommunications and information exchange between systems - Local and metropolitan area networks - Specific requirements Part 11: Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) Specifications Amendment 5: Enhancements for Higher Throughput
IEC 62680-1 Ed. 1.0 b:2013	USB	Universal serial bus interfaces for data and power - Part 1: Universal serial bus specification, revision 2.0
IEC 62680-2 Ed. 1.0 b:2013	USB	Univ. serial bus interfaces for data and power - Part 2: Universal serial bus - Micro-USB cables and connectors specification, revision 1.01

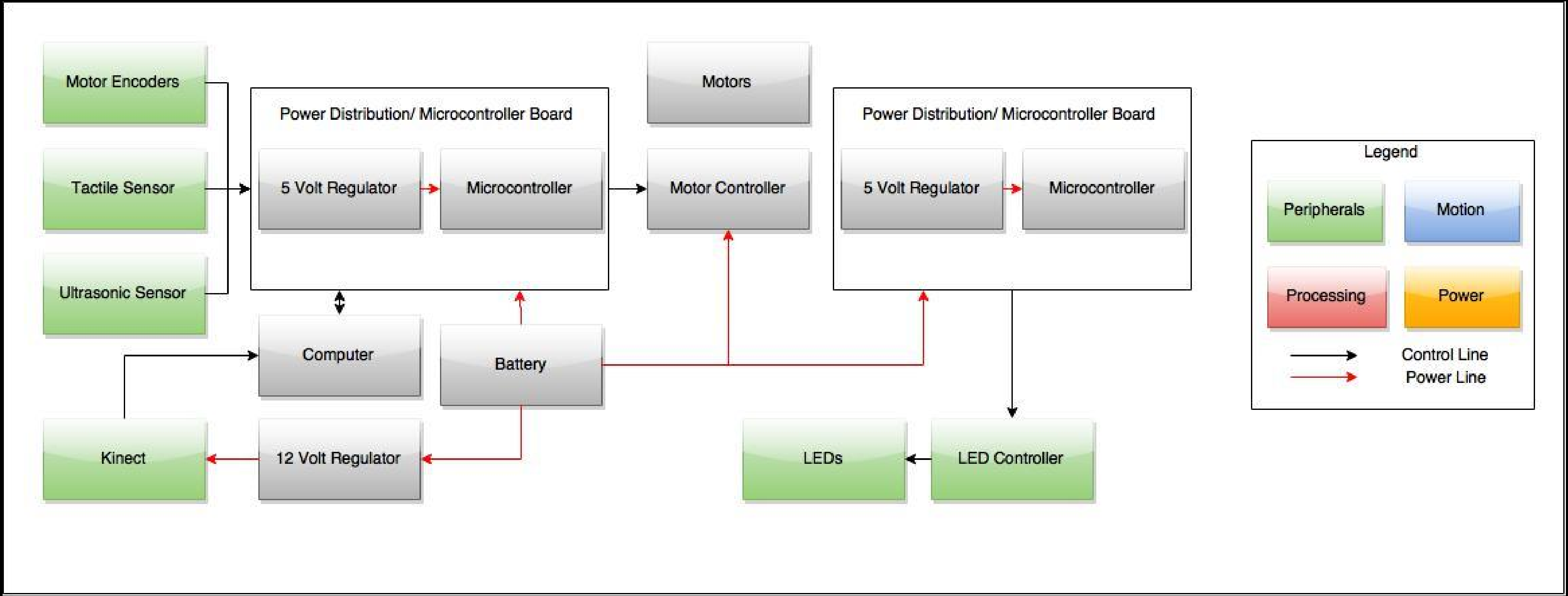
BSR/IEEE 1873-201x	Mapping	Standard for Robot Map Data Representation for Navigation
IEC 60335-2-29 Ed. 4.2 b:2010	Battery Charger	Household and similar electrical appliances - Safety - Part 2-29: Particular requirements for battery chargers
IEC 62676-1-1 Ed. 1.0 b:2013	Video Surveillance	Video surveillance systems for use in security applications - Part 1-1: System requirements - General
IEC 62676-2-2 Ed. 1.0 b:2013	IP video	Video surveillance systems for use in security applications - Part 2-2: Video transmission protocols - IP interoperability implementation based on HTTP and REST services

Hardware Design

Overall Block Diagram

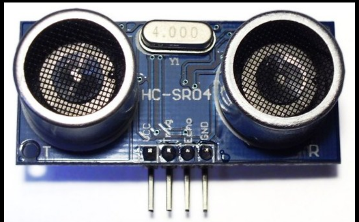


Peripherals



Ultrasonic Sensor - HC-SR04

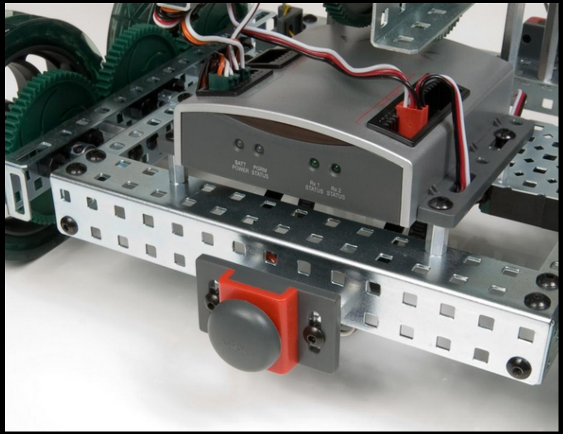
- Middle layer of obstacle avoidance
- Two Ultrasonic Sensors on the front



Working Voltage (V)	5
Working Current (mA)	15
Minimum Range (cm)	2
Maximum Range (M)	4
Measuring Angle	15 degree
Price ($)	8.99/2

Tactile Sensor

- Used as last layer of obstacle avoidance.
- Four Vex Bumper Switches
  - Two on the front corners
  - Two on the back corners
  - $12.99 for two



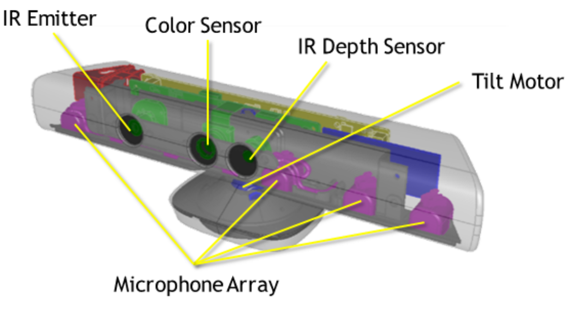
Motor Encoders

- Vex Motor 393 Integrated Encoder Modules
- Made for the motors that we have chosen, replaces the back cover
- Can be daisy chained and uses I2C to communicate with the microcontroller
- $29.99 for two

Microsoft Kinect

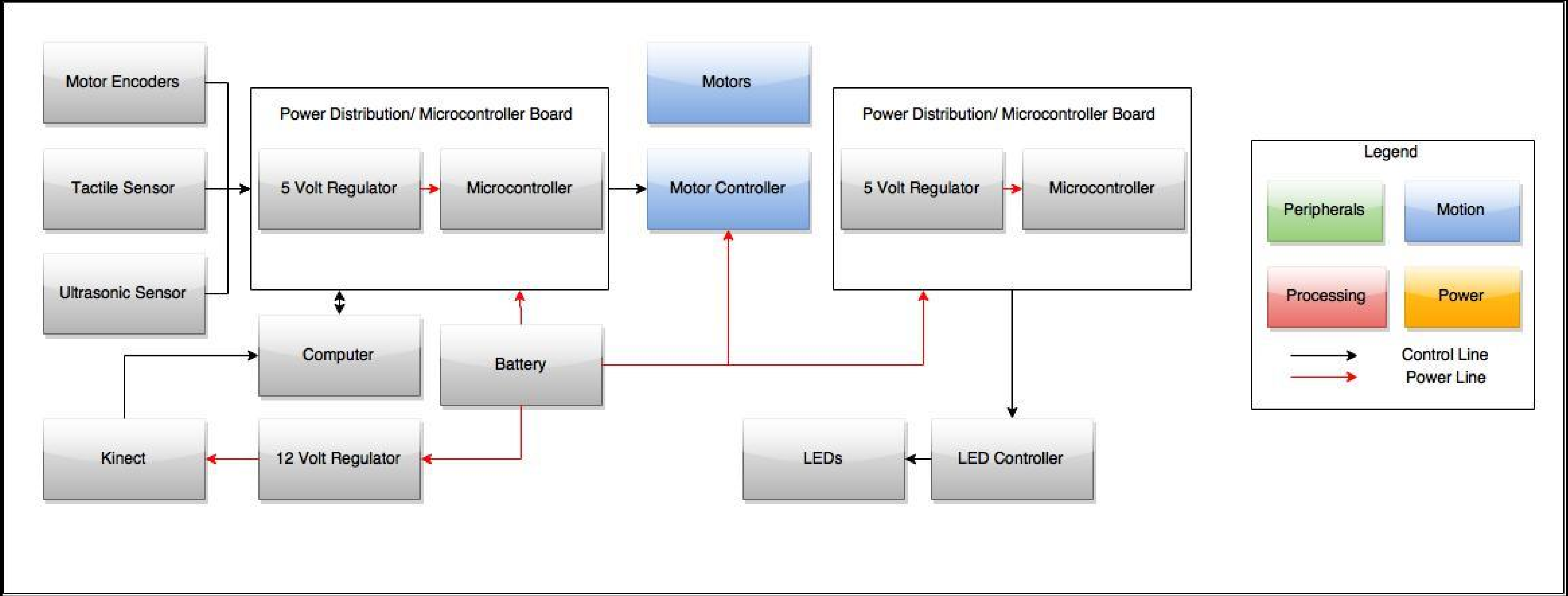
- Developed for the Xbox 360
- RGB camera with a resolution of 1280x960
- Infrared (IR) emitter and an

  IR depth sensor



- Microphone array
- 3-axis accelerometer
- Tilt Motor
- Requires a power adapter to work with a computer
- Costs $20.00 (used)

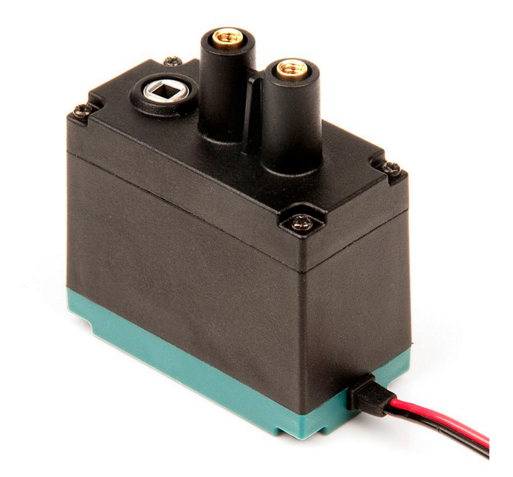
Motor Controller and Motors



VEX Motor Controller 29

- Small form factor
  - <2” in length
  - <1” width and height
- Inexpensive
  - $10.00 x 4
- Uses Pulse Width Modulation
  - Speed Control
  - Direction Control

Vex 2-Wire Motor 393



- Runs on 7.2V
- Multiple Gear Ratios
- $14.99 x 4
- Compatible with the VEX Chassis

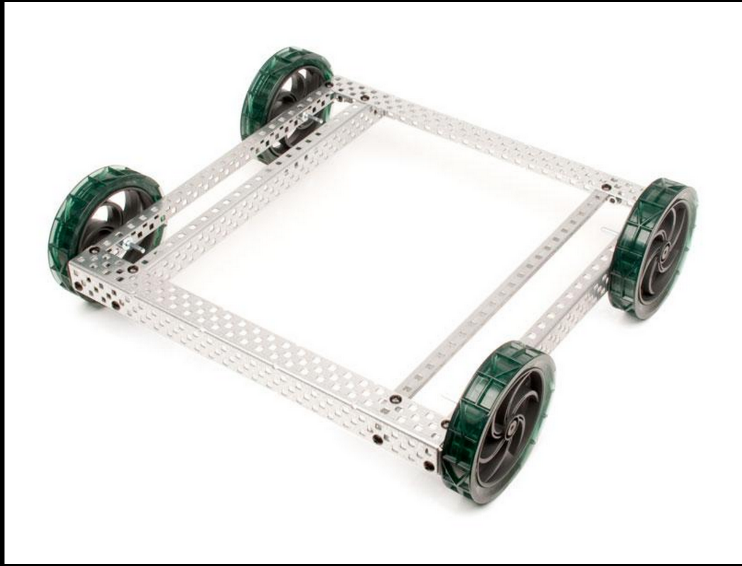
	Output Stage Driving Gear	Output Stage Driven Gear	Output Speed (RPM)	Output Stall Torque (N*m)	IME Ticks per Revolution
Standard Motor 393 Gearing	10t	32t	100	1.67	627.2
High Speed Option (included with Motor 393)	14t	28t	160	1.04	392
Turbo Gear Set (sold separately)	18t	24t	240	0.7	261.333

Wheels

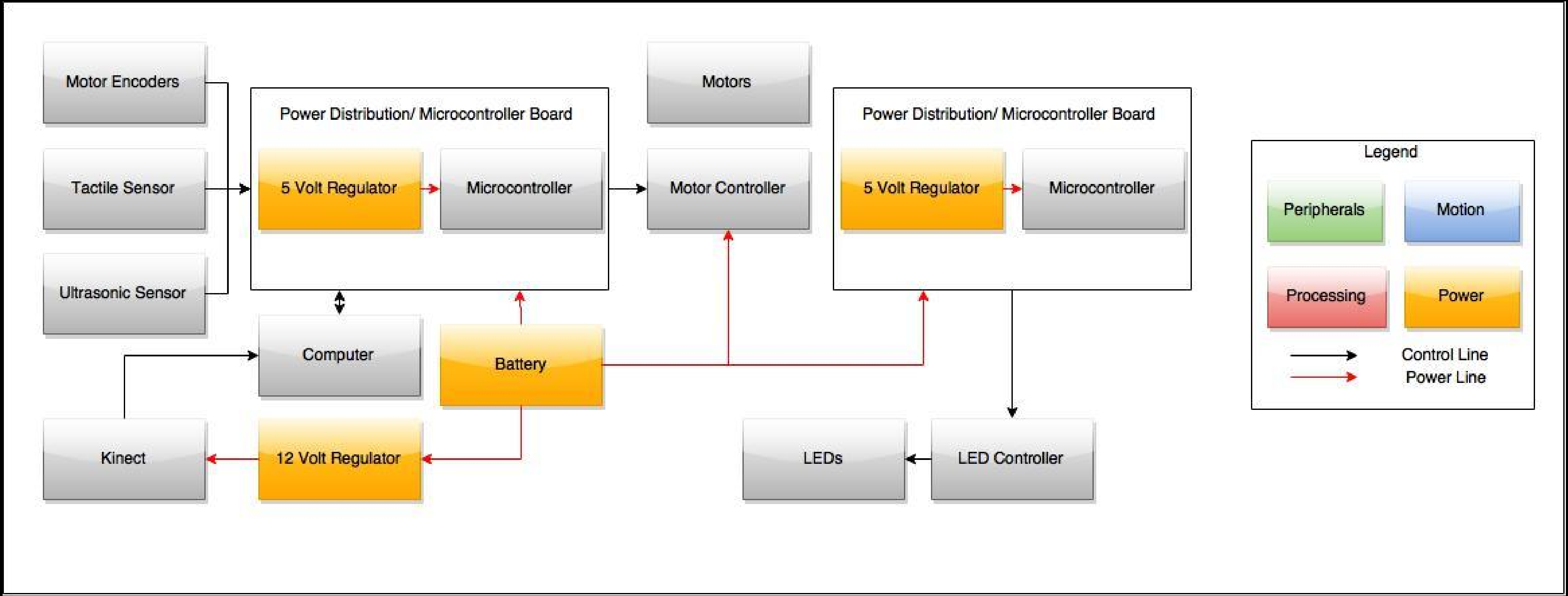
Wheel Type	Mecanum	Omni	Traction
Image			
Price	$60.00 for 4	$25.00 for 2	$10.00 for 4
Advantage	• Best Mobility • Can move in any direction	• Reduces Friction • Greater Mobility	• Simple • Inexpensive • Great Traction
Disadvantage	• Slippage • Complexity • Price	• Slippage • Price	• Lacks mobility

Chassis

- Medium Chassis Kit - VEX Robotics
- Rectangular Form Factor
- 12.6” X 12.6”
    - Acceptable Size
    - Adjustable width
- Polycarbonate top
- Chassis only - $21.35
- Suitable for tank drive



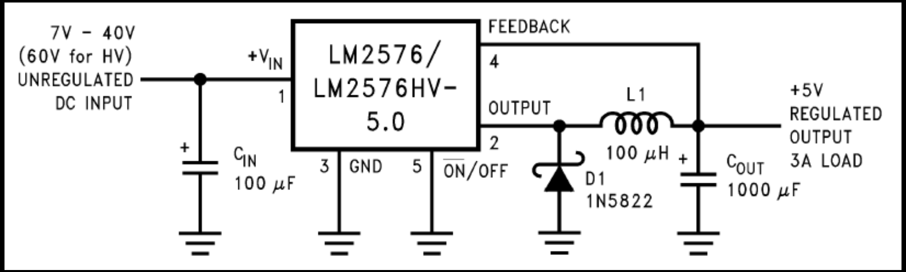
Power



Motor Encoders
Tactile Sensor
Ultrasonic Sensor
Power Distribution/ Microcontroller Board
5 Volt Regulator
Microcontroller
Motors
Motor Controller
Power Distribution/ Microcontroller Board
5 Volt Regulator
Microcontroller
Computer
Battery
Kinect
12 Volt Regulator
LEDs
LED Controller
Legend
Peripherals
Motion
Processing
Power
Control Line
Power Line

5 Volt Regulator

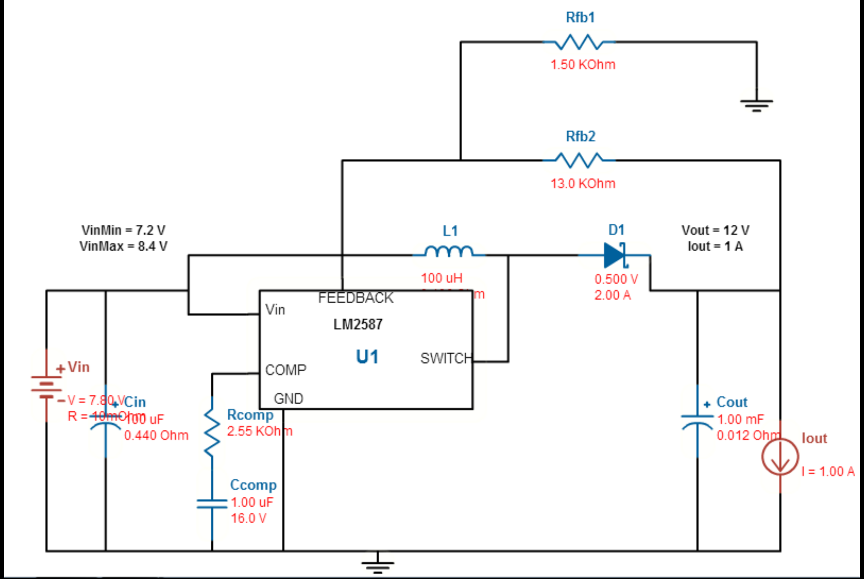
Voltage Regulator	**LM2576-5**
Max Input Voltage (V)	40
Output Voltage (V)	1.23 to 37
Peak Current (A)	3



Reference Schematic from TI’s LM2576 Datasheet

12 Volt Regulator

Voltage Regulator	LM2587-ADJ
Max Input Voltage (V)	40
Output Voltage (V)	0 to 60
Peak Current (A)	5



Schematic designed in TI’s WEBENCH Power Architect

Nickel-Metal-Hydride Battery

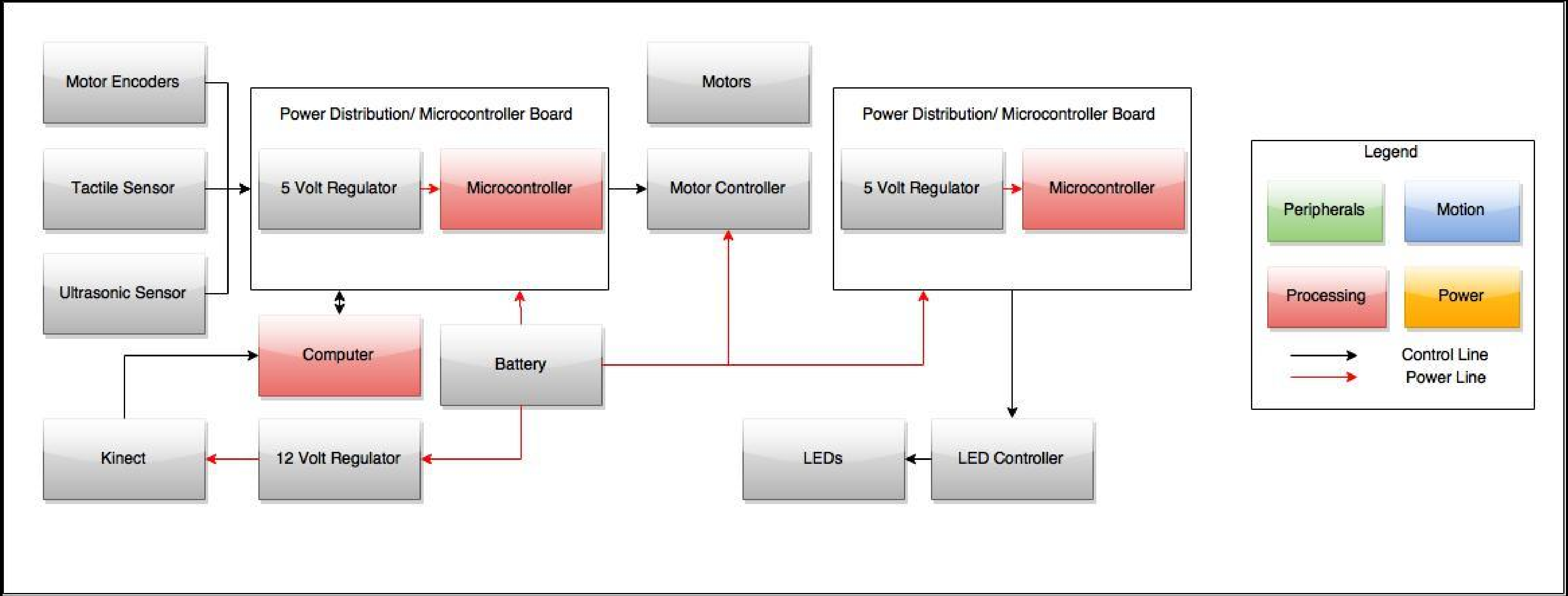
Advantages	30–40 percent higher capacity than a standard NiCd Less prone to memory than NiCd Simple storage and transportation; not subject to regulatory control Environmentally friendly; contains only mild toxins Nickel content makes recycling profitable
Limitations	Limited service life; deep discharge reduces service life Requires complex charge algorithm Does not absorb overcharge well; trickle charge must be kept low Generates heat during fast-charge and high-load discharge High self-discharge; chemical additives reduce self-discharge at the expense of capacity Performance degrades if stored at elevated temperatures; should be stored in a cool place at about 40 percent state-of-charge

Nickel-Metal-Hydride Battery Cont.

- Price was also important
- Designed to be as cost effective as possible
- 5000mAh will allow our battery to run for an acceptable amount of time

Battery (Chemistry)	Capacity (mAh)	Price ($)	Voltage (V)
Tenergy (NiMh)	5000	32.99	7.2
Tenergy (Li-Ion)	5000	55.00	7.4

Processing



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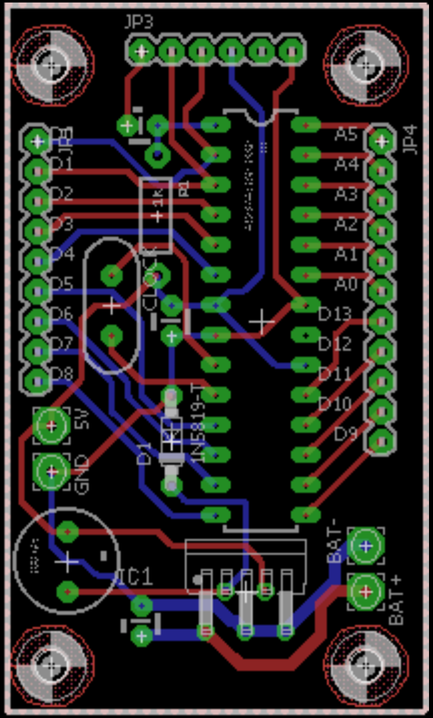
Microcontroller

- ATmega328P
- Arduino Bootloader
    - Access to libraries

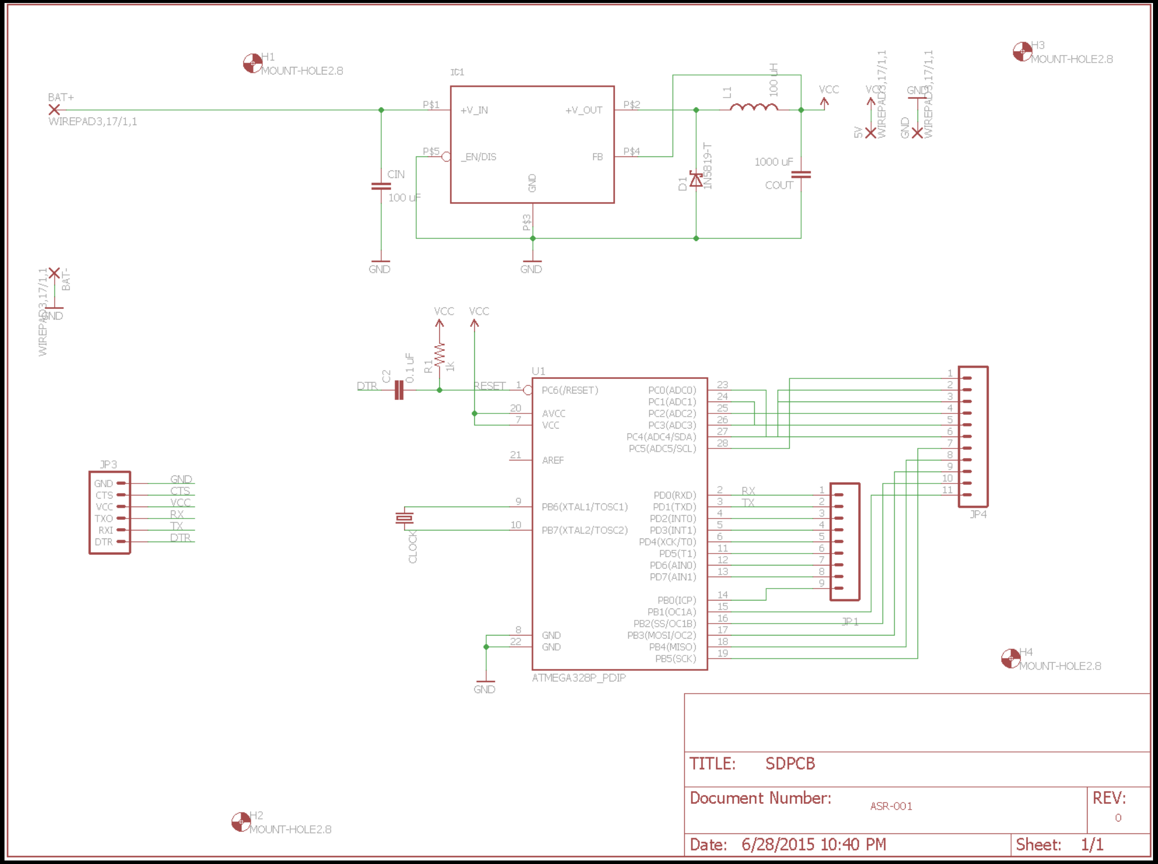
Architecture (bits)	8
Frequency (MHz)	16
Max Operating Voltage (V)	5.5
Program Memory (KB)	32
RAM (KB)	2
USART/SPI	1/1
I2C	1
I/O Pins	26 max
Price per Unit	$3.38 (Digi-Key)

PCB Design

- Decided to combine the board for the microcontroller and power distribution
- It has power and data ports for the sensors



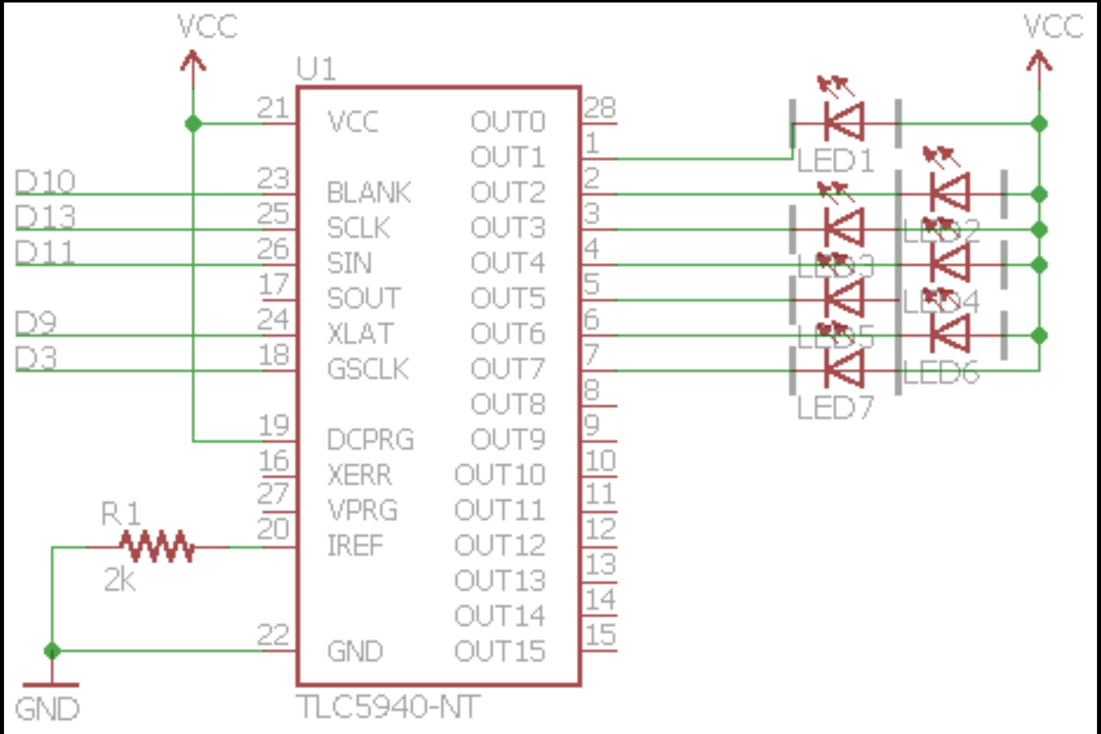
PCB Schematic



TLC5940NT - Common Anode LED Driver

- 16 Channels
- 12 bit grayscale PWM control
- Drive capability (Constant-Current Sink)
  - 0mA-120mA (Vcc > 3.6V)
- Serial Data Interface
- Dot Correction (For LED Brightness Variation)
  - 6 bits
  - Storable in integrated EEPROM

LEDs and Driver Design

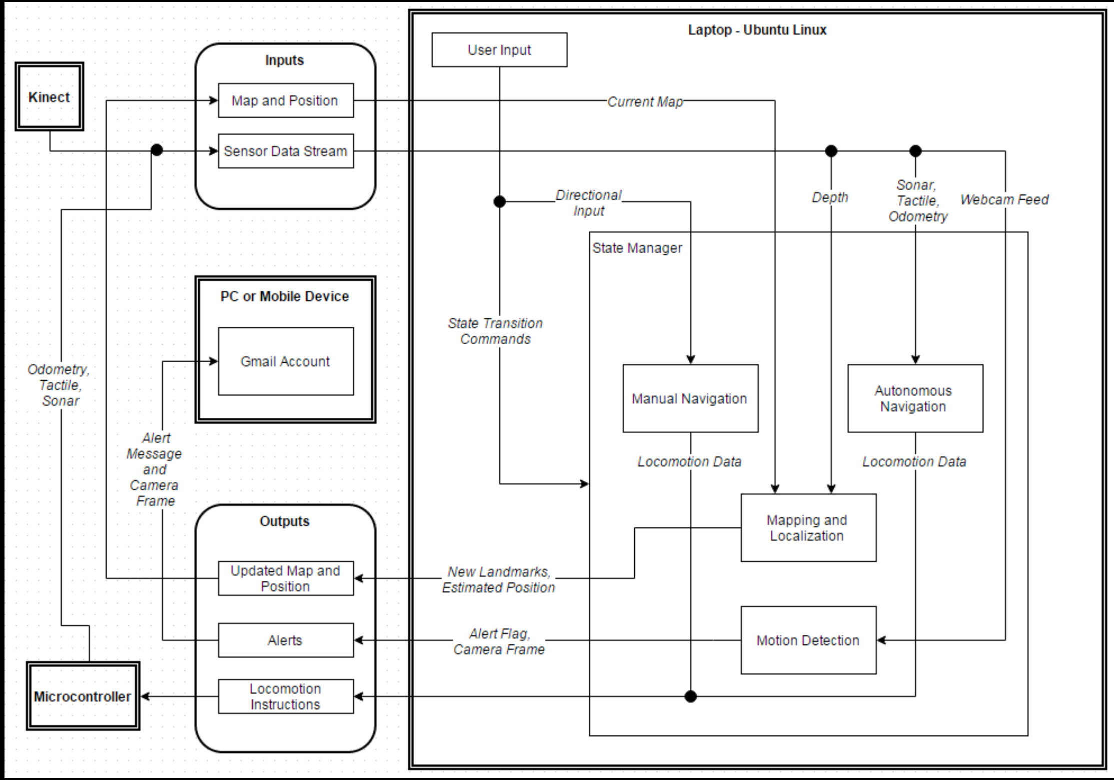


Computer

- Laptop will act as a server for processing and receiving instructions
- ASUS U52JC
  - i3 2.53 GHz
  - 4GB RAM
  - 6lbs

Software Design

High Level Software Architecture



Development Environment

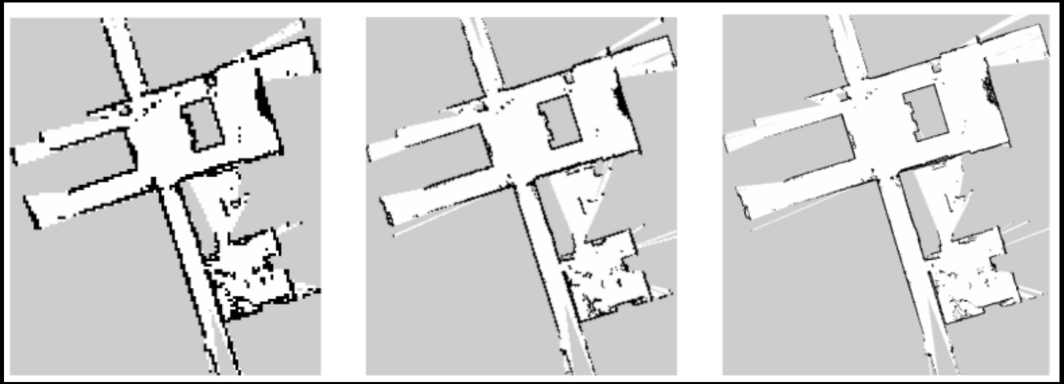
- Client Laptop for Remote View and Control
- Server Laptop running Ubuntu Linux
- ROS
  - SLAM
  - Hardware Drivers
  - General Framework
- OpenCV
  - Computer Vision Systems

SLAM

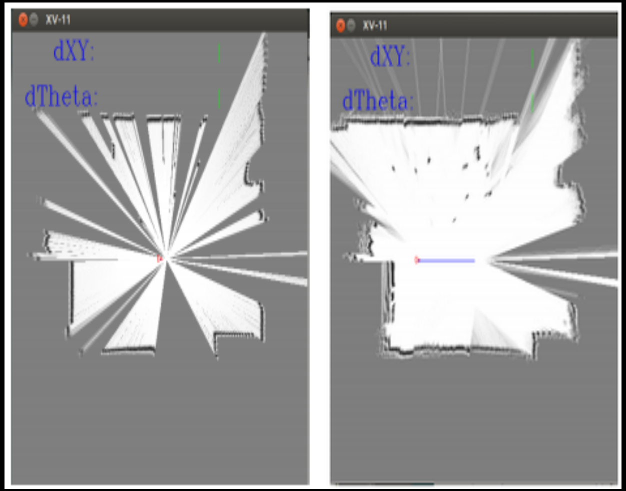
- Simultaneous Localization and Mapping
- Original approach
  - Modify BreezySLAM
  - Didn’t originally plan on using ROS
- Attempted Approach
  - Use available ROS packages for SLAM
  - HectorSLAM - Uses No Odometry
  - GMapping - Uses Odometry

SLAM Examples

HectorSLAM



GMapping



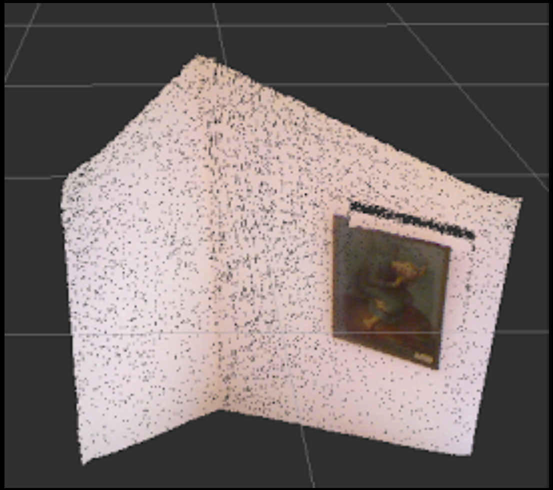
BreezySLAM

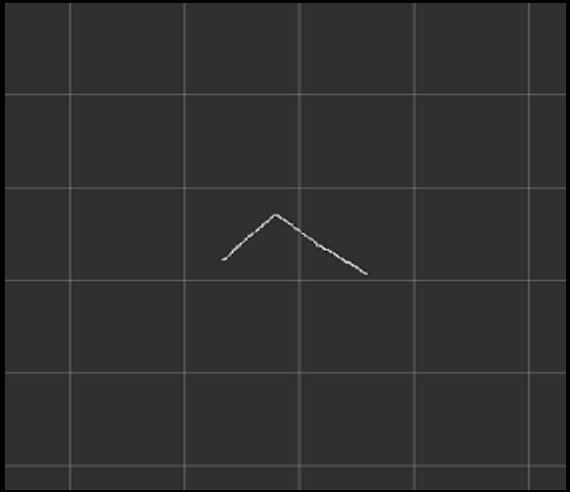
SLAM With Kinect

- Problem
  - Kinect supplies 3D depth clouds
  - Our SLAM choices output 2D grids
- Solution
  - Slice the depth cloud
  - Trick SLAM into thinking the kinect is a laser scanner

ROS is Awesome

- Our idea was available as a ROS node





R.O.S.

“The Robot Operating System (ROS) is a flexible framework for writing robot software. It is a collection of tools, libraries, and conventions that aim to simplify the task of creating complex and robust robot behavior across a wide variety of robotic platforms.”

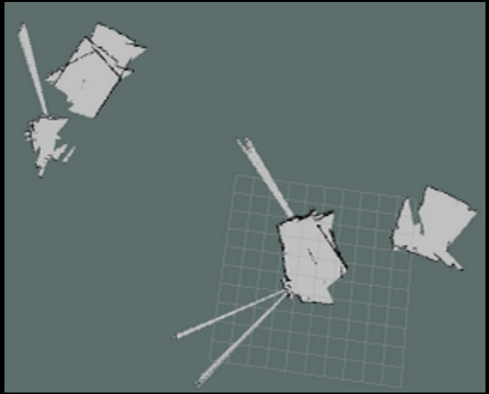
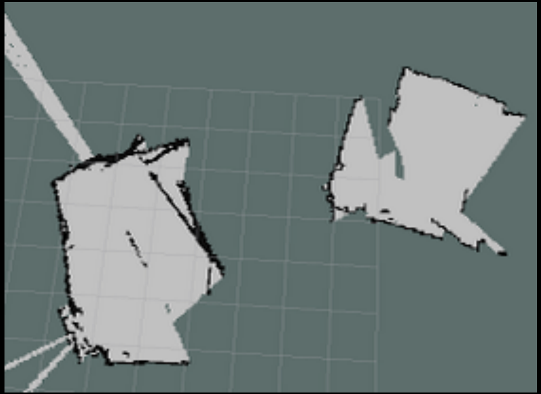
R.O.S.

- “Meta” Operating System
- Open-source under BSD License
- C++, Python, Java, Lisp
- Network of nodes (processes)
- ROS Core
    - ROS Master
    - Parameter Server
    - rosout

- `Topics`
    - `Stream-like Communication`
    - `TCP/IP or UDP`
    - `Publishers`
    - `Subscribers`
- `Services`
    - `TCP/IP or UDP`
    - `Function-like Communication`
    - `Server`
    - `Client`

Mapping is Difficult

- We applied both GMapping and HectorSLAM
- Experimented and tested for months
- Unfortunately, we never achieved a fully realized map

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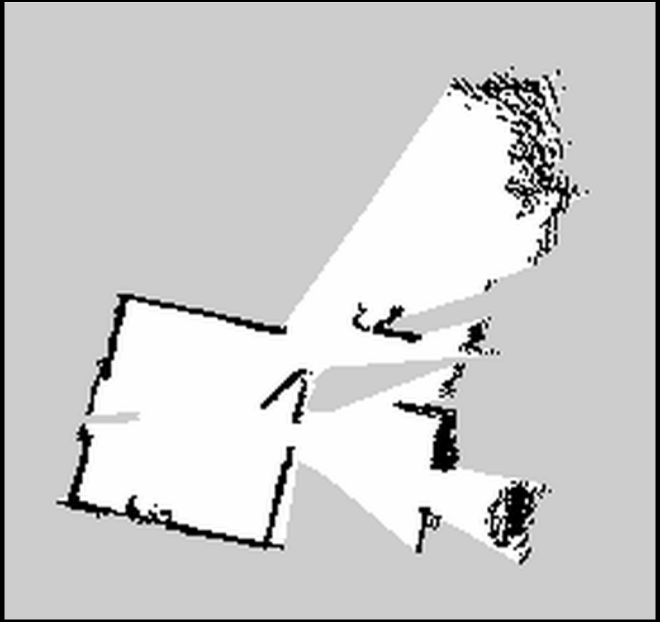
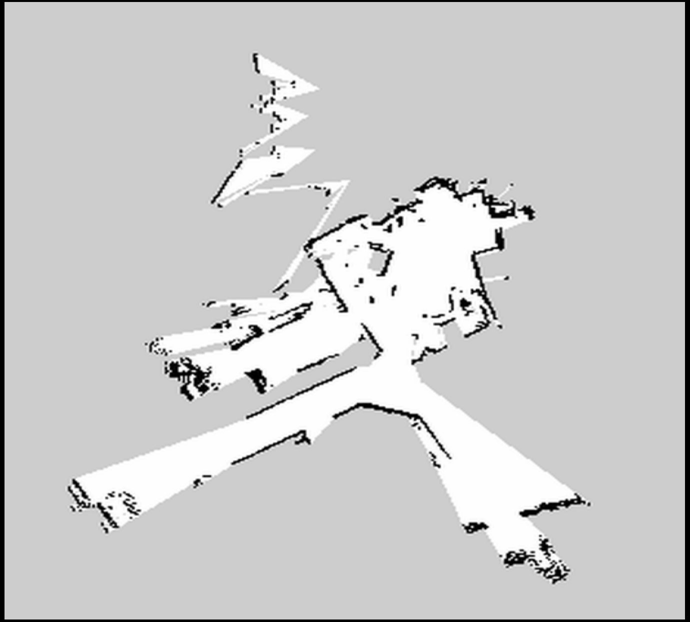


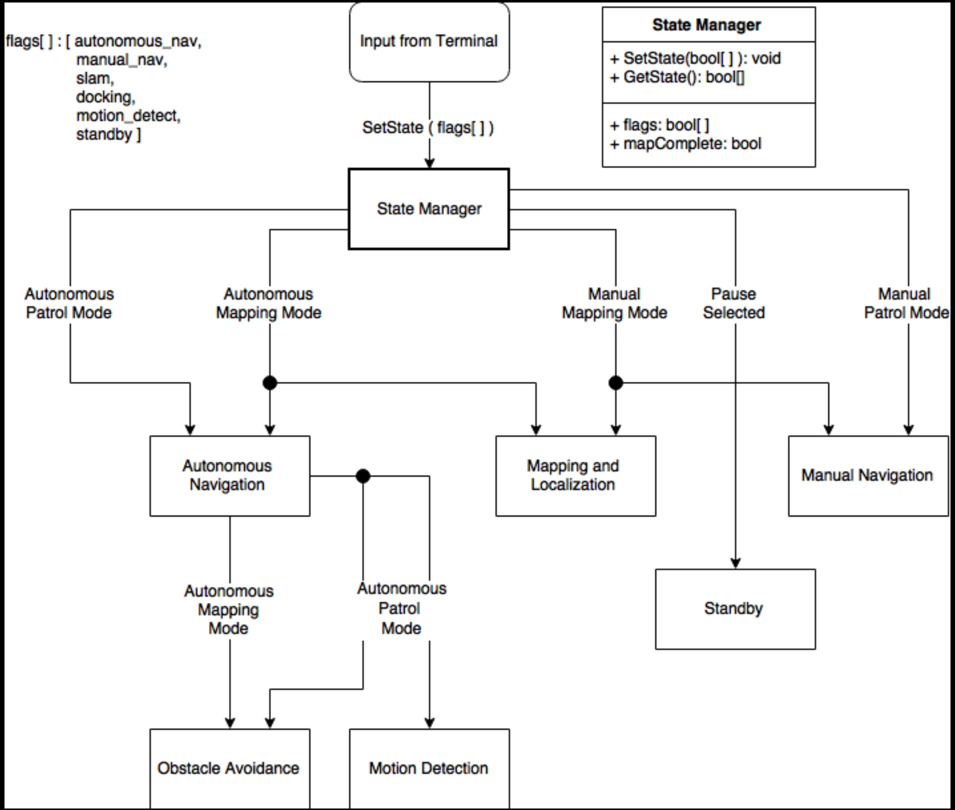


Control

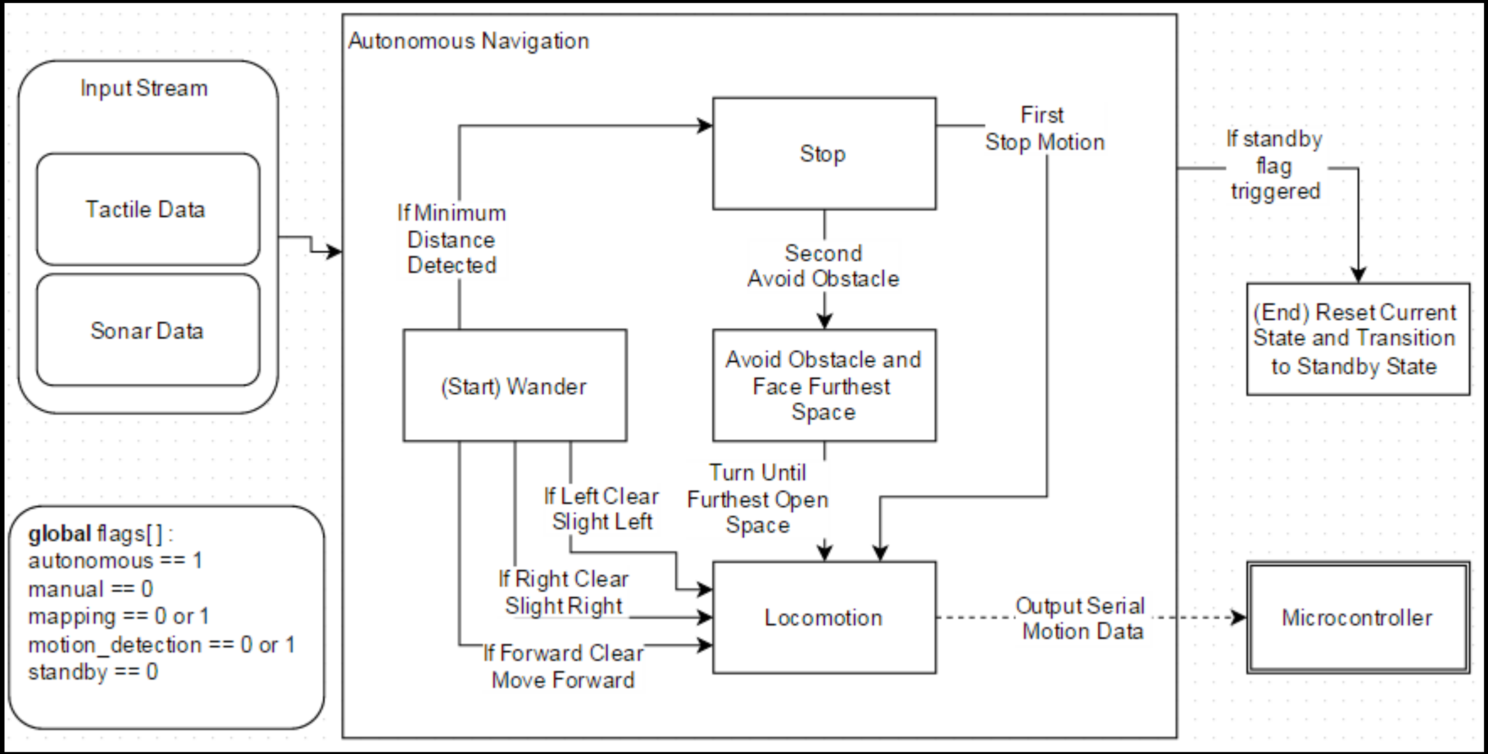
- Treat the ASR like a remote access computer
- Use a VNC Viewer to view and control the full desktop
- Integrate ROS visualization tools
- Easier for us, more time for other systems
- Ex)

```
asr@asr-ws: $ asr map -m
asr@asr-ws: $ asr patrol -a
asr@asr-ws: $ standby
```

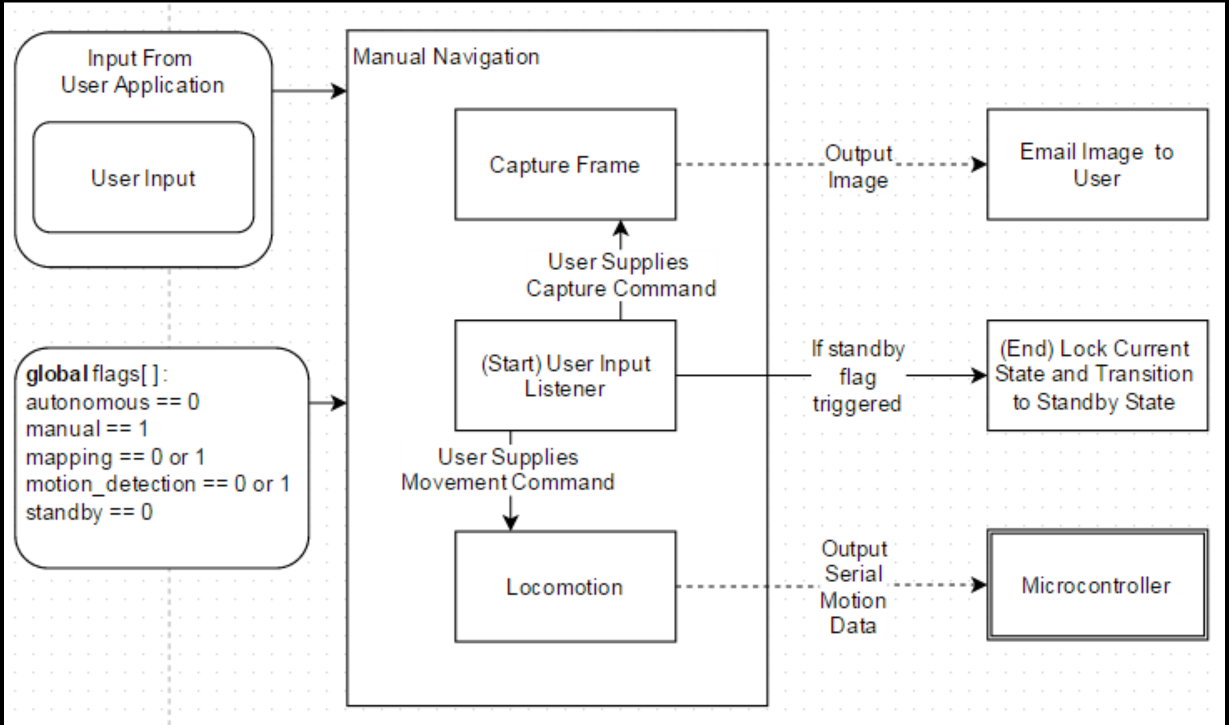
State Manager



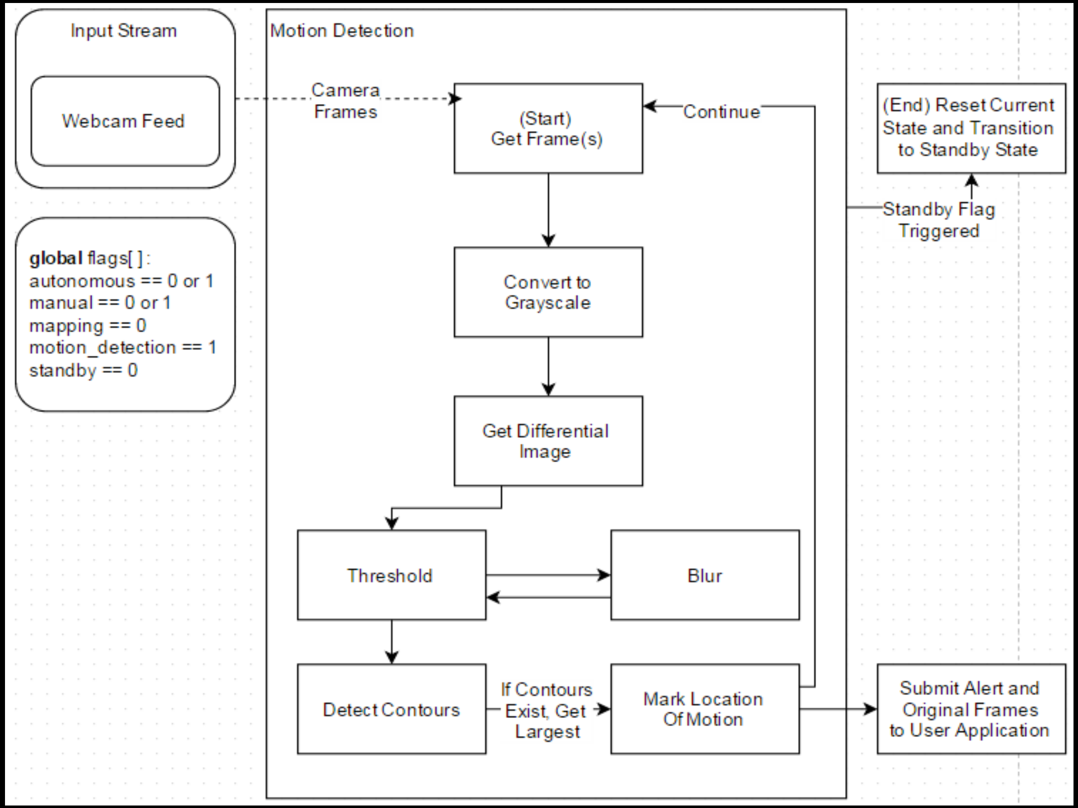
Autonomous Navigation



Manual Navigation



Motion Detection



Open-Source

- ROS
  - HectorSLAM
    - Used for mapping and localization
    - Built custom launch file
  - Depth Image to Laser Scan
    - Used to convert depth cloud to a fake laser scan
  - ROS Arduino Bridge
    - Driver for communicating with arduino, motors, encoders, and sensors
    - Reconfigured and customized for use with our hardware
    - Tuned PID controller
  - Libfreenect Stack
    - Kinect drivers
  - TF
    - Set up various transforms for use in visualization
  - Map Server
    - Hosts and saves map
  - RVIZ
    - Used as a base to customize a user interface

Open-Source

- OpenCV
  - Image processing functions for motion detection
- Arduino
  - Vex 29 Motor Controller Drivers
  - Vex 393 Encoder Drivers
  - NewPing

Administrative Content

Work Distribution

Name	Electrical System	Hardware Assembly	Hardware Programming	Software Systems
Brian	P	S	S	S
Nick	S	P	T	T
Trevor	T	T	P	P

P - primary
S - Secondary
T - Tertiary

Development Budget

Part	**Quantity**	**Unit Price**	**Expected Cost**	**Actual Cost**
Ultrasonic Module HC-SR04 Distance Sensor	4	$8.99 (for two)	$17.98	$8.99 - Already Own 2
VEX Bumper Switch	4	$12.99 (for two)	$25.98	$12.99 - Already Own 2
Microsoft Kinect	1	$20.00 (Used)	$20.00(Used)	$0.00 - Already Owned
Vex Motor 393 Motor Encoders	4	$29.99 (for two)	$59.98	$59.98
ATmega328P	1	$3.70	$3.70	$0.00 - Already Owned
Mintduino	1	$24.99	$24.99	$0.00 - Already Owned
PCB	3	$21.75 (for three)	$21.75	$21.75
Vex 393 Motors and Motor Controller 29	5	$24.98	$124.90	$124.90
3.25 inch Vex Wheels	4	$19.99 (for four)	$19.99	$0.00- Already Owned
Robot Chassis - Vex medium chassis	1	$21.35	$21.35	$21.35
Tenergy 7.2V 5000mAh NiMH battery	1	$89.00 (set of two)	$89.00	$89.00
Tenergy Battery Charger	1	$22.99	$22.99	$22.99
Voltage Regulators and LED circuit components	N/A	N/A	$20.00	$20.00
Grand Total			$479.01	$381.95

Build Budget

Part	**Quantity**	**Unit Price**	**Total**
Ultrasonic Module HC-SR04 Distance Sensor	4	$8.99 (for two)	$17.98
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Tenergy Battery Charger	1	$22.99	$22.99
Power Regulators and LED circuit components	N/A	N/A	$20.00
Grand Total			$442.62

Financing

- Project sponsored by Boeing
  - $580.11
- Partially financed ourselves

Issues

- ROS
  - Extremely powerful but extremely steep learning curve
  - Inexperienced, had to learn from scratch
  - Most development time was spent learning ROS, debugging ROS issues, and trying to figure out how to do things the ROS way
- Navigation
  - ROS navigation stack proved very difficult to work with and configure
  - Never accomplished our goal of using the map to navigate, so we had to fall back on our reactive system
  - Sonar and tactile is only so powerful, we still sometimes hit pitfalls

Achievements

- **Autonomous Control**
  - Robot has a robust but vulnerable autonomous navigation algorithm completely reliant on its reactive system
- **Remote Control**
  - Simple and effective terminal interface with well defined modes of operation and easy to use
- **Mapping and Localization**
  - Mapping and localization can be done reasonably well with manual control, but not very well with autonomous control
- **Object Avoidance**
  - Robot is capable of avoiding most obstacles but occasionally falls into pitfalls
- **Motion Detection**
  - Robot has a robust motion detection algorithm which catches 99% of motion and has very few false positives
- **User Alerts**
  - Robot has a reliable system for alerting the user and it integrates with their everyday life

Questions?