CarryU Trash Bin

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Problem description

At large households, people need to transfer their trash bin to the curb and take it back on the trash collection day. This is a manual process for which householders need to keep track of dates and spend physical efforts. According to survey, over 90% of respondents are glad to get rid of this task for reasons of lifestyle improvement and safety. Automation opportunities exist for needs catering to elderly customers, busy middle-agers, tech-savvies and the solution to this problem leads one early preparation for the future market of home IoT systems.

In preparation, we designed an auto-guided trash bin carrier that with a one-time learning from human demonstration, activates itself on cleaning day to drive between the house and the roadside curb for its inside trash to be dumped.

Customer needs and specifications

Stakeholder identification

- Primary market: suburban house owners

Desired functionalities

- Automatic trash disposal (requires accurate and robust navigation algorithm for household trash delivery)
- Trash collection tracking (functional in day and night)
- Terrain adaptability

SELECTION CRITERIA	WEIGHT	TRACK	WHEEL	HALF TRACK	RAIL
TERRAIN ADAPTABILITY	3	0	-	0	0
WEATHER ADAPTABILITY	2	0	-	-	-
NAVIGATION ERROR	2	0	-	0	+
PAYLOAD	1	0	-	-	+
EASY TO CONTROL	2	0	-	-	+
COST	3	0	+	+	-
EASY TO ASSEMBLE	3	0	+	-	-
DURABILITY	1	0	-	0	+
COMPATIBILITY	2	0	+	-	-
RELIABILITY	2	0	-	0	+
SCORE	NA	0	-5	-10	-2

Figure 1: *Pugh chart of core sub-functions.*

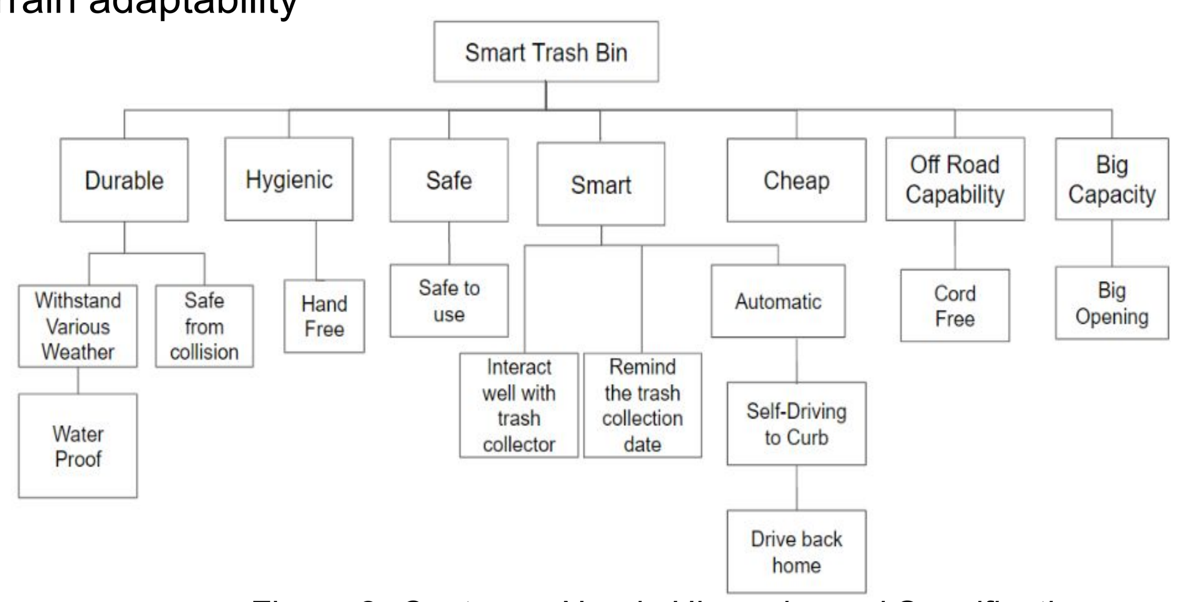

Figure 2: *Customer Needs Hierarchy and Specifications.*

Concept generation and selection

Selection process

- Abandoned track design and battery recharging sub-function.

Key ideas and considerations

- Navigation: motion, odometry and infrared and ultrasonic sensors integrated with accurate navigation algorithm for robust driving and obstacle avoidance.
- Wheel design: maneuverability and easiness for maintenance and repair.
- Reasonable traveling distance and climbing slope.

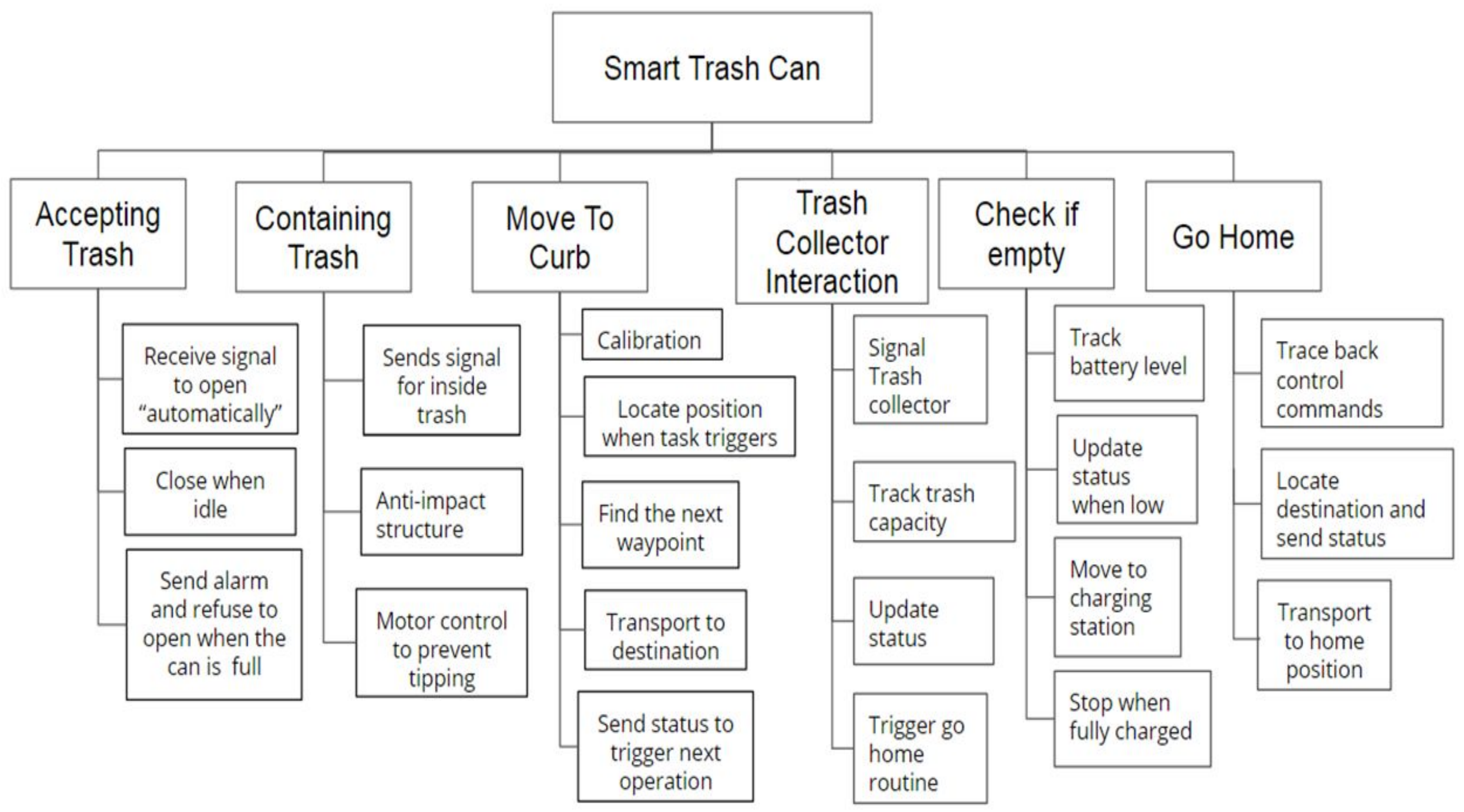

Figure 3: *Function Decomposition.*

Concept description

Bin & electronic component Carrier

- Assembled using 80/20 bars and laser cut acrylic board, whose stress is simulated in ANSYS

Motor bracket

- Longer front motor bracket create 5% angle and make bin naturally sit back and lie on the frame.

Navigation core component

- Navigation = Encoder + Compass + IR + Ultrasonic

Figure 4: *Final CAD design.*

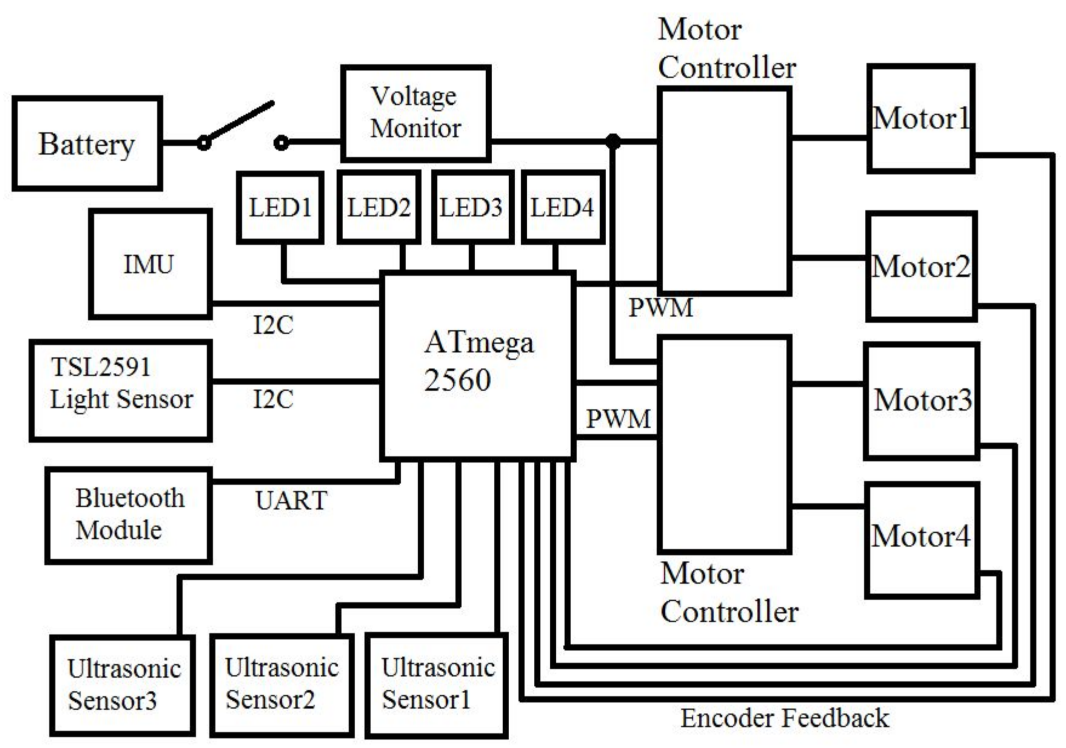

Figure 5: *Schematic.*

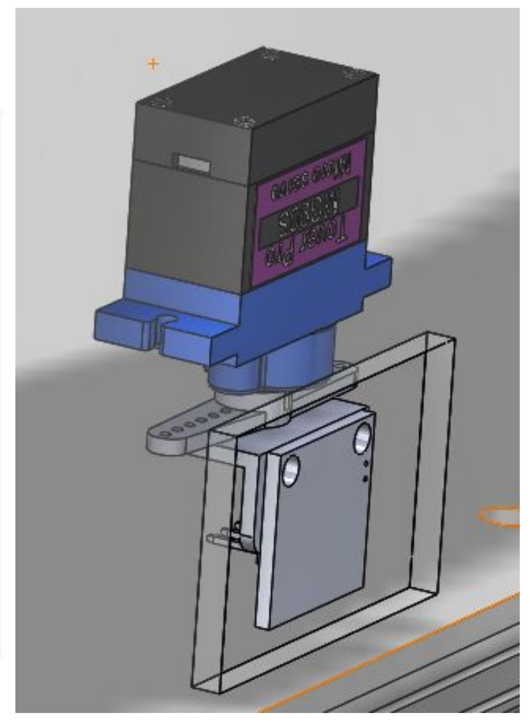

Figure 6: *Servo design.*

Analysis

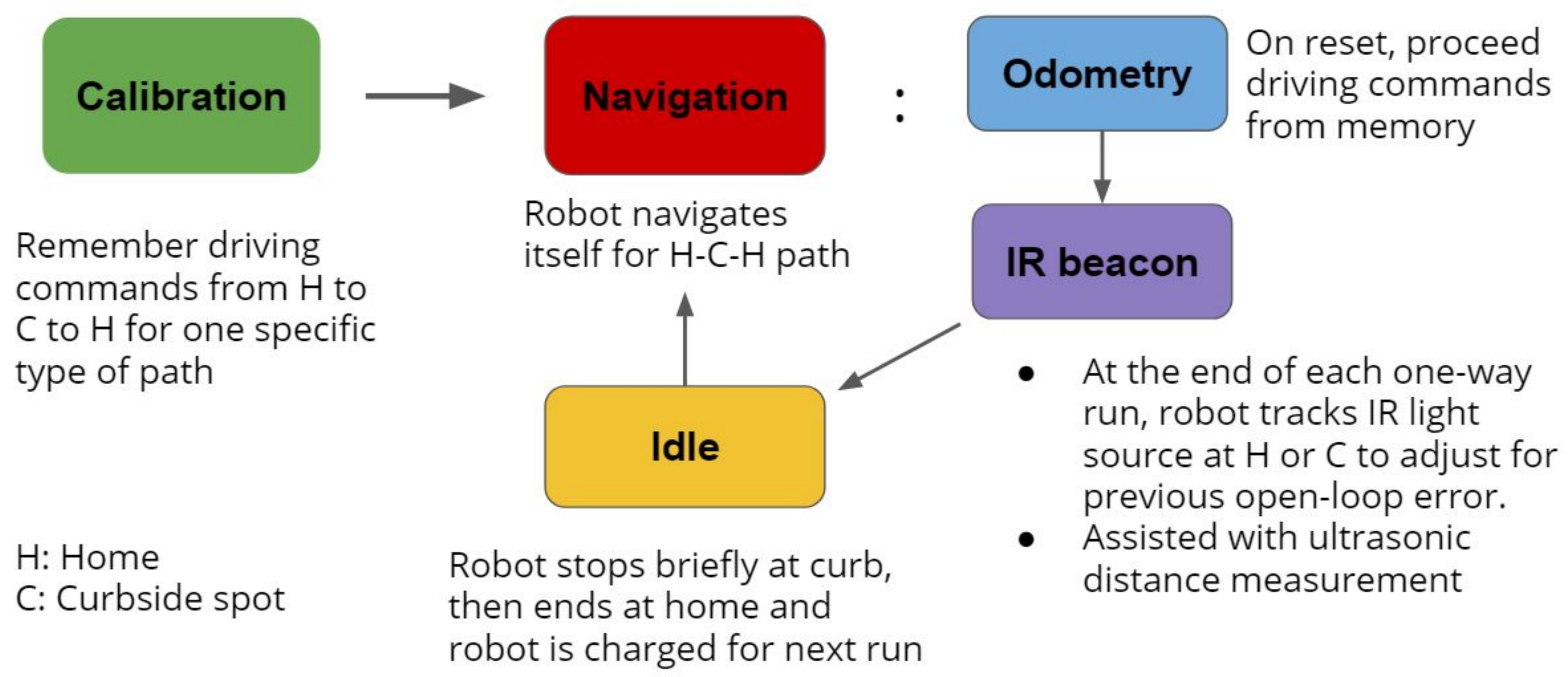

Figure 7: *Functional analysis diagram of CarryU automatic trash delivery robot.*

Compass sensor performance test and analysis

- LPF gives reasonable accuracy (±0.5°) and response time (T = 0.3 sec).
- Time constant is 311.2ms.

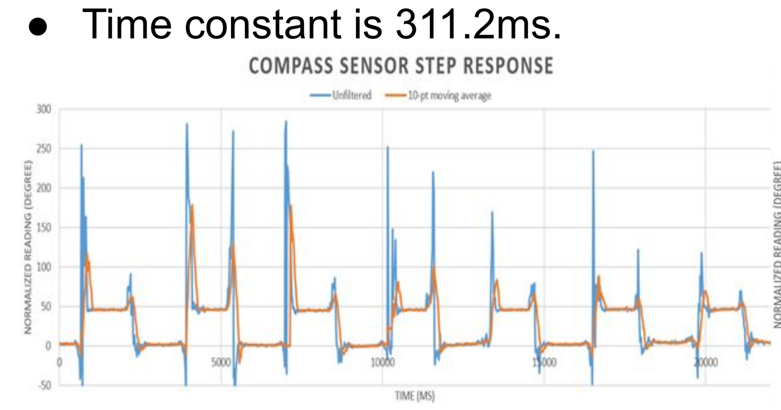

Figure 8: *Step Response of Compass*

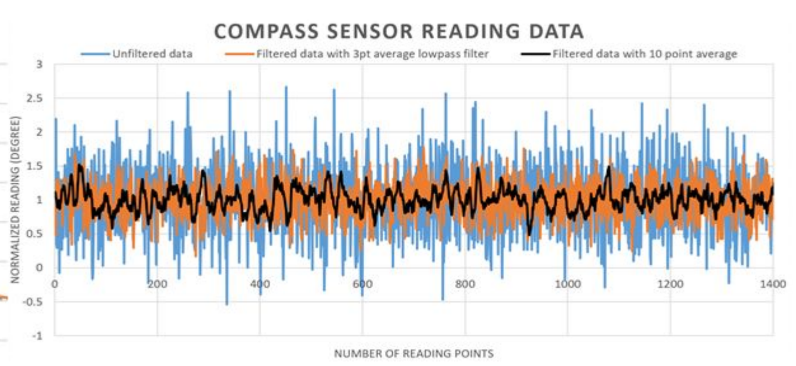

Figure 9: *Compass Reading with LPF at Various Sample Number.*

Infrared sensor analysis

- $L = 4.8671 * \exp(-0.0450 * \text{Intensity}) + 1.3331 * \exp(-0.0016 * \text{Intensity}) - 0.3$.
- Error of computation = 5.02%.

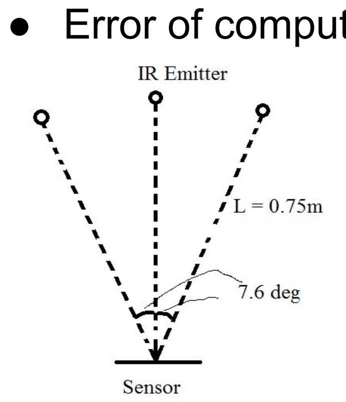

Figure 10: *IR Test Demonstration.*

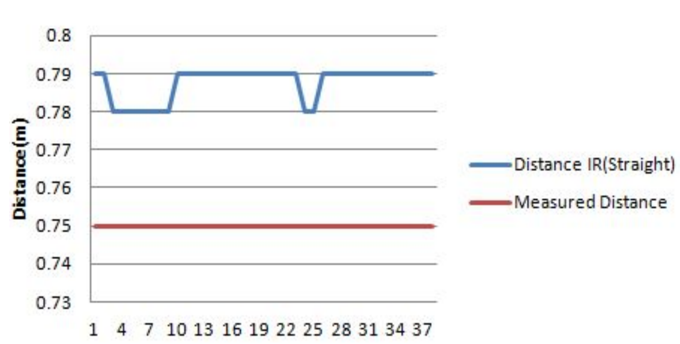

Figure 11: IR Distance Measurement Test.

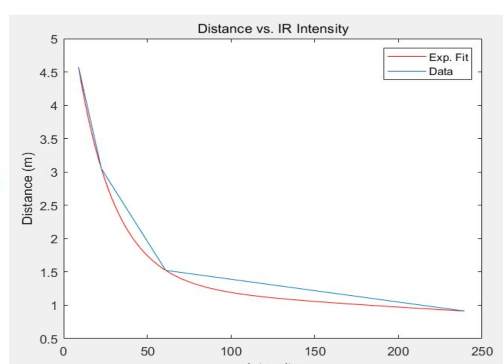

Figure 12: Intensity vs. Distance & Fit From Data.

Ultrasonic sensor analysis

- The SR-04 ultrasonic sensor we used will be suitable for < 3m distance measurement with up to 15 cm error, and large sampling delay time (2s) can be used to marginalize sensor's sensitivity to measurement disturbance.

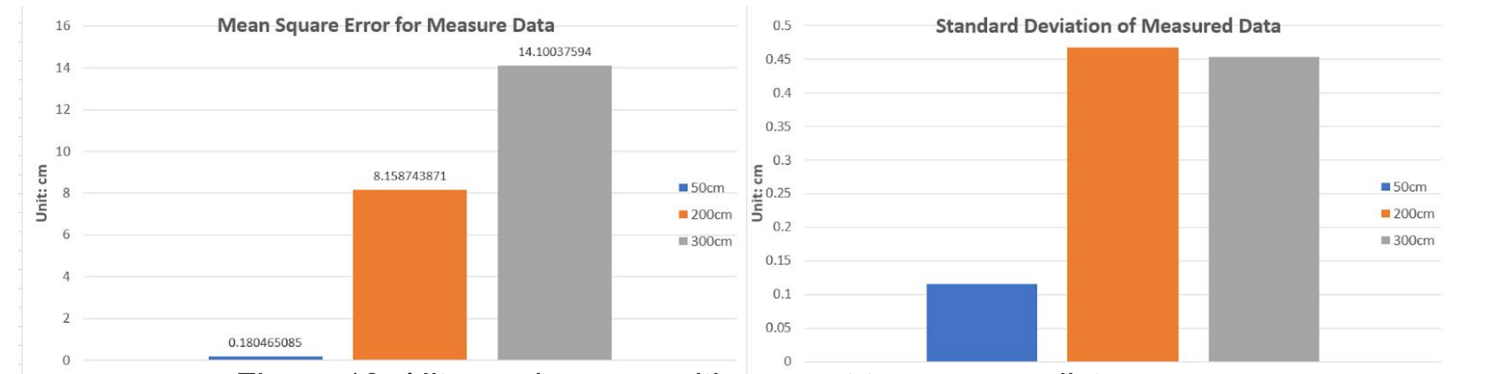

Figure 13: *Ultrasonic errors with respect to measure distance.*

Finite Element Analysis

- Acrylic board's yield stress: 76 MPa
- Maximum equivalent stress: 25.2 MPa
- Safety factor: 5.4167

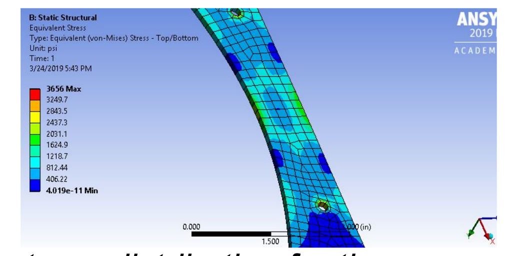

Figure 14: *Max von-Mises stress distribution for the upper plate.*

Final prototype testing

Motor analysis and load testing

- Requirement: drive a 25kg robot with 157mm diameter wheels to climb 10º incline with an acceleration of 0.1 m/s^2.
- Calculated required torque for each motor = 16.01kg*cm. Actual torque for selected motor = 45 kg*cm.
- Load Test: drive the robot carrying the maximum specified weight on a 10º hill to measure its performance.

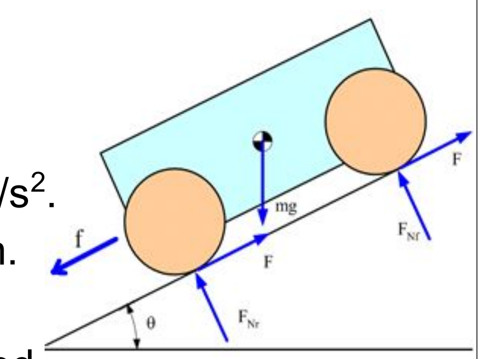

Figure 15: *Dynamic model of robot.*

Conclusion: the motors are able to drive the robot with 0.1 m/s^2 acceleration.

Odometry testing

- Drive robot between home to curb, iteratively measured the vertical and horizontal error after each round.

Conclusion: the odometry algorithm is very accurate, the positional error is less than 1.03m per 100m of travel.

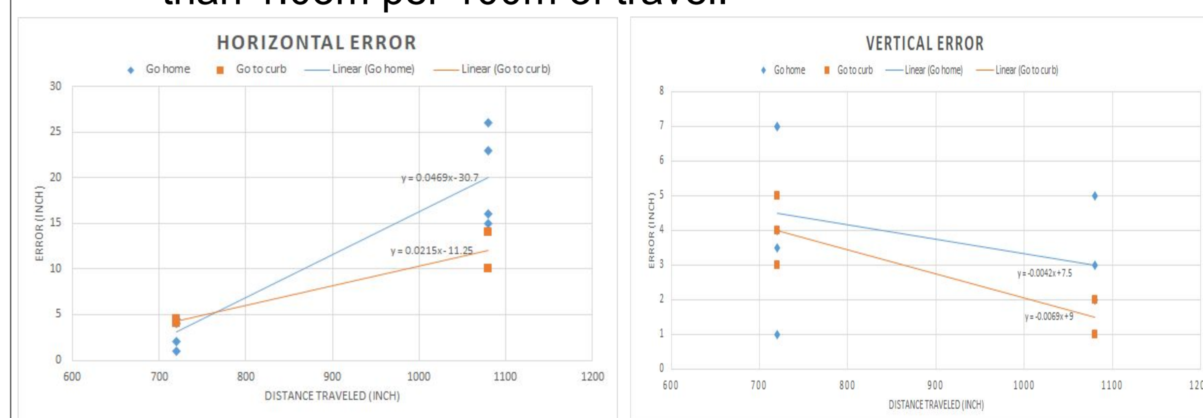

Figure 16: *Odometry Test Result (a) Horizontal Error (b) Vertical Error*

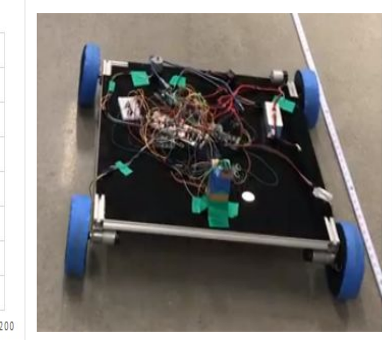

Figure 17: *Odometry Testing.*

Navigation testing

- Tested robustness of navigation system in outdoor, uneven terrain, and at night
- Result shows that the navigation system is robust under these conditions with accuracy error no more than 19.8% of indoor navigation error

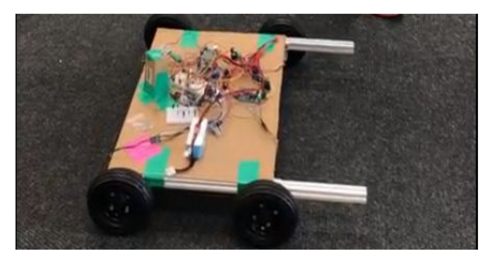

Figure 18: Night condition.

Figure 19: Outdoor and uneven terrain condition

Conclusions

Final prototype evaluation

- Final prototype successfully fulfill the most important need of automatic trash disposal, capable to deliver trash to the curb with high accuracy and robustness.

Market competence analysis

- Difference with real product: potential improvement could lies in the modularity of core sub-functions, which includes the arrangement of electronic wiring and mechanical parts. More intelligent obstacle avoidance algorithm to be developed.
- Market competence: our prototype has high positional accuracy whenever returning back home, and our automatic trash bin is more user friendly. Our trash bin has better maneuverability and off-road capability.