IEEE R5 Robotics Competition 2015

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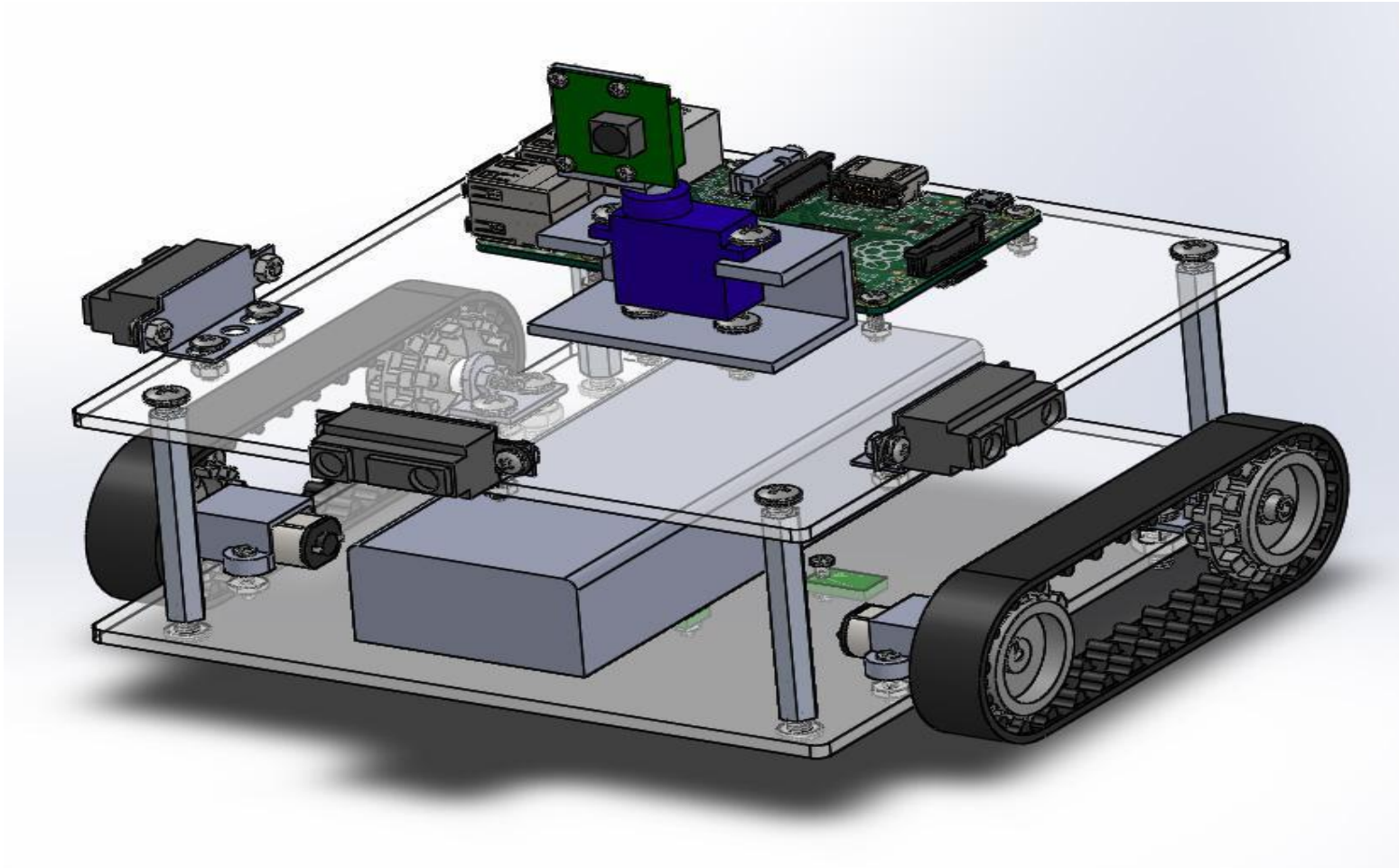
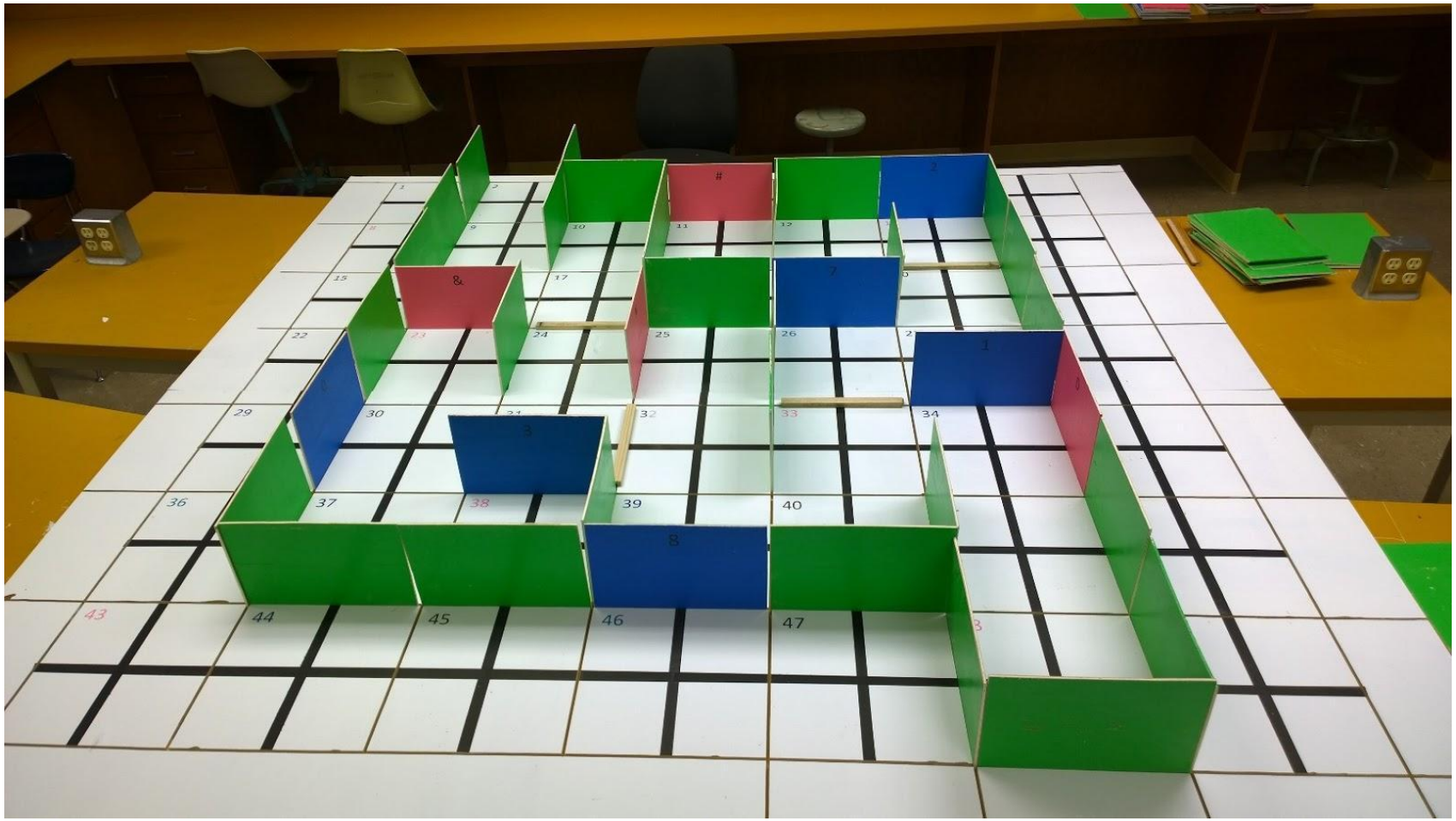
Sponsors

Department of Electrical and Computer Engineering

Robot Prototype



The Competition Maze



R5conferences.org

COMPETITION RULES

- 3 Rounds Qualifying & 1 Final Round
- Main Objective: Find Critical Path and Subsequently Run It
- 2 Parts for Each Run
- Part 1: Robot learns the maze
- Part 2: Robot runs critical path

Simply correctly finishing a critical path run qualifies for the final round

SPECIAL RULES

- Damaging the maze results in DQ
- Robot must be <7.5” tall
- Robots cannot split into separate parts
- Jumping, Climbing, and Flying are not allowed
- Runs will end if robot is stationary for 10 seconds
- Wireless Communication with Robot is not allowed
- Robots will be sequestered between rounds

COMPETITION SCORING

Qualifying Rounds (1,2,3)

• Entering New Square (Part 1)		+1
• Correct Critical Path Move		+2
• Lighting A Correct Light	+1	
• Repeating A Path Move	-1	
• Touching Wall (per square)		-1
• Moving Off Critical Path (part 2)		-1
• Easter Egg Number	+1	
• Easter Egg Alphabetical	+2	
• Easter Egg Symbols	NA	

COMPETITION SCORING

Final Round

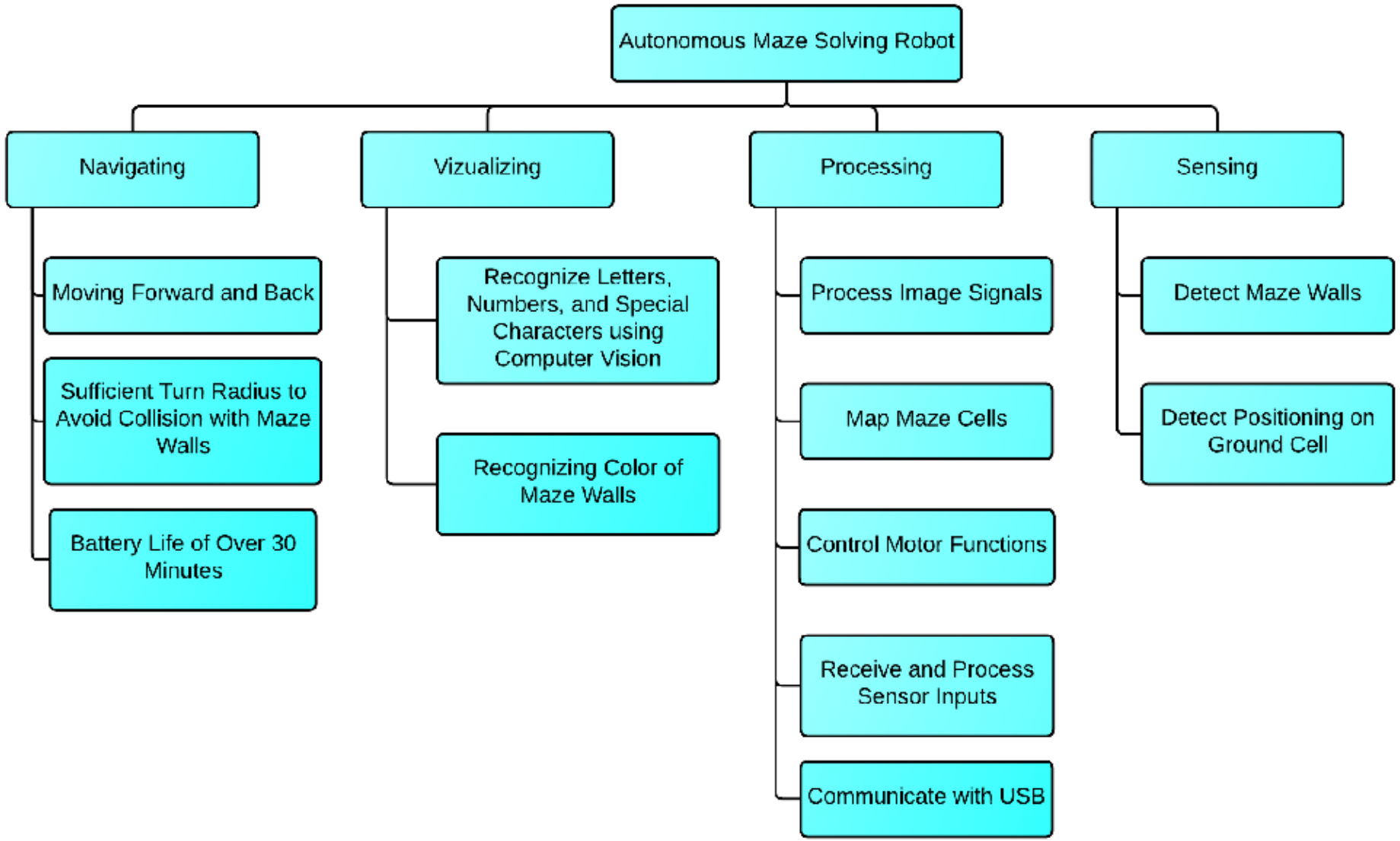
• Adjusted Critical Path Execution Time	Winning Criteria
• Search Path Execution Time	Tiebreaker
• BTB – Base Time Bonus	Fastest Critical Path Time in Finals
• Easter Egg Number	+1 +5% of BTB
• Easter Egg Alphabetical	+2 +15% of BTB
• Easter Egg Symbol	NA (Perfect Score Challenge)

Scoring

- Available scores
  - 32points for 5’x5’ maze
  - 50points for 6’x6’ maze
  - 71points for 7’x7’ maze
- Penalties
  - -1point for repeating a path move (part 1,2)
  - -1point for touching a wall (max penalty per square) (part 1,2)
  - -1point for moving of the critical path (part 2)
- Potential score increase
  - Perfect score challenge (+1point for each correctly identified special character)
  - If fastest critical path time in finals
    - Plus 5% of critical path time for each number correctly recognized
    - Plus 15% of critical path time for each number correctly recognized

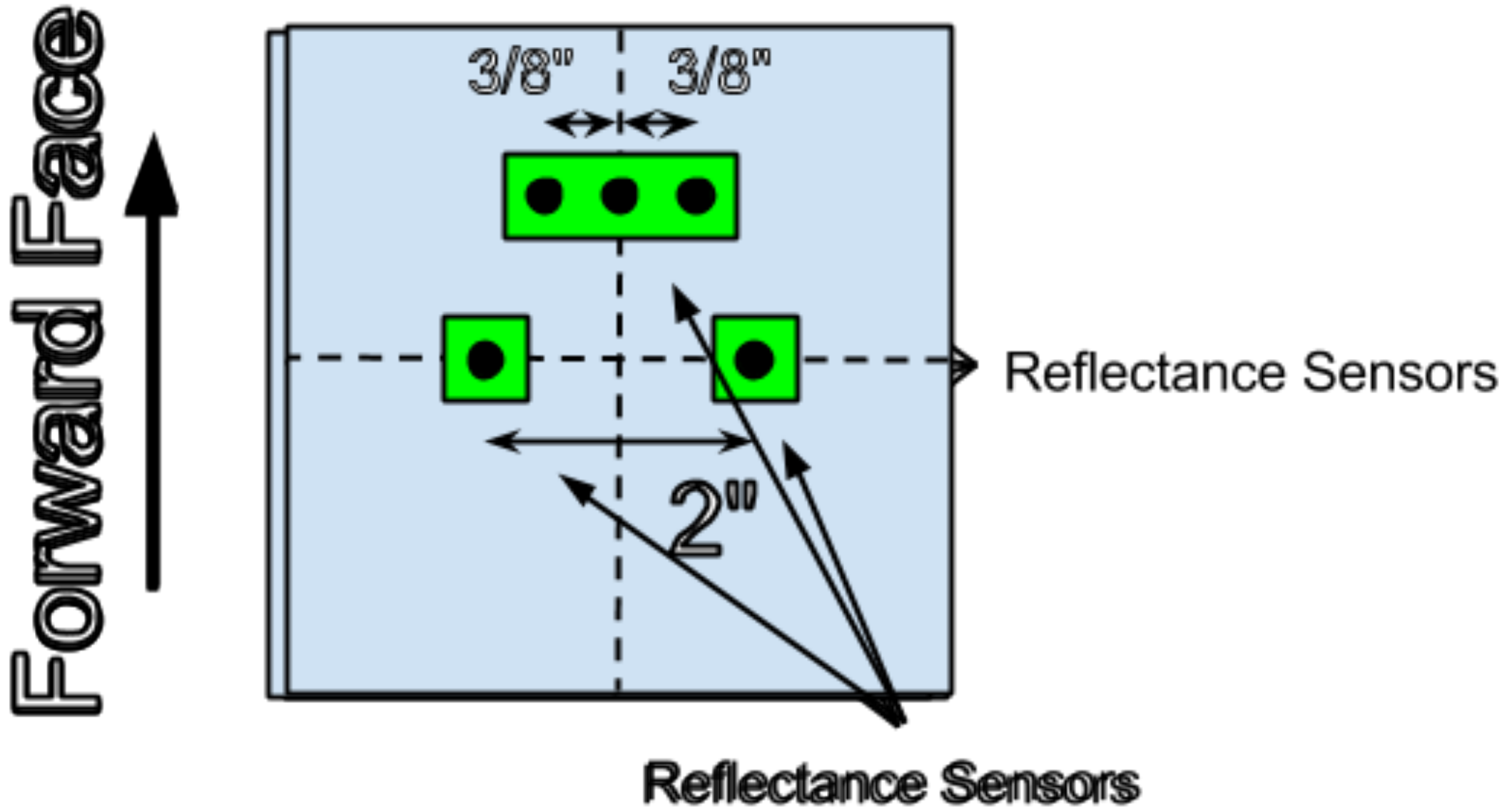
Ranking criteria – Winning criteria and successive tie breakers

1. Lowest adjusted time for execution of critical path in finals
2. Highest scoring (points) of all critical path attempts in finals
3. Lowest adjusted time in finals search path run
4. Highest combined point total in finals round
5. Highest combined point total in all rounds

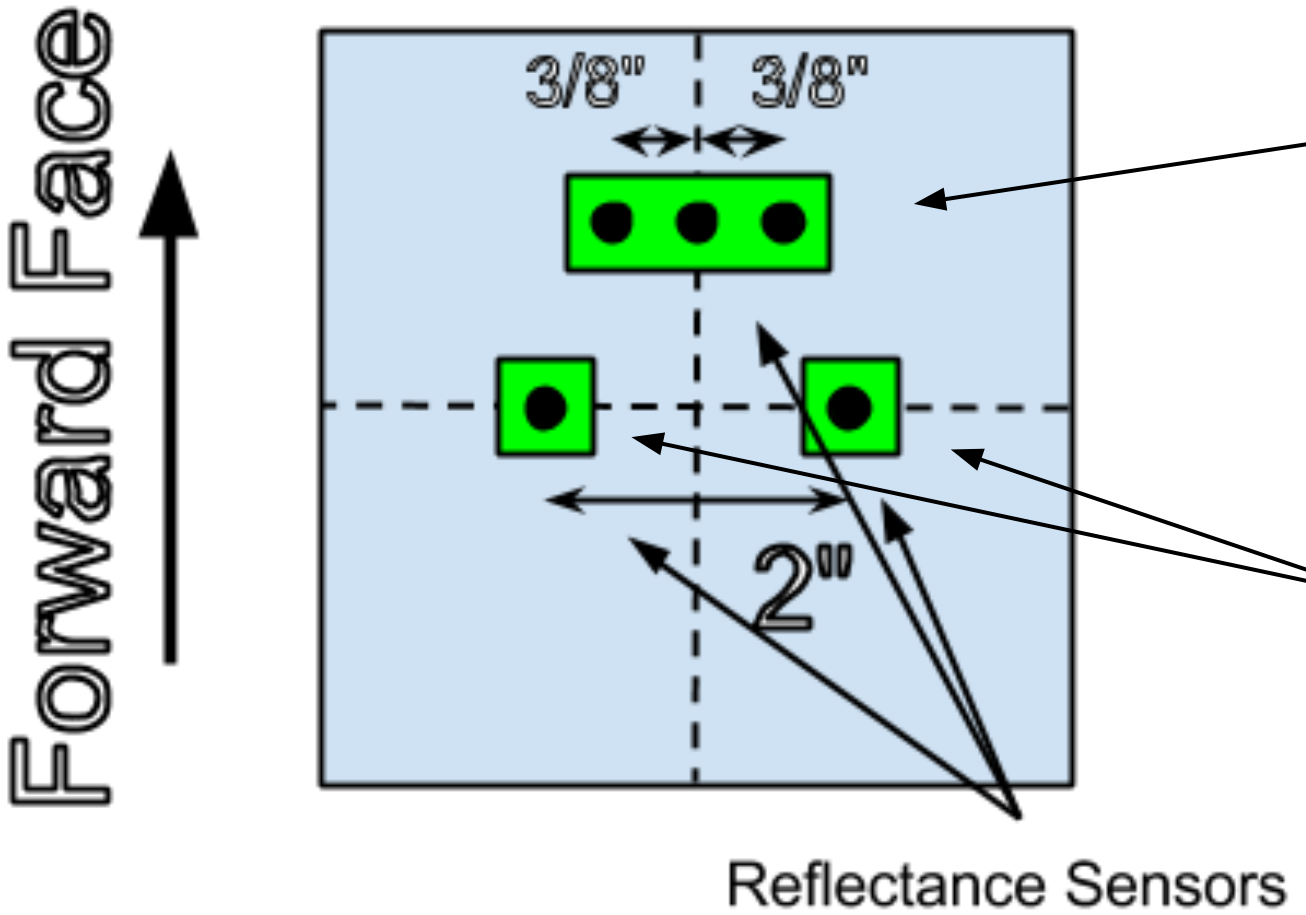

Autonomous Maze Solving Robot
Navigating
Vizualizing
Processing
Sensing
Moving Forward and Back
Sufficient Turn Radius to Avoid Collision with Maze Walls
Battery Life of Over 30 Minutes
Recognize Letters, Numbers, and Special Characters using Computer Vision
Recognizing Color of Maze Walls
Process Image Signals
Map Maze Cells
Control Motor Functions
Receive and Process Sensor Inputs
Communicate with USB
Detect Maze Walls
Detect Positioning on Ground Cell

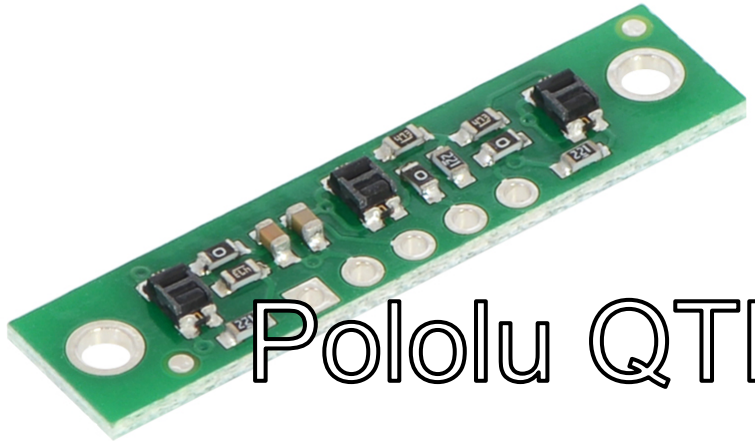
Engineering Specifications

- Battery Life > 30 Min
- Speed: Over .82 ft/s
- 100% Character Recognition Accuracy
- Wall Detection Range: 15.24 cm
- Motor Torque: 0ver 25 oz-in
- Size: 8” x 8” x 7.5”


Forward Face
3/8"
3/8"
2"
Reflectance Sensors
Reflectance Sensors

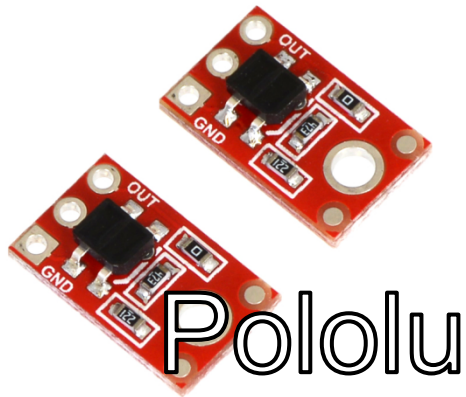
Ground Sensor Design





Pololu QTR - 3A

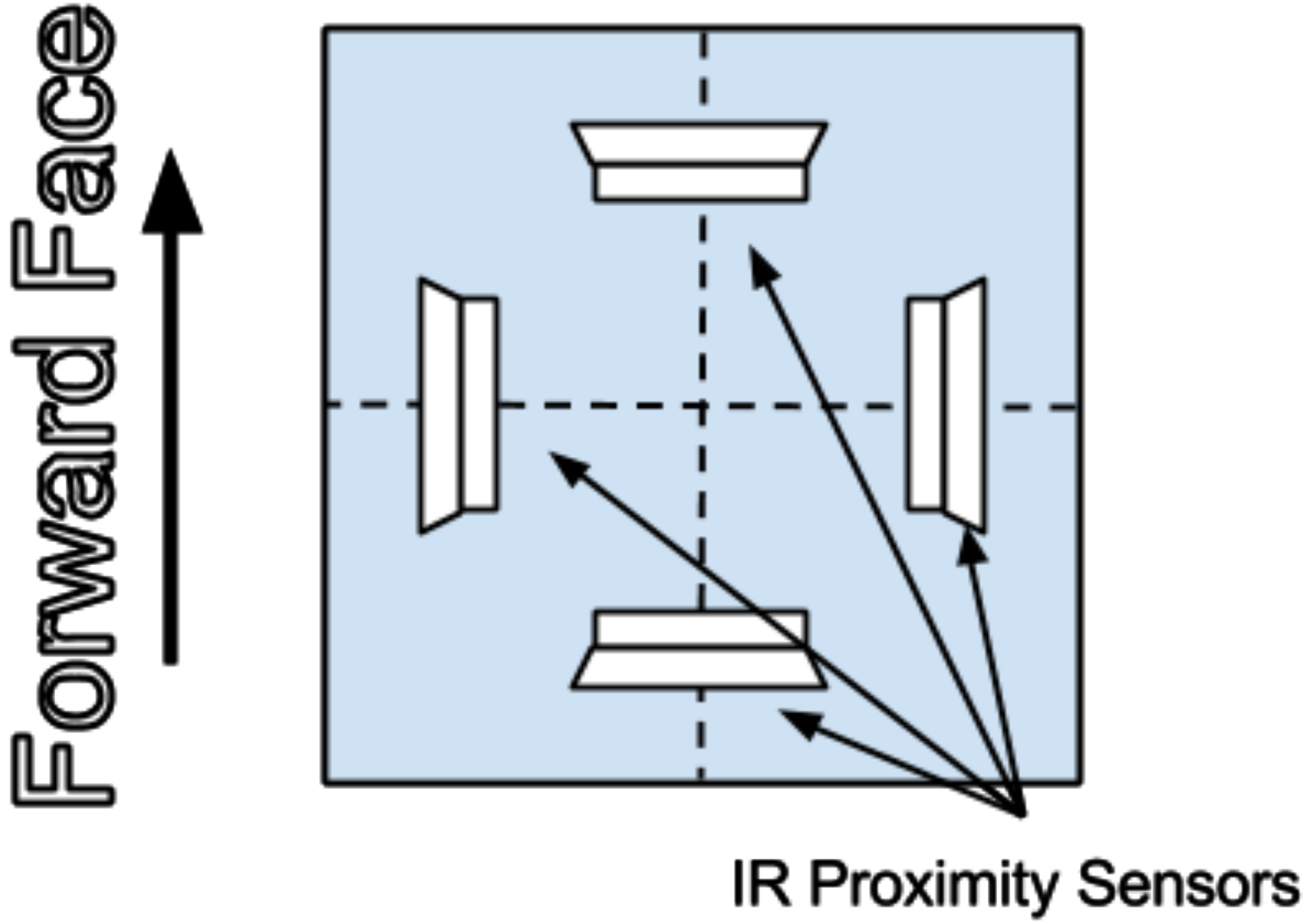
$4.95 from Pololu Analog Output



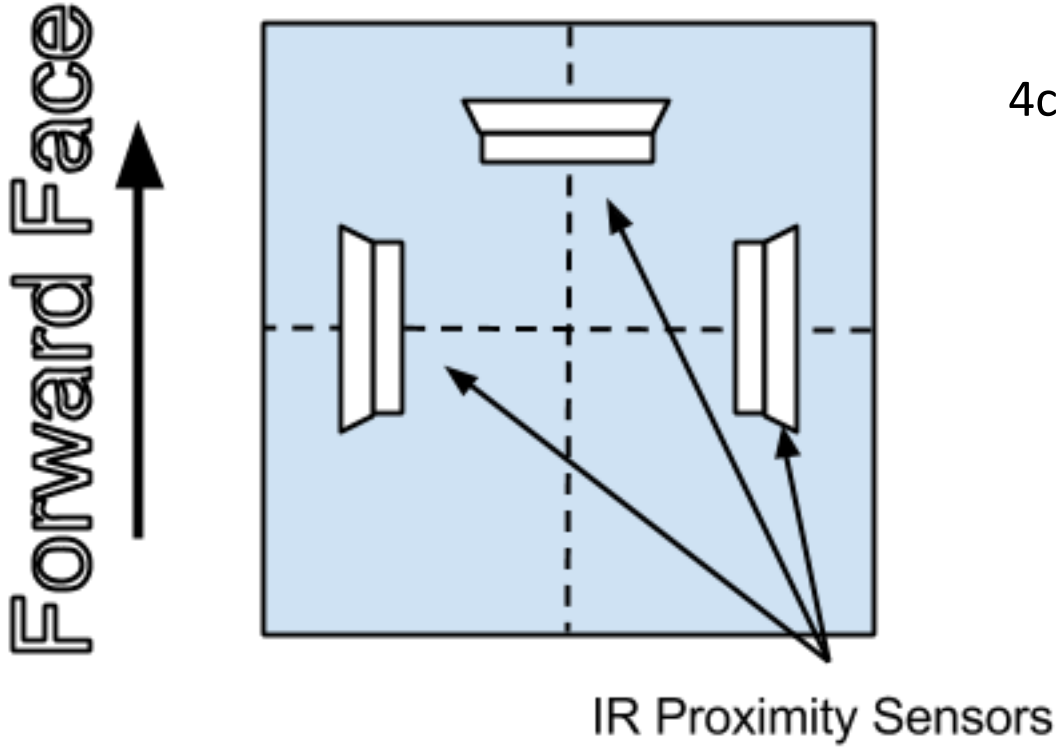
Pololu QTR - 1A

$4.25 from Pololu Analog Output

pololu.com


Forward Face
IR Proximity Sensors

Wall Sensor Design



4cm - 30cm range (1.5” to 12”)

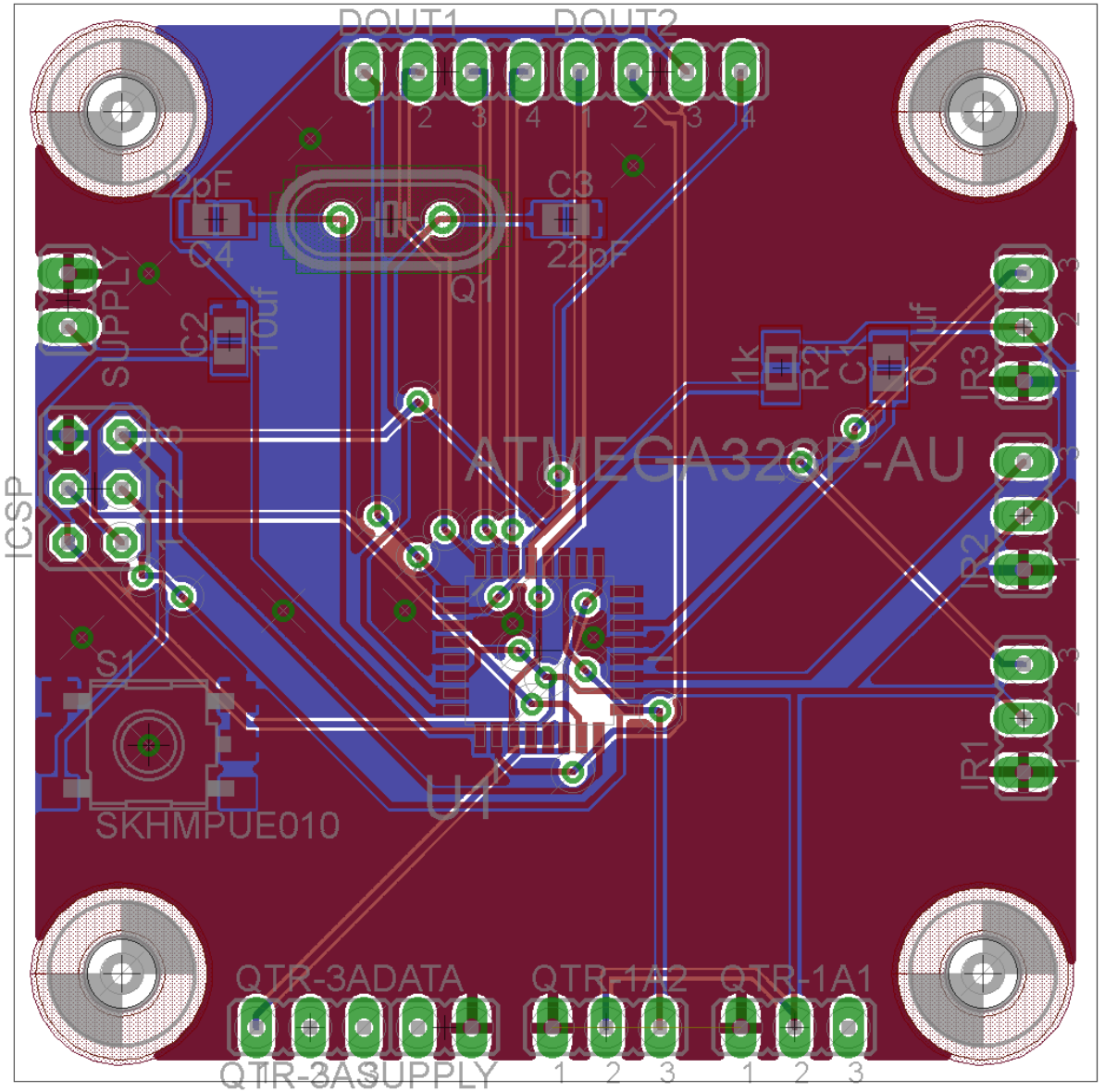
Analog Voltage Output

$7.40 ea. from Digikey

Sharp GP2Y0A41SK0F

Sensor Interface Board

- Sensors output an analog signal, which the Raspberry Pi cannot read as it has no onboard analog to digital converters.
- An Atmel 328p microcontroller has enough ADCs to preprocess these signals for the Pi.
- A board was designed to use the microcontroller to interface the sensors with the Pi.
- The PCB can be prototyped by SeeedStudio for under $10, and components can be assembled by us for under $20.

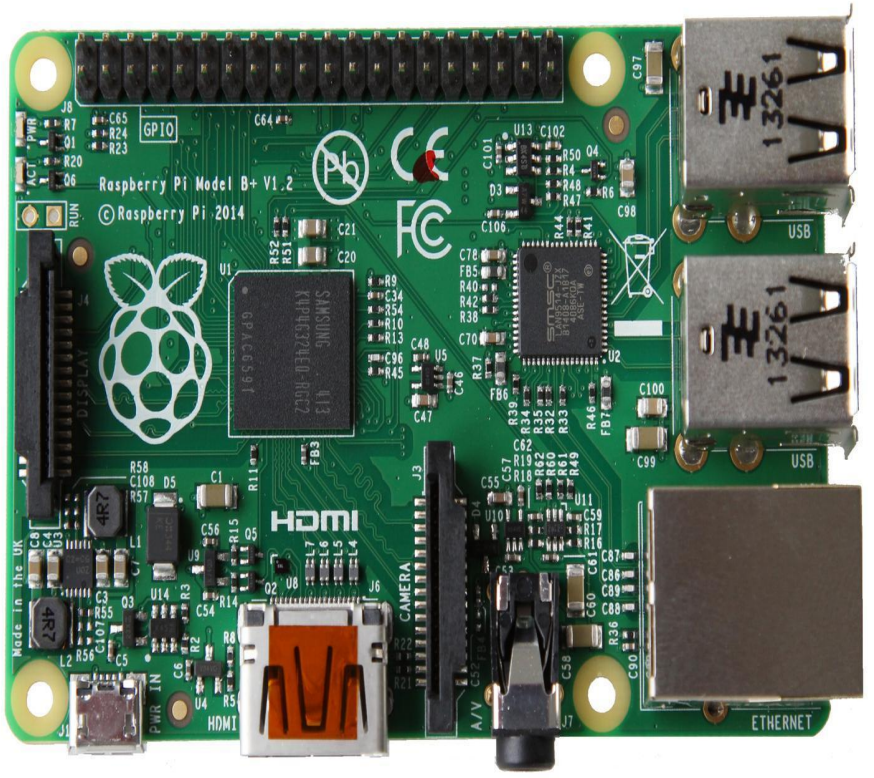


	Propeller C3	Raspberry Pi B+	Arduino DUE
Fast (0.4)	0.114	1.00	0.120
Size (0.2)	1	0.880	0.774
Cost (0.4)	0.389	1.00	0.764
Score	0.401	0.976	0.508

Raspberry Pi B+:

Clock Rate: 700 MHz
GPIO Pins: 27
Dimensions: 85mm x 56mm
Price: $35.00

- Dedicated Camera Port
- 4 USB Ports
- Storage on SD card
- Lightweight Linux Operating System
- Ability to run multiple programming languages
- Large development community

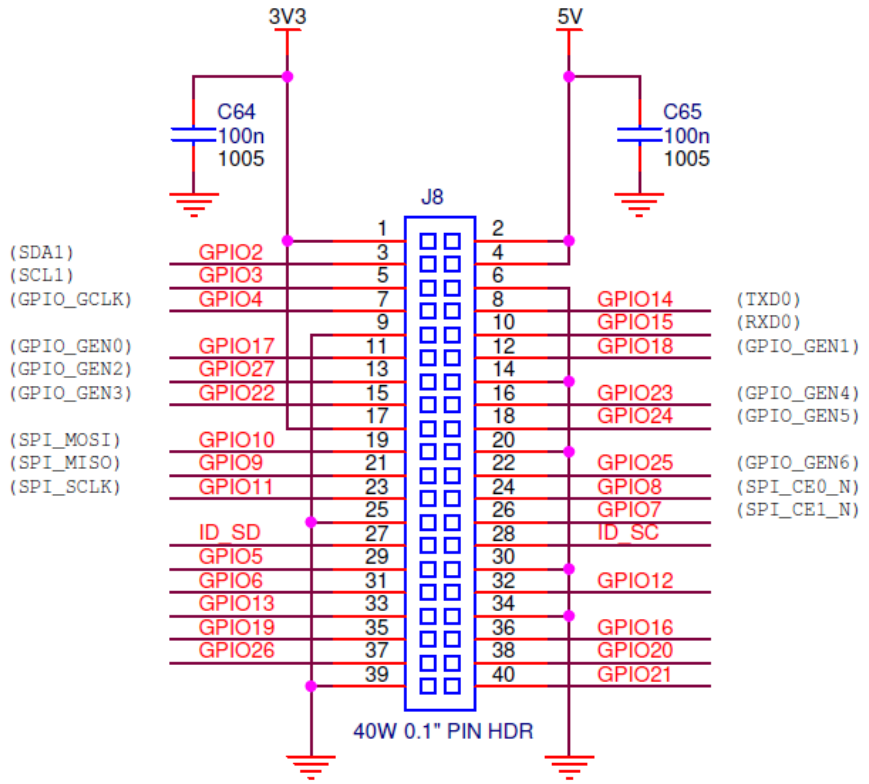


raspberrypi.org

	Python	C++
CPU Time (0.1)	28,054 (0.1209 Normalized)	3,392 (1.0 Normalized)
Raspberry Pi GPIO Library (0.3)	1.0	0.5
OpenCV (0.3)	1.0	1.0
PiCamera Library (0.3)	1.0	0.5
Total Score	0.91209	0.7

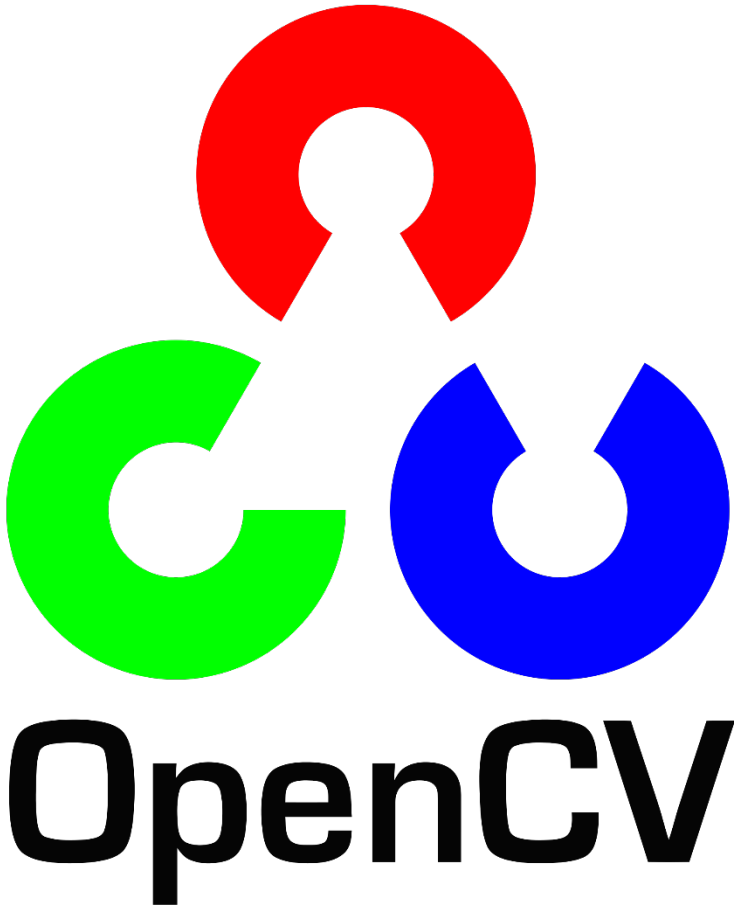
RPi.GPIO

- Programming Language: Python
- Relevant Applications:
  - Setting Raspberry Pi GPIO pins for input and output
  - Generating pin outputs
  - Gathering pin inputs



raspberrypi.org

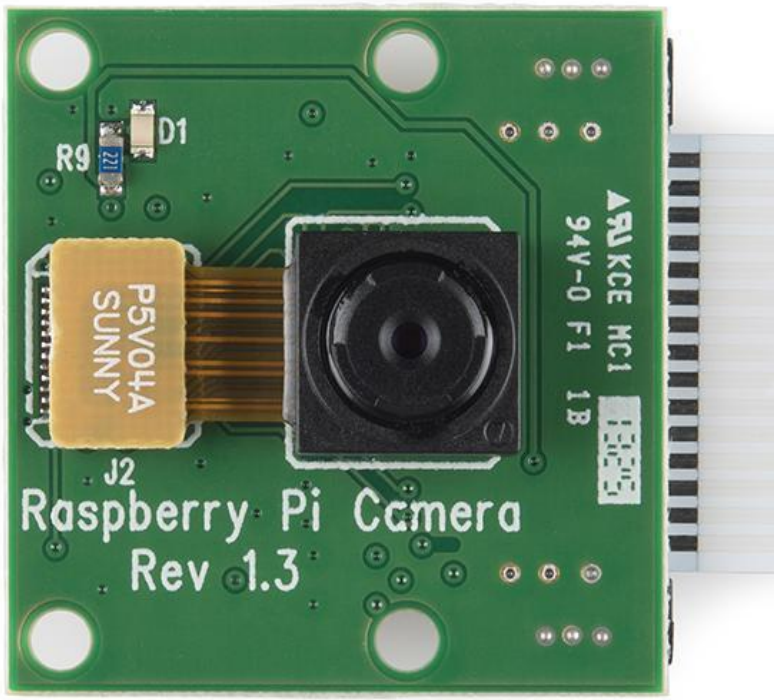
- Free open source software
- Inventor: William Garage
- Supports Linux and Python implementation
- Relevant Applications:
  - Mobile Robotics
  - Segmentation and Recognition
  - Artificial Neural Network
  - K-Nearest Neighbor Algorithm



opencv.org

PiCamera Library

- Compatible with the Raspberry Pi Camera Module and Raspberry Pi Camera Module Ports
- Accesses the Raspberry Pi command line tools from Python
- Relevant Applications:
  - Capturing Images
  - Capturing Videos
  - Importing images and videos to OpenCV



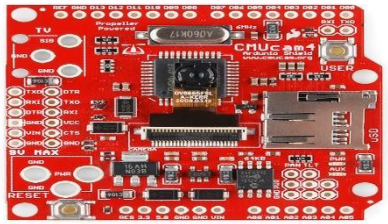
raspberrypi.org

Vision

Hardware

- Camera modules
  - The Pi camera

  - The CMUcam4



Software

- Prepacked software
  - Tesseract
    - Huge number of libraries, slow, demands bigger storing space
- Developed
  - Using the Respivid for color sensing
  - Using Respisttill for capturing
  - Using Python & OpenCV for image analyzing

Camera module selection

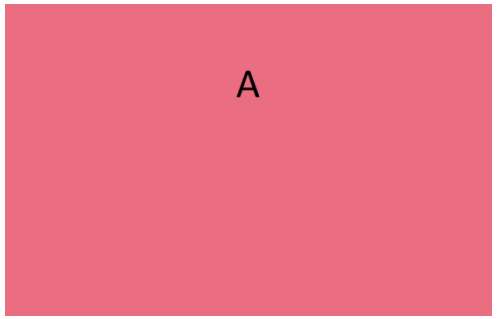
	CMUcam4	Raspberry Pi Camera Module
Cost	$115-$130	$25-$35
Power & data connections	Dedicated power connection / serial data	Dedicated power/ data CSI high bandwidth bus
Dimensions	52.25mm*53.50mm*13mm	25mm*20mm*9mm
Software interface	Arduino interface library	Respisttill, Respistillyuv, Respivid.
Power	4-9 volts, 250 mA	4.75-5 volts, 200mA
Pan/Tilt	Yes	No
µSD Card	Yes	No

Maze walls & related rules

- Walls with numbers, empty or letters

- 1234567890
- !@#$%^&*()

- No characters

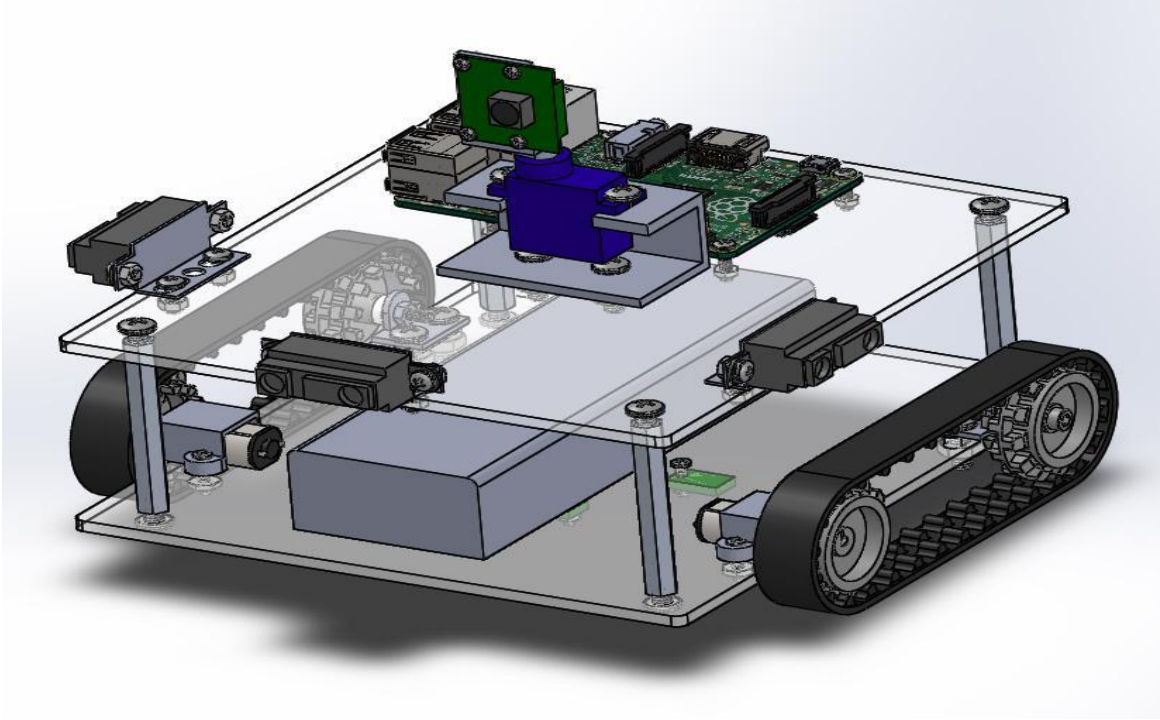


- ABCDEFGHIJKLMNOPQRSTUVWXYZ
- !@#$%^&*()

In each maze of 6'*6' and 7'*7' there will be 20 easter eggs
a. 8-ea - Numbers
b. 2-ea- Letters
c. 10-ea- Others

Engineering analysis

- Camera on the top tier.
- Camera 6’’ high of the maze floor.
- Camera on servo to be able to move. around scope up to 360° horizontally.
- Take a picture if the robot is centered and the camera senses pink or blue walls using Respivid.
- Small picture size for faster processing.

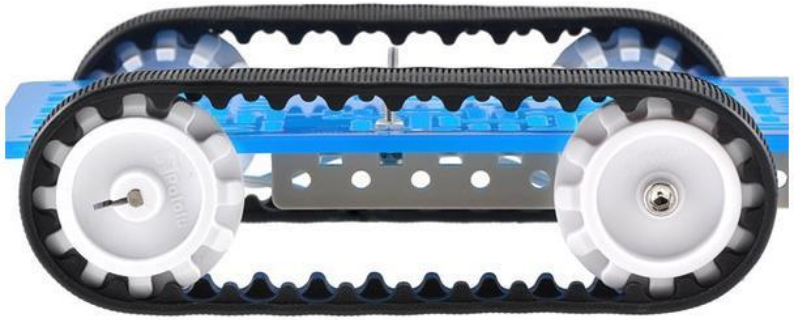


Platform Design Matrix

Criterion	Weight	2-wheel	4-wheel	Swerve-wheel	Treads	Mecanum
Maneuverability	10	s	s	+	s	+
Speed	8	s	s	s	s	s
Easy to Align	8	-	-	+	-	+
Power Consumption	6	+	s	-	s	s
Robust	6	s	s	s	+	-
Lightweight	5	+	s	s	s	s
Size	4	s	s	s	s	s
Uneven Terrain	7	-	s	s	+	-
Complexity	7	+	s	-	+	-
Cost	5	+	-	-	s	-
Total +		4	0	2	3	2
Total -		2	2	3	1	5
Overall		2	-2	-1	2	-3
Weighted		-16	-13	0	12	-7

Tread Design

- Lynxmotion 2” track
- BASICatom standard gm track kit
- Pololu 30T tank track set



Robotshop.com

Motor Specification

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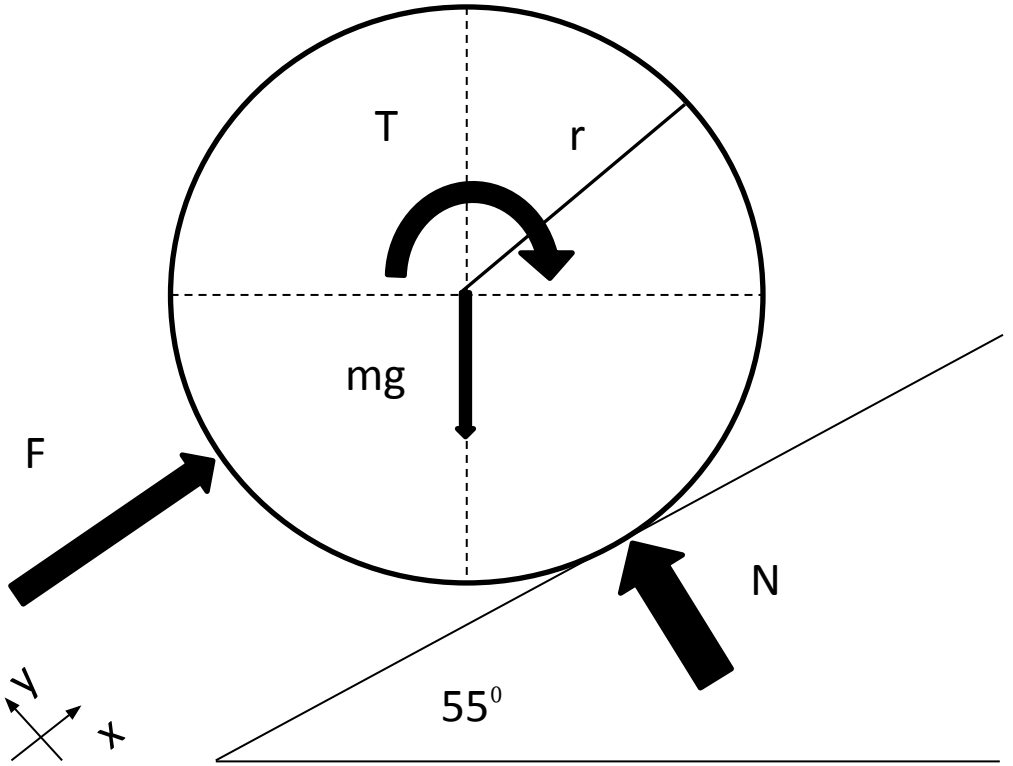
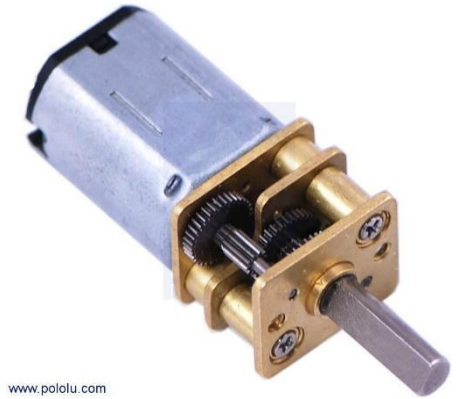
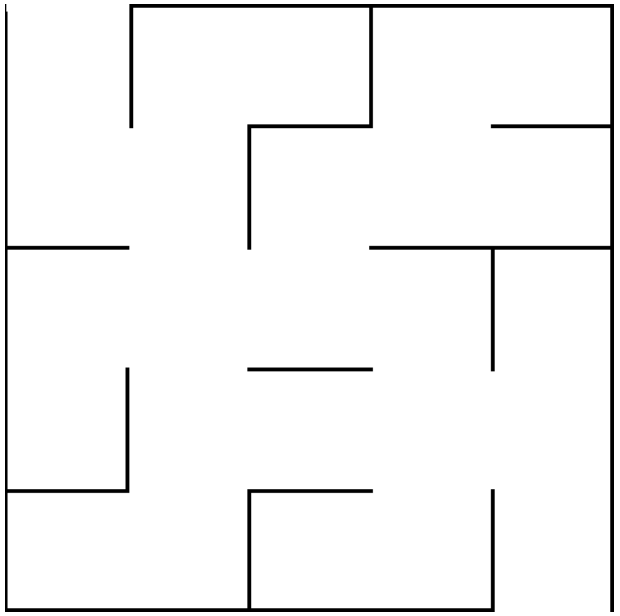


Pololu 210:1 Micro Metal Gearmotor

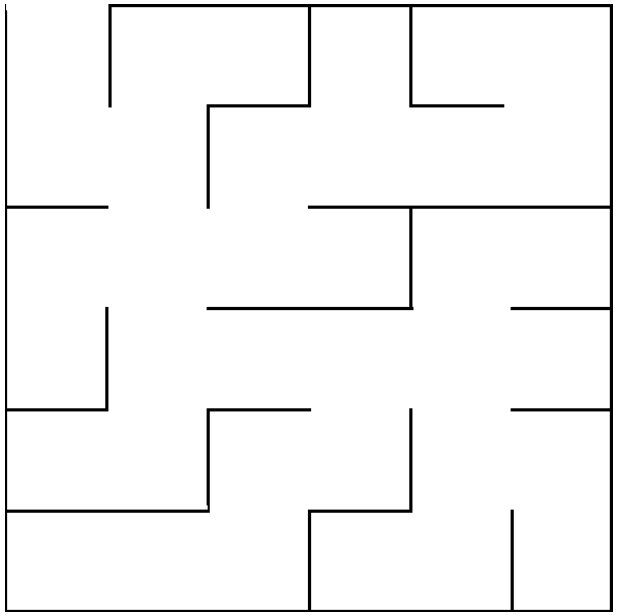
- 40 oz-in
- 200 rpm



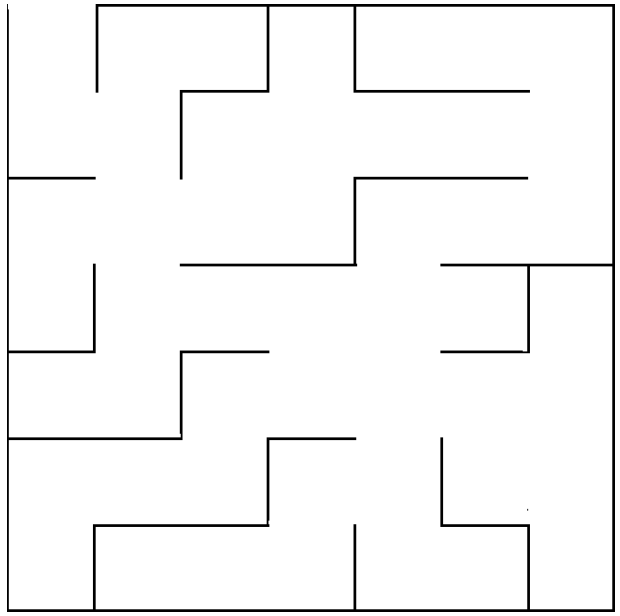
Maze analysis



5’x5’ Maze, 25 squares
Allotted time is 3minutes.
If we have to go through a square twice, we have 3.6 sec/ft. For the 200rpm motor we have; it will take .745 sec/ft, allowing for turning time



6’x6’ Maze, 36 squares
Allotted time is 4minutes.
if we have to go through a square twice, we have 3.33 sec/ft. If we take 1 sec for the camera to capture a picture, we will have 2.33 sec/ft. For the 200rpm motor we have, it will take .745 sec/ft and the rest of the time for turning time

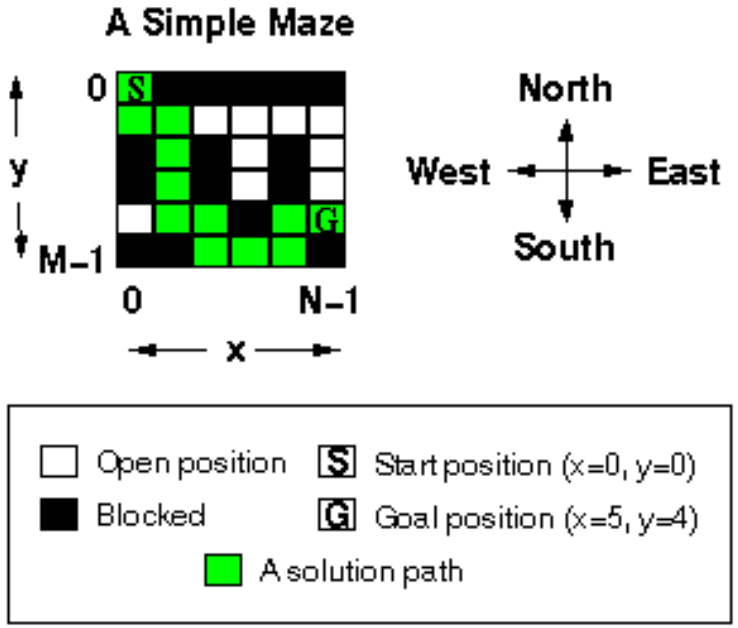


7’x7’ Maze, 49 squares
Allotted time is 5minutes.
If we have to go through a square twice, we have 3.06 sec/ft. If we take 1 sec for the camera to capture a picture, we will have 2.06 sec/ft. For the 200rpm motor we have it will take .745 sec/ft leaving the rest for turning time

Solving the maze

Recursively solving the maze

- findPath(x,y)



- Matrix example

```
S#####
.....#
#.####
#.####
...#.G
##...#
```

'.' - where the robot can move (open positions)
'#' - obstacles (blocked positions)
'S' - start position (here, x=0, y=0)
'G' - goal (here, x=5, y=4)

```
S+xx##
#+#xxx
#+##x#
.+#x##
#+++#G
#.#+++
```

Power

7.2V 3800mAh NiMH Pack

UBEC 5V/6V Voltage Regulators

Robot Lifetime Expectation

Robot powered by 7.2V 3800mAh NiMH battery

Module Power Needs:
Main Motors(2x): 1600mA
Raspberry Pi: 500mA
Raspberry Pi Camera: 250mA
Sensors: 125mA
TOTAL: 4075mA

- These values are worst case loads, based on all devices pulling max current and motors in a stall.

With these loads, we can estimate the life of our battery to be around an hour.

3800mAh/4075mA = 0.93 Hours

Engineering Specs Met

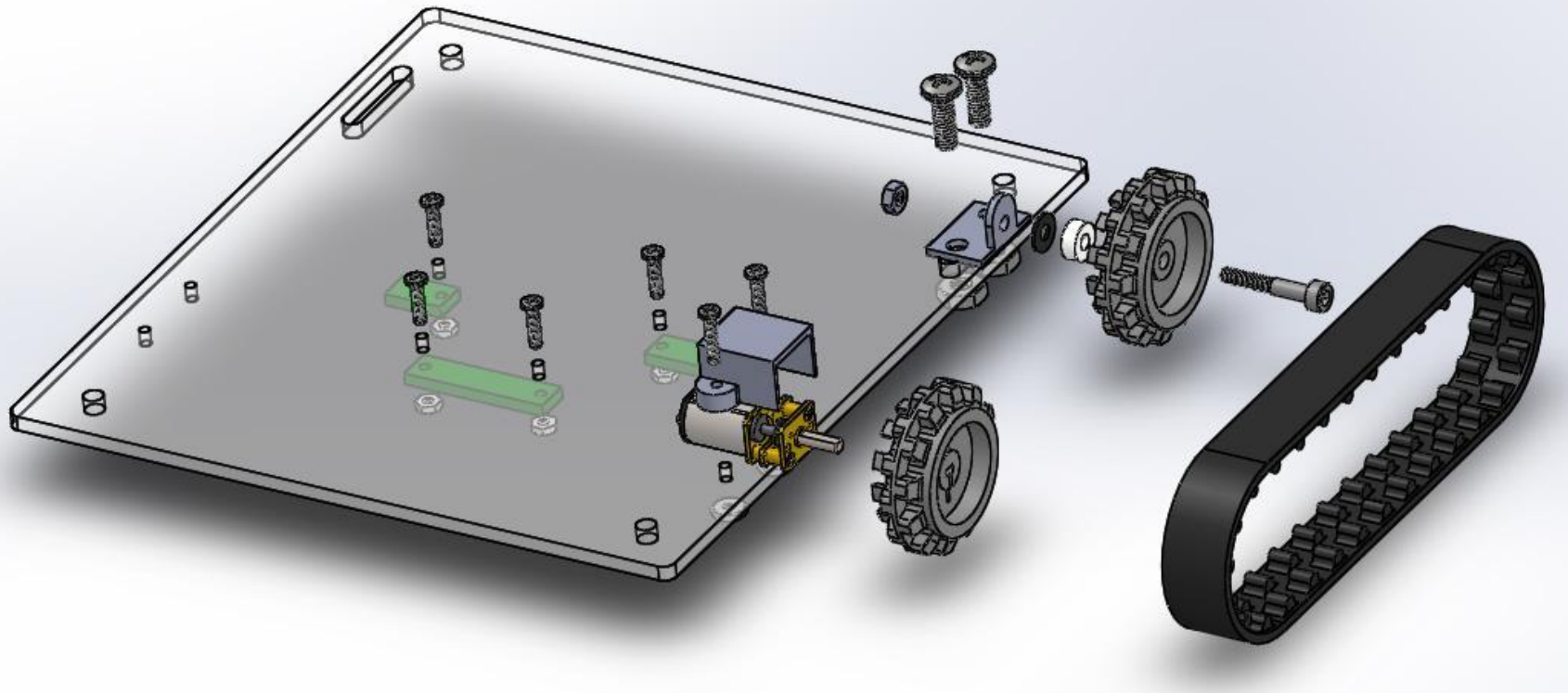
- Battery Lifetime: 1 hour
- Speed: 1.344 ft/s
- 100% Character Recognition
- Wall detection Range: 4 cm to 30 cm
- Motor Torque: 40 oz-in
- Size: 6.5” x 6” x 6”

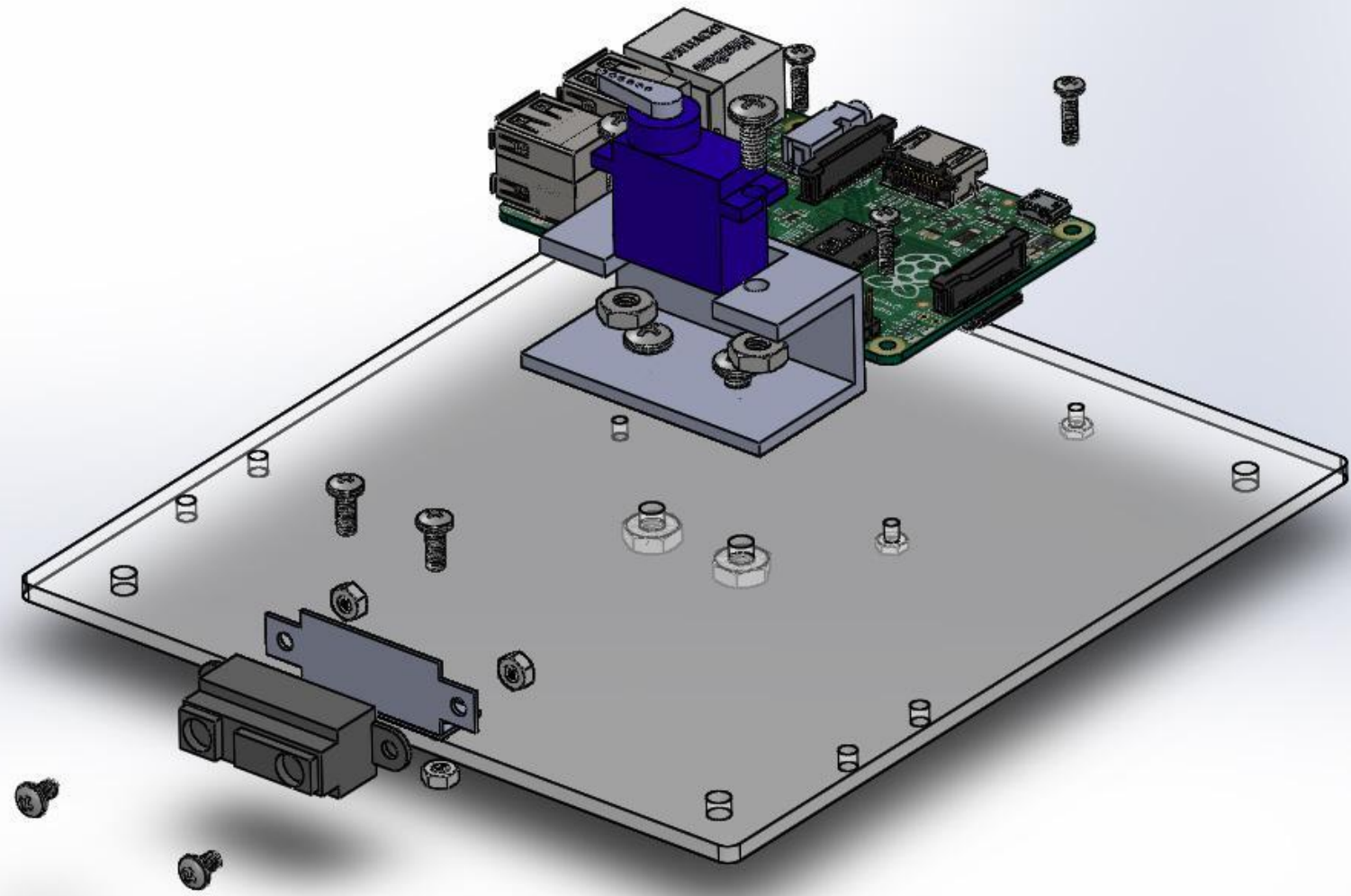
Manufacturing

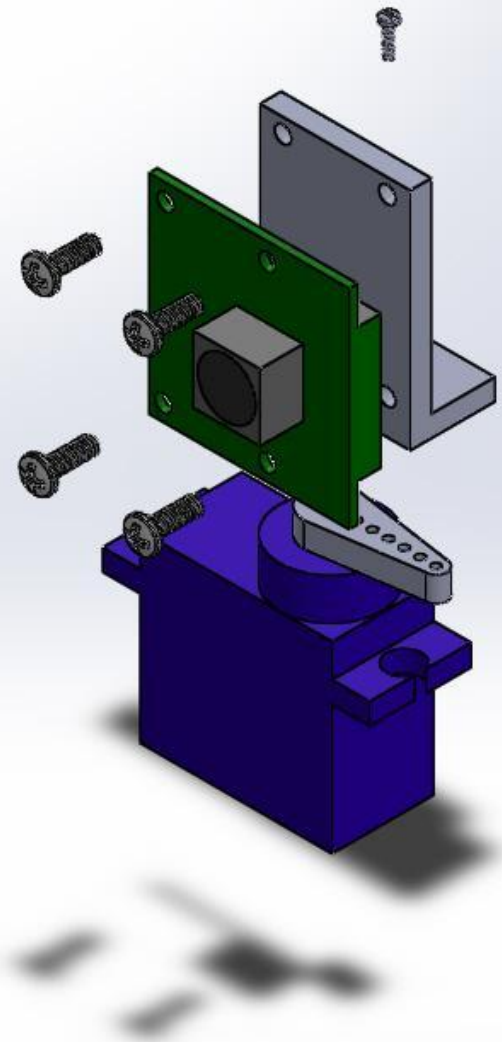
- 6.5”x6” acrylic sheets
- Custom idler bracket
- Custom idler spacer
- Custom servo bracket
- Custom camera bracket

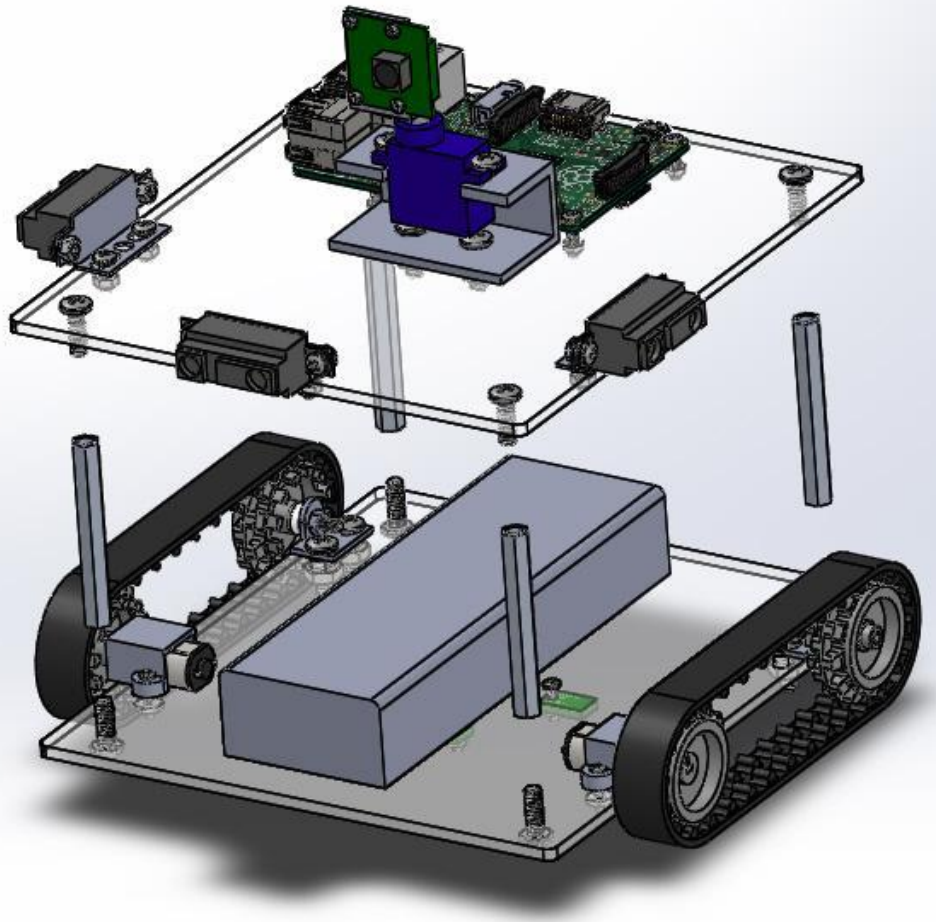
Assembly

- 2 tier design allows ample room for components
- Ensured IR sensors were not obstructed
- Camera was placed to ensure maximum visibility
- USB is easily accessible

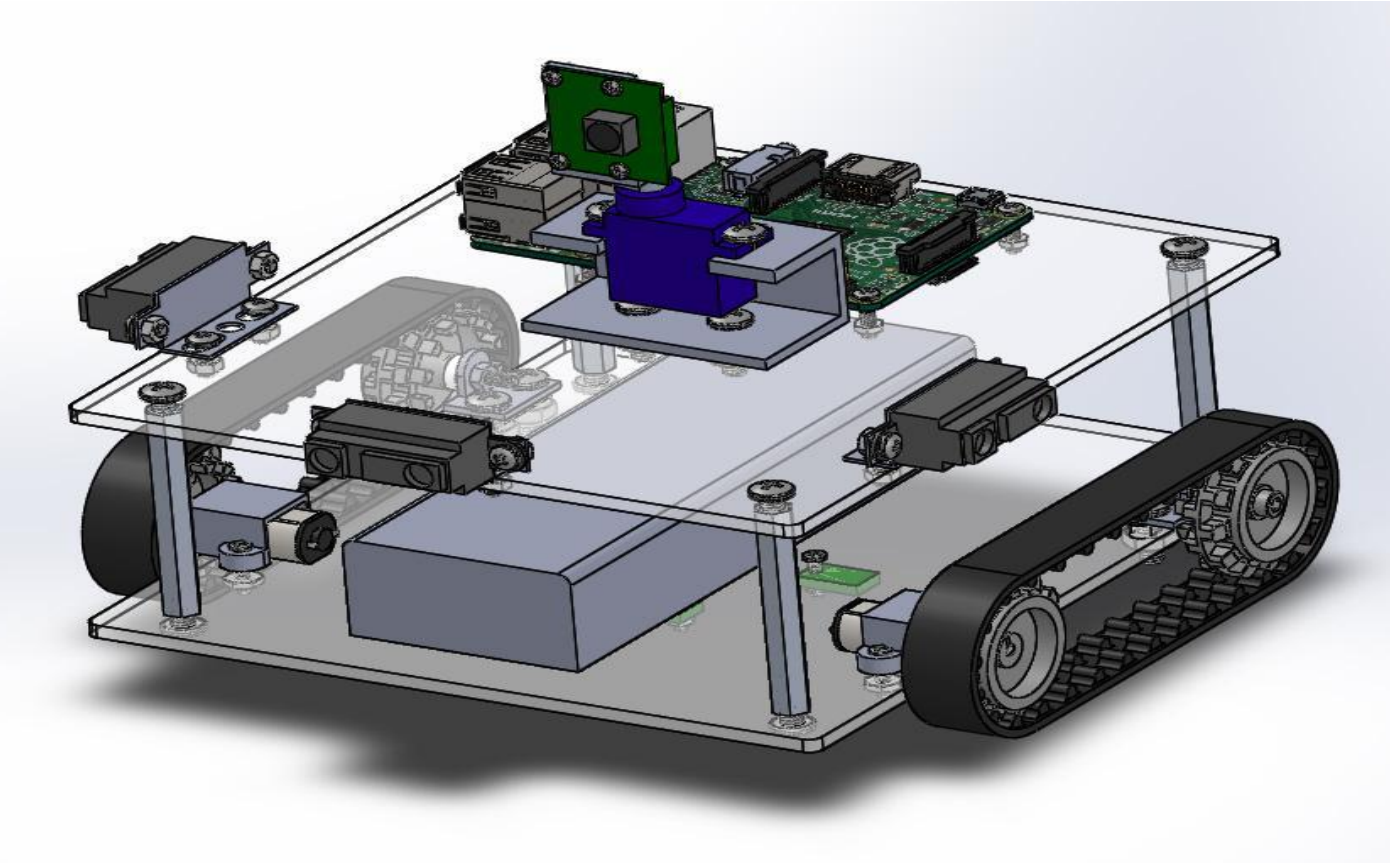








Completed Assembly



Basic Bill of Materials

Part	
Raspberry Pi B+	$ 37.49
Camera Module	$ 27.21
Sensors	$68.63
Test Maze	$ 230.36
Sensor Board	$ 33.38
Chassis/Movement	$ 69.33
Power	$ 63.00
Total:	**$ 529.40**

Testing Plans

- Testing for Robotic Movement and Sensor Recognition
- Testing for Character Recognition
  - Camera-Pi connection working correctly.
  - Camera can take pictures and store them with relative square number.
  - Camera can record video and stored correctly.
  - Camera responses to the robot position by taking pictures if pink or blue walls.
  - System can recall a stored picture and process it for potential character identification.
  - Existence and correct configuration of the output file
- Testing for Low Voltage Warning
- Testing for Maze Solving of 5x5 Grid
- Testing for Maze Solving of 6x6 Grid
- Testing for Maze Solving of 7x7 Grid

Testing Plans

- Motors
  - Test for individual motor output
  - Test for max speed with 2 motors installed
  - Test for turning clearance and angular velocity
  - Test for overcoming maze obstacles (speed bumps)
- Battery Runtime Test
  - Connect Battery to all motors and have them run at full speed.
  - Measure with Voltmeter and time to see how long till depletion
- Voltage Regulation Test
  - Connect both regulators to battery
  - Add devices to voltage buses one at a time while measuring voltage level of the buses to ensure stability under heavy load.
- Sensors
  - Calibration of microcontroller to output proper signal to Raspberry Pi
  - Test microcontroller outputs with dummy loads (LED indicators)
  - Software test of whether Raspberry Pi is reading the microcontroller data

Safety Concerns

- Robot will be disqualified if it is not safe to operate deemed by the judges
- Safe turning radius to avoid collisions with the maze walls which will result in deducted points and possible disqualification
- Wires in the robot must be tied down safely to ensure no disconnection or shorting
- Edges must be rounded off in order to assure safe handling

Fall Semester Timeline

- August: Assigned Project
- September 18th: Needs and Objectives Statement Written
- September 23rd: Functional Decomposition Finished and Roles Delegated
- October 1st: Designed Proximity Sensor Layout
- October 5th: Designed Reflectance Sensor Layout
- October 7th: Treads Chosen as Mobility Platform
- October 8th: NiMH Chosen as Battery Type
- October 9th: PiCamera Module Chosen as Vision Apparatus
- October 10th: Raspberry Pi B+ Chosen as Controller
- October 17th: Mid-Term Oral Presentation Given
- October 20th: Conceptual Design Report Turned In

- October 30th: PiCamera Library Chosen as Camera Manipulation Package
- November 1st: OpenCV Chosen as Vision Software Package
- November 2nd: RPi.GPIO Chosen as GPIO Manipulation Package
- November 7th: Designed Sensor PCB
- November 14th: Python Chosen as Programming Language
- November 28th: Robot Model Completed in SolidWorks
- December 3rd: Final Oral Presentation Given
- December 7th: Preliminary Design Report Turned In

January 14th – January 16th

- Ordering of Parts

January 19th – February 13th

- Manufacturing of Robot and Test Maze Completed
- Algorithm Writing

February 16th – March 2nd

- Testing for Robotic Movement and Sensor Recognition
- Testing for Character Recognition
- Testing for Low Voltage Warning

March 2nd – March 16th

- Testing for Maze Solving of 5x5 Grid

March 16th – March 23rd

- Testing for Maze Solving of 6x6 Grid

March 23rd – March 30th

- Testing for Maze Solving of 7x7 Grid

March 30th – April 16th

- Tweaking of Algorithm and Robot Design for Maximization of Competition Score

April 17th

- IEEE R5 Robotics Competition in New Orleans, LA

Appendix

Spring Semester Timeline

- January 14th – 16th: Order All Parts
- January 19th – February 13th: Completion of Test Maze and Robot
- January 14th – February 13th: Completion of Algorithm
- February 16th – March 2nd: Completion of Testing for Robotic Movement and Sensor Recognition
- February 16th – March 2nd: Completion of Testing for Character Recognition
- February 16th – March 2nd: Completion of Testing for Low Voltage Warning
- March 2nd – March 16th: Completion of Testing for Maze Solving on 5x5 Grid
- March 16th – March 23rd: Completion of Testing for Maze Solving on 6x6 Grid
- March 23rd – March 30th: Completion of Testing for Maze Solving on 7x7 Grid
- March 30th – April 16th: Tweaking of Algorithm and Robot Design for Maximization of Competition Score
- April 17th: IEEE R5 Robotics Competition in New Orleans, LA

Part	Supllier	Cost	Qty	Ext Price
Raspberry Pi	Amazon	37.49	1	37.49
Camera Module	Amazon	27.21	1	27.21
Sensors				
QTR-3A	Pololu	4.95	1	4.95
QTR-1A	Pololu	4.25	2	8.50
Sharp IR Sensor	Digikey	7.40	3	22.20
Bracket Pair	Pololu	3.49	2	6.98
Crimp Connector	Pololu	0.79	2	1.58
3-Pin JST Cable	Pololu	1.25	3	3.75
M3 Machine Screws	Pololu	0.99	4	3.96
Hex Nuts M3	Pololu	0.99	4	3.96
6" F-F Servo Cables	Pololu	1.95	4	7.80
SubMicro Servo	Pololu	4.95	1	4.95
Test Maze				
4'x8'x3/4" MDF	Lowes	35.59	2	71.18
4'x8'x1/4" Ply	Lowes	21.92	2	43.84
Gal White	Lowes	16.98	1	16.98
Qt. Green	Lowes	20.44	2	40.88
Qt. Pink	Lowes	20.44	1	20.44
Qt. Blue	Lowes	20.44	1	20.44
Paint Marker	Amazon	10.25	1	10.25
Painter's Tape	Amazon	6.35	1	6.35
Sensor Board				
PCB Fab	SeeedStudio	9.90	1	9.9
Atmel 328p	Digikey	3.85	1	3.85
0.1 uF Cap	Digikey	0.09	10	0.89
22 pF cap	Digikey	0.29	10	2.94
10 uF	Digikey	0.50	10	5
Res 1k	Digikey	1.72	5	8.6
Osc 16Mhz	Digikey	0.36	5	1.8
Headers	Digikey	0.40	1	0.4
Body and Movement				
Pololu 30T track	Pololu	14.95	1	14.95
Pololu micrometal gearmotor	Pololu	15.95	2	31.90
1/8" Acrylic sheets (12"x12")	Pololu	5.64	2	11.28
2" standoffs (10 pack)	Pololu	7.95	1	7.95
Pololu gearmtor bracket pair (extended)	Pololu	3.25	1	3.25
Power				
Tenergy 7.2V		27.00	1	27.00
NiMH Smart Charger		18.00	1	18.00
Hobbywing Regulator		9.00	2	18.00

References

http://www.raspberrypi.org/documentation/hardware/camera.md
https://www.cs.bu.edu/teaching/alg/maze/
http://elinux.org/RPiconfig
http://www.open-electronics.org/computer-vision-with-raspberry-pi-and-the-camera-pi-module/
http://www.rs-online.com/designspark/electronics/knowledge-item/r-pi-ffc-connectors
http://mipi.org/specifications/camera-interface#CSI1