Formal Design Document

Brunette, Jacob   Fullerton, Dilyn   Watt, Ryan   Yao, Dickson

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Executive Summary

The following is a design for an autonomous passenger transportation vehicle.

The chassis will have two units which conveniently assemble and may be adjusted separately. The robot will feature four wheels, allowing for maximal maneuverability, including rotation as well as forward and reverse motion. It will also have a bin that will serve as luxurious seating for multiple passengers

The spacious underside of the bottom chassis component will house PCBs that control sensors and drive motors. PCBs corresponding to electrical components will be positioned to minimize the length of wires and to group wires for their respective purposes. A hollow region between the two chassis sections will house the wiring, allowing for a clean design and easy debugging.

The drive system was designed to meet our expectations and out-perform yours, as the system's components were selected based on calculations that were made under the assumption of adverse conditions. Actuators drive a high-precision multi-jointed arm for passenger pickup.

The operation of the vehicle is programmed to have well-defined modes of operation for particular activities. These states are designed to respond to any scenario with specific behaviors, including responses to possible failures.

This design seeks to advance passenger transport technology and mitigates the risks wherever possible for the best transportation solution.

Contents

List of Figures

List of Tables

Preface

Uber has consistently been on the cutting edge of the personal transportation industry, and K. West Robotics is excited to be a part of Uber's transformative business. This document details the design of an autonomous robot with the purpose of bringing a "Fast, Efficient and Intelligent" solution to Uber's self-driving vehicle needs.

A team of experts who have been trained through the Engineering Physics program at UBC have collaborated to design this innovative project known as the Uber Bot. Authors Jacob Brunette and Dickson Yao have experience designing vehicles through their work in UBC Solar, a design team building a solar powered electric vehicle. Brunette is responsible for the design of the chassis in the Uber Bot, while Yao has organized its electrical systems. The performance of all drive and actuator systems are specified by author Ryan Watt, who has vast experience in this area. Lastly, author and professional programmer Dilyn Fullerton has planned the strategy and software of the Uber Bot.

We thank our board of directors for their continued support in the efforts of this project and review of its design.

Chapter 1

Overview of Basic Strategy

1.1 Overarching Design Philosophies

The following philosophies will guide the overall development of the robot.

Modularity:
In physical design and behavioral functionality, separate components and functions should be separable and independently testable.

Design for redesign:
The design should aim to support both major changes and minor tweaks to structure and functionality.

Adaptability over performance:
In general, the ability of the robot to function in a wide range of scenarios should be preferred over raw performance.

Simplicity:
In general, a simple solution should be preferred over a more complicated solution.

Testability:
The performance of the robot should not heavily rest on any component (either physical or computational) that cannot be rigorously tested for correctness, or whose limitations are not well understood.

Intelligence:
The design should aim to obtain as much information as possible and make as much use of that information as much as is feasible, given hardware and software limitations.

1.2 Winning the Competition

Ultimately, the objective at hand is to win Uber's autonomous robot competition. Why is this robot going to win? Simple:

Agility:
The use of central wheels will allow this robot to turn around at dead ends or when faced with other obstacles. The combination of central wheels and a double-jointed arm will also serve to allow this robot to get passengers that are especially difficult to reach.

Intelligence:
The software model for this robot will be rigorously designed and tested so that the robot does not waste valuable time going in circles or moving back and forth between obstacles. It will realize when its current mode is not working and swiftly take appropriate action.

Prioritization and opportunism:

This robot's eye is on the prize. The moment it picks up a passenger, its first priority will be to get that passenger safely to its destination. Of course it would not pass up the chance to take on another rider, should the opportunity present itself.

Chapter 2

Chassis

2.1 Summary of Design

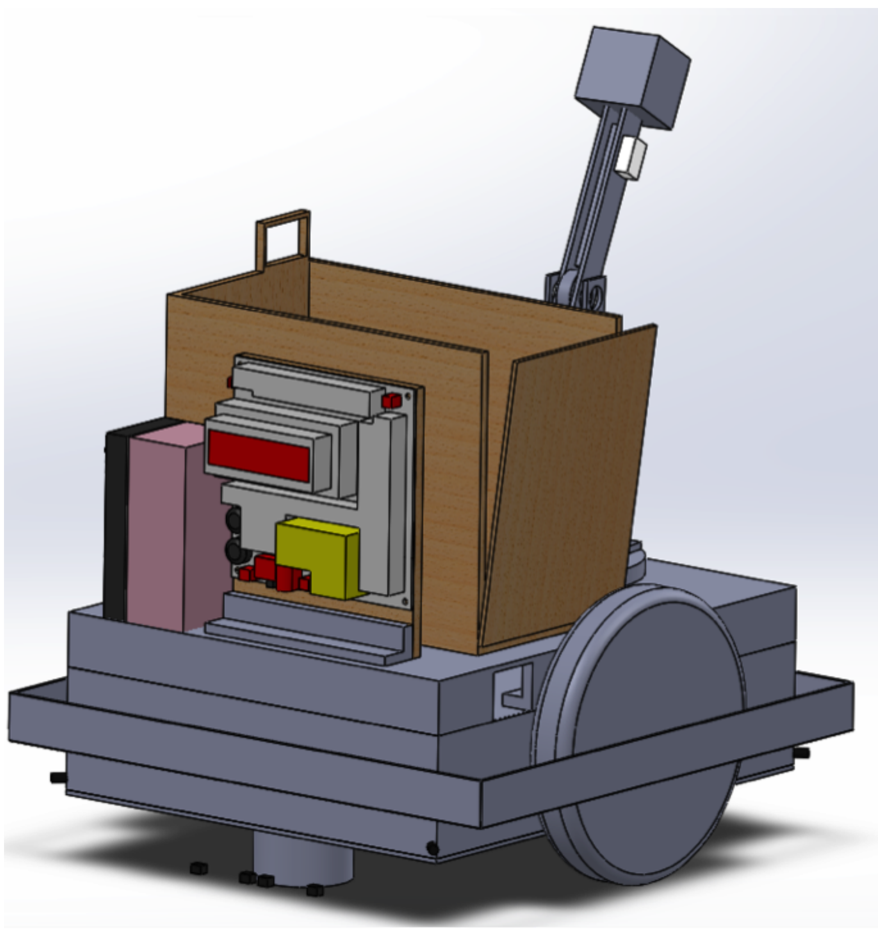


Figure 2.1: Fully-assembled robot

The chassis will be split into two halves (top and bottom) to allow for ease of assembly and modification. The structural strength of the chassis will come from the bottom half, which will house the wheels, motors, and all PCBs. The top half will be fabricated to leave a 1-inch cavity in between to allow for wiring between the bottom PCBs and the TINAH. The two halves will be screwed together such that they are separable for easy access to the motors and PCBs.

Elements will be modular when possible, allowing independent assembly. The ability to separate the two halves will allow components to be removed or adjusted at any time, regardless of their position on the robot. This will ensure some flexibility for redesign without requiring a complete refabrication of the chassis.

2.2 Top Half

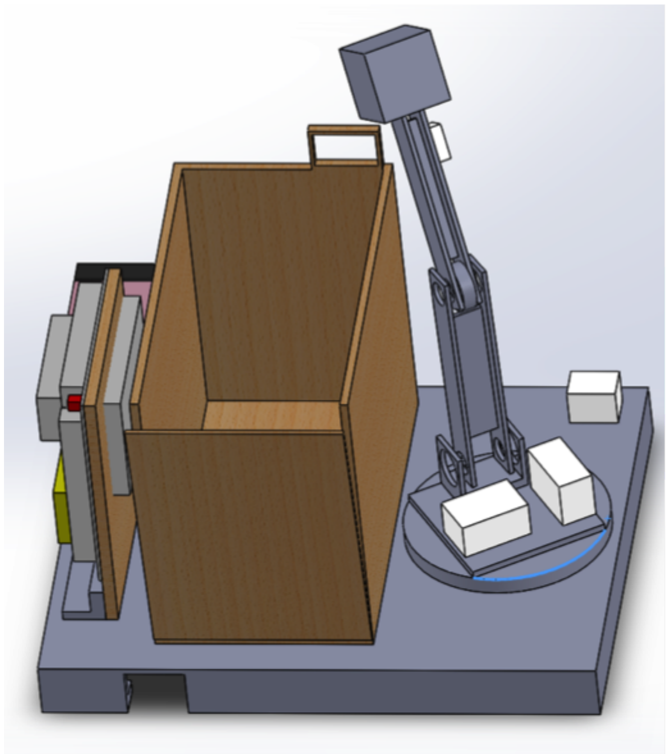


Figure 2.2: Robot top half

The top half (Figure 2.2) will house the arm, TINAH board, passenger bin, and all sensors besides tape-following QRDs. The arm will be mounted towards the rear on a square lazy Susan bearing, whose full range of motion is represented by a circle in the figure. The lazy Susan will be controlled by a stepper motor, allowing over 180 degrees of motion. The bin will be positioned in the middle of the robot between the base of the arm and the TINAH board. A hinge on the near side will allow it to be emptied, and a cut-out in the lower left will allow space for wires to be fed out of the hollow space below up to the TINAH.

The arm will be double jointed, allowing for specifying the positioning of the claw in both height and extension. The motor-controlled lower (base) joint will be mounted on the lazy Susan. The upper (elbow) joint will have a pulley that is affixed to the forearm. This pulley will be operated by a string connected to a motor on the lazy Susan. A claw (represented by a block in this model) will be fixed to the end of the arm and will be opened and closed by a small motor affixed to the arm. Two QSDs will be mounted above the elbow joint to provide sensory input for beacon detection.

2.3 Bottom Half

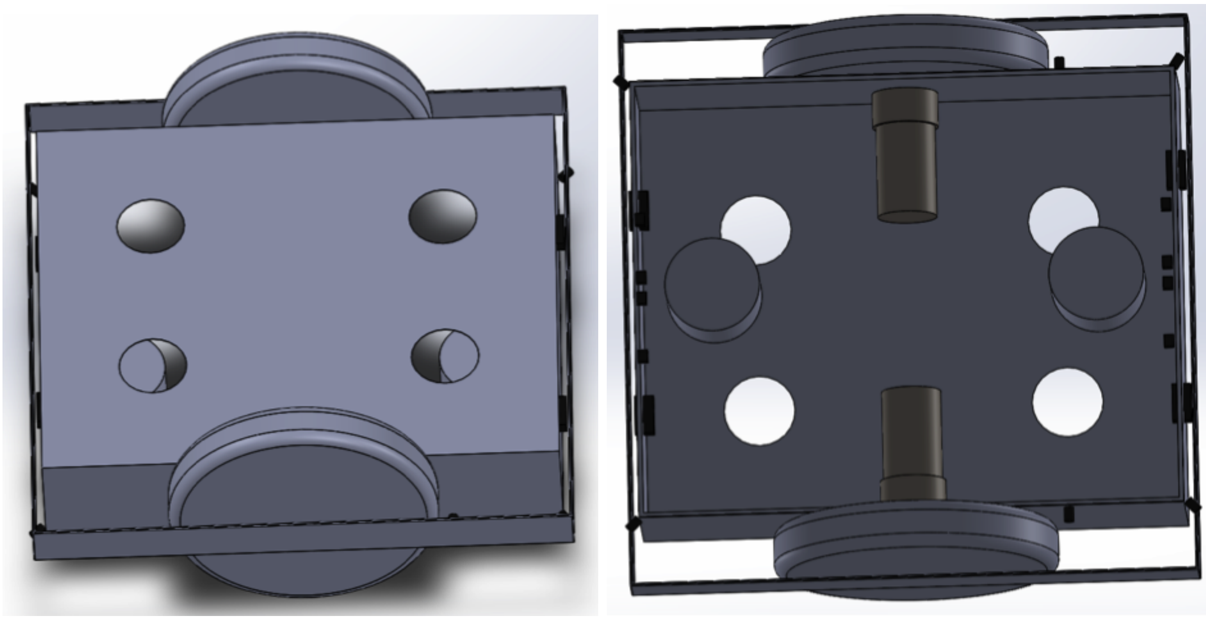


Figure 2.3: Robot bottom half

The bottom chassis (Figure 2.3) will fully enclose an interior, which will contain the PCBs and motors. The PCBs will be affixed to the top inside of the enclosure, to the left and right of the motors. Holes on the top section will allow wires to be fed between the TINAH and the PCBs.

The whole chassis will rest on four wheels: two powered wheels on the outsides of the chassis middle and two rotary wheels on the front and back of the center of the underside of the chassis. In the figure, the cylinders on the bottom represent the full range of motion of the rotary wheels.

2.4 Components

The components used are documented in Table 2.1.

Table 2.1: List of physical components

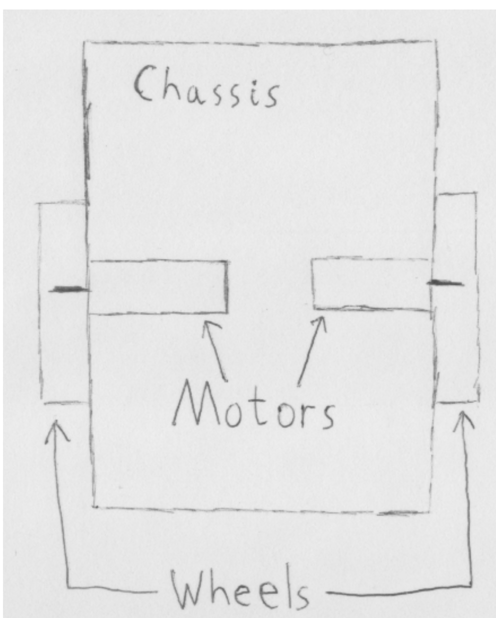
Part	**Material**	**Estimated mass**	**Method of fabrication**
Chassis bottom, base	Steel	345 g	Water-jet, bender
Chassis bottom, cover	Steel	175 g	Water-jet
Skirt	Aluminum (sheet)	17 g	Water-jet, bender
Springs (skirt support)		15 g	Prefab
Chassis top, base	Press-board / Plexiglas	272 g	Laser cutter
Lazy Susan bearing		90 g	Prefab
Arm base	Press-board	23 g	Laser cutter
Arm, bottom half	Plexiglas	20 g	Laser cutter
Arm, top half	Plexiglas	20 g	Laser cutter
Arm pulley		5 g	Prefab
Claw	Aluminum (ABS?)	27 g	Water-jet, 3D-printer (if ABS)
Container	Press-board	468 g	Laser cutter
Container hinge		15 g	Prefab
TINAH mount	Press-board	64 g	Laser cutter
TINAH support	Press-board	18 g	Laser cutter
Battery mount	Press-board	40 g	Laser cutter
Main wheels		225 g	Prefab
Rotary wheel system	Press-board, cardboard	50 g	Laser cutter
TINAH		200 g	Supplied
Battery		150 g	Supplied
	Total	**2240 g**	

Chapter 3

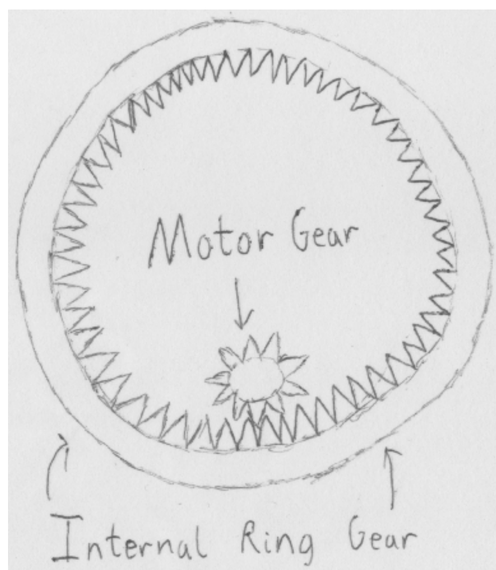
Drive System

3.1 Motor and Drive Mechanism

The primary drive system to facilitate navigation will be composed of two Geared Barber Coleman Motors mounted to the underside of the bottom chassis component. These will be mounted with gears to interface with the large $\sim$ 6 inch diameter wheels which will be mounted to the chassis and have internal ring gears mounted on their inside edge to get the desired gear ratio for proper interaction with the motors. See Figure 3.1.



(a) Underside of chassis, motor placement



(b) Internal ring gears meshing with motor gears

Figure 3.1: Wheel drive mechanism

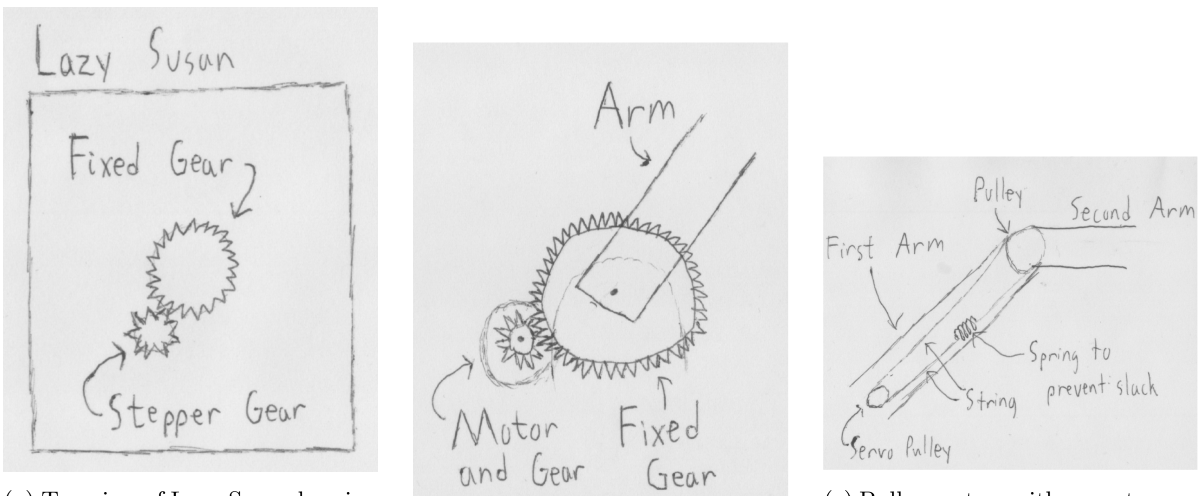
The turning method will use differential speeds of the wheels to create a rotation about the center of the robot. This will allow for slight adjustments while following tape as well as complete 360 degree rotation while not in translational motion.

3.2 Actuator

The arm will be controlled at four points:

- The arm will rest on a Lazy Susan bearing to support rotation parallel to the ground, which will be driven by a stepper motor for highly accurate arm positioning.
- The base joint of the arm will be driven by a Geared Barber Coleman Motor using feedback control and a large gear ratio to support the relatively large torques generated by the arm.
- The central joint of the arm will be driven by a base mounted Servo motor which will control a belt-like pulley system, using string for weight-minimization.
- The claw on the end of the arm will be driven by a Baby GM3 motor.

See Figure 3.2 for schematics.



(a) Top view of Lazy Susan bearing interfacing with stepper

(b) Base joint attached with motor

(c) Pulley system with servo to control central joint

Figure 3.2: Actuation of arm

3.3 Components

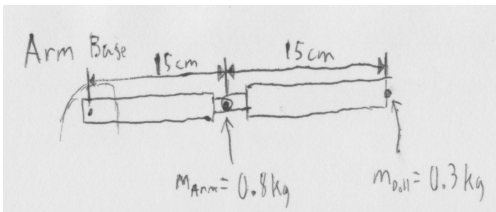
Drive and actuator components are documented in Table 3.1.

Table 3.1: Drive and actuator system components

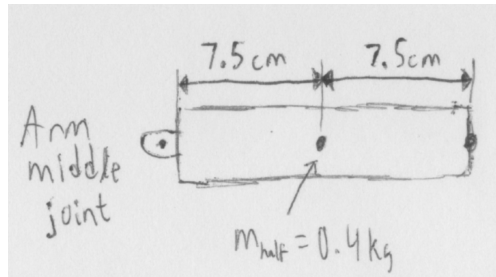
Component	**Stall torque (N·cm)**	**Max. speed (rpm)**	**Stall current (A)**	**No-load current**
Servo motor	42	59	N/A	N/A
Geared Barber	20	470	1.3	0.1
Coleman motor				
Baby GM3 motor	17	146	0.5	0.1
Vexta C005C-90215P Stepper Motor	13.1	60+	Set using driver	Set using driver

3.4 Performance

The following performance parameters were derived using poor case scenarios by modeling the arm as fully extended, using rounded up mass values from what the SolidWorks model suggests as well as the following approximation figures. See Figure 3.3 and Tables 3.2-3.6.



(a) Point mass distribution, full arm



(b) Point mass distribution, forearm

Figure 3.3: Point mass distribution of arm

Table 3.2: Approximate performance parameters

Parameter	**Value**	
Robot mass	3	kg
Arm total mass	0.8	kg
Passenger mass	0.3	kg
Robot moment of inertia about center	300	$N \cdot cm^2$
Arm max. moment of inertia about base	312.5	$N \cdot cm^2$
Forearm moment of inertia about elbow	62.5	$N \cdot cm^2$
Arm length	25	cm

Table 3.3: Drive system operating parameters

Parameter	**Value**	
Gear ratio (wheels : motor)	4	
Speed (targeted)	0.3	m/s
Acceleration	3.56	m/s^2
Avg. current draw (during use)	0.6	A
Appx. energy draw (per heat)	864	J

Table 3.4: Lazy Susan bearing operating parameters

Parameter	**Value**	
Gear ratio (bearing : motor)	4	
Angular speed (avg.)	0.5	rad/s
Angular acceleration	0.166	rad/s^2
Avg. current draw (during use)	0.3	A
Appx. energy draw (per heat)	144	J

Table 3.5: Arm base joint operating parameters

Parameter	**Value**	
Gear ratio (joint : motor)	12	
Angular speed (avg.)	1.0	rad/s
Angular acceleration (min.)	0.470	rad/s^2
Avg. current draw (during use)	1.1	A
Appx. energy draw (per heat)	528	J

Table 3.6: Arm elbow joint operating parameters

Parameter	**Value**	
Gear ratio (joint : servo)	2	
Angular speed (avg.)	0.7	rad/s
Angular acceleration (min.)	0.300	rad/s^2
Avg. current draw (during use)	0.5	A
Appx. energy draw (per heat)	240	J

Chapter 4

Electrical Design and Sensor System

Many sensors are used in the Uber Bot's electrical system to enable tape sensing, passenger detection and collision detection. Additionally, advanced motor control is made possible with external H-bridge circuits.

4.1 TINAH Resources

Due to the limitations in the I/O resources on the TINAH board, comparators will be used to complement QRD1114 phototransistors, providing a digital output rather than analog. Furthermore, potentiometers will be used to adjust when the comparators trigger, which will decrease its dependence on their height from the ground and enhances modularity. In addition, several of the TINAH's servo motor outputs will be repurposed to drive DC motors with PWM, instead of servos.

TINAH pin usage is documented in Table 4.1.

4.2 Electrical Design

The enclosed cavity of the lower chassis that houses the driving motors will also house the PCBs. These will be arranged such that they span the area of the chassis enclosure, allowing for ease of wiring by avoiding stacks of PCBs. The space will be divided between PCBs as follows: the stepper motor controller in the front right, sensor-supporting circuitry in the front and back, and the drive motor controller in the middle. Figure 4.1 shows the layout of the PCBs on the chassis. Sensor-supporting circuits for sensors will be further divided into two sides, separating circuits with digital outputs from those with analog outputs to aid in grouping wires.

PCB usage and connections are documented in Table 4.2.

4.3 Physical Wiring

The positions of the PCBs will make for ease of wiring, as the motor control PCB is in close proximity to the motors, and the front and rear PCBs are near their respective groups of sensors. Moreover, the cavity beneath the removable top of the chassis will provide an unobstructed route for the wires.

Physical wiring of cables for the TINAH and PCBs is documented in Table 4.3.

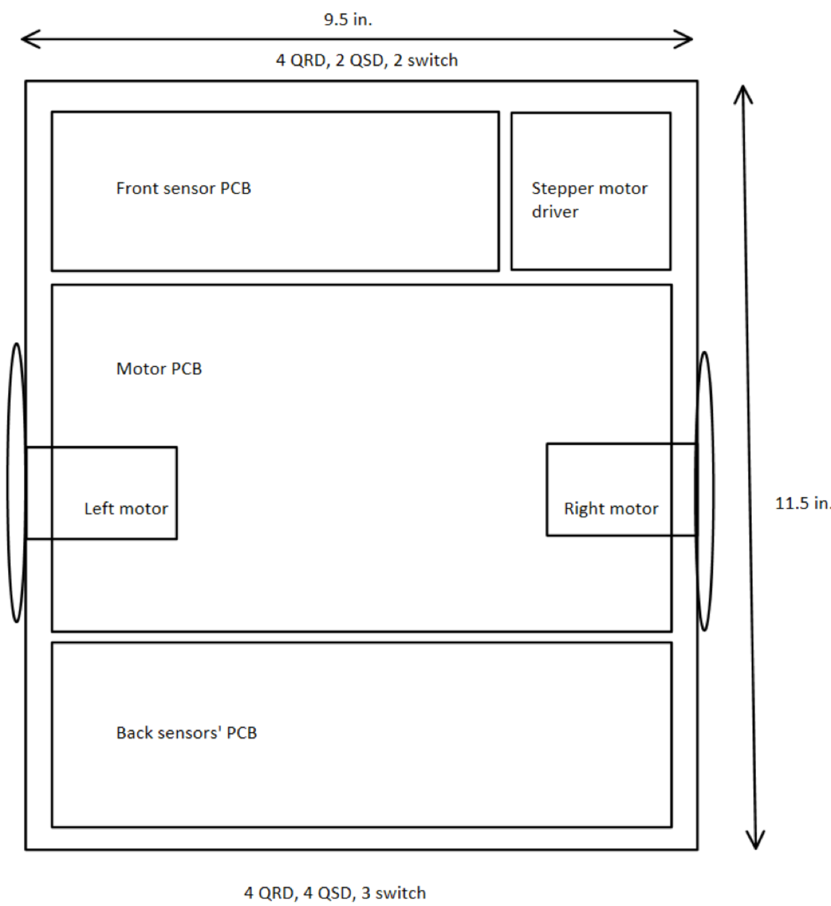


Figure 4.1: Layout of PCBs

Table 4.1: Usage of TINAH board pins

Digital pins			
Pin	Sensor	Location	Purpose
1	QRD1114	Front left	Tape following
2	QRD1114	Front right	Tape following
3	QRD1114	Front left	Intersection detection
4	QRD1114	Front right	Intersection detection
5	QRD1114	Back left	Tape following
6	QRD1114	Back right	Tape following
7	QRD1114	Back left	Intersection detection
8	QRD1114	Back right	Intersection detection
9	Switch	Front	Collision detection
10	Switch	Back	Collision detection
11	Switch	Left	Collision detection
12	Switch	Right	Collision detection
13	Switch	Claw	Claw grabbing
14	Stepper motor controller	Front	All windings off signal pin
15	Stepper motor controller	Front	Pulse signal pin
16	Stepper motor controller	Front	Rotation detection pin
Analog pins			
Pin	Sensor	Location	Purpose
0	QSD124	Right	Passenger detection
1	QSD124	Left	Passenger detection
2	QSD124	Corner	Passenger detection
3	QSD124	Corner	Passenger detection
4	QSD124	Corner	Passenger detection
5	QSD124	Corner	Passenger detection
6	QSD124	Arm elbow	Beacon detection
7	QSD124	Arm elbow	Beacon detection
Motor control output			
Pin	Motor	Location	Purpose
1	Baby motor	Arm base	Rotation of arm base
2	Geared Barber Coleman	Below chassis	Left wheel
3	Geared Barber Coleman	Below chassis	Right wheel
4	Geared Barber Coleman	Arm base	Claw
Servo motor control output			
Pin	Motor	Location	Purpose
1	Servo	Arm elbow	Rotation of arm elbow
2	Stepper motor	Arm base	Rotation of Lazy Susan
3			
4			

Table 4.2: PCB naming, usage, and connections

Purpose	Size	Wires	Connections with TINAH
Front sensors	$7.250'' \times 3.000''$	2×1 Power and ground 3×4 QRD1114 2×2 Switches 2×2 QSD124	Ribbon cable with 6 digital inputs 2 wrapped wires for analog inputs
Rear sensors	$9.500'' \times 4.500''$	2×1 Power and ground 3×4 QRD1114 2×3 Switches 2×4 QSD124	Ribbon cable with 7 digital inputs Ribbon cable with 4 analog inputs
Motor control	$9.500'' \times 4.000''$	2×1 Power and ground 2×4 Motors	8 wrapped wires to motor output
Stepper motor	$2.285'' \times 2.210''$	2×1 Power and ground 5×1 Stepper motor	Power supply 3 digital outputs 2 wires to PWM of servo output

Table 4.3: Physical wiring cables

Wiring harness	From	To
Power supply wires	TINAH battery nuts	Strung between front sensors PCB, to motor control PCB, then rear sensors PCB.
Front sensors' input	Chassis front	Front sensor PCB
Rear sensors' input	Chassis rear	Rear sensor PCB
Motors	Chassis middle	Motor control PCB
Servo for arm elbow	Chassis rear (servo inputs)	TINAH servo output
Stepper motor control	TINAH servo output	Stepper motor
Front sensor PCB outputs	Front sensor PCB	TINAH digital and analog I/O pins
Rear sensor PCB outputs	Rear sensor PCB	TINAH digital and analog I/O pins
Motor output	TINAH motor outputs	Motor control PCB: external H-bridges

Chapter 5

Software and Algorithms

5.1 Philosophy

The following philosophies will guide the development of the robot.

Modal operation:
The robot will always have a current state, which consists of a series of modes that define what control sequences are engaged.

Modularity:
Modes will be independent (for the most part) and independently testable.

Well defined failure modes:
Robot's failure behavior will be well-defined and exhaustive, with loops for all conceivable failures and even loops for unknown errors.

Avoidance of infinity:
Behaviors will be restricted with timeouts so that no procedure can go forever. Also, the robot's decision making will be influenced by some degree of randomness (possibly variable) so as to prevent infinite loops.

Knowledge of surroundings:
Sensors will be used to provide the robot with as much information as possible. To the degree that it is feasible, this information will be stored and used to guide the robot and make it as aware as possible to its environment.

5.2 Modes of operation and control

The state of the robot at any given time will be defined by a single *major mode* and one or more *minor modes* or *failure modes.*

Major modes will be independent of one another and independently testable. They will each have a well-defined goal and a well-defined method of assessing whether that goal is reached.

Minor modes can be in operation concurrently with one another and with a single major mode. They will define more specific behaviors and control sequences.

Failure modes will be triggered when something does not go according to plan, and they will define how to go about resolving the issue.

Figure 5.1 shows the a basic schematic of the envisioned relationship between major modes, including the minor modes that may be active concurrently and the failure modes that may be triggered. For more details, the reader should consult Appendix B on page 22.

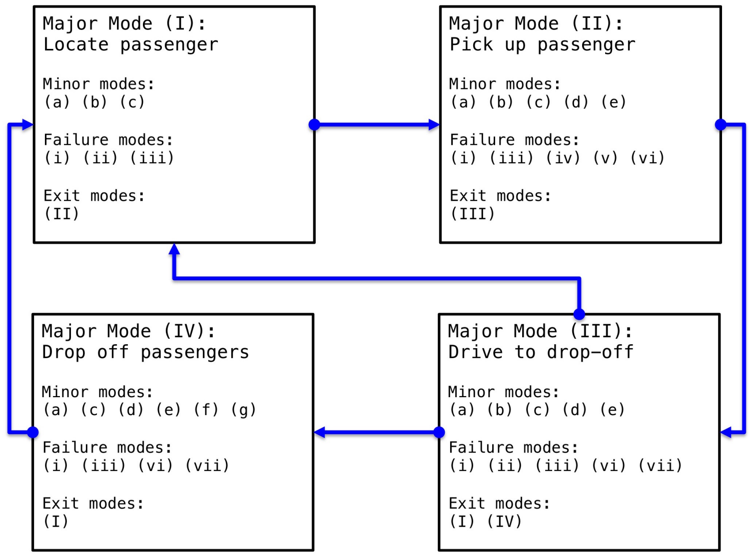


Figure 5.1: Relationships between major software modes. See Appendix B for more details.

5.3 Avoiding the Halting Problem

We know from the works of Alan Turing that the Halting Problem is, in general, undecidable. However with good practice and planning, infinite loops can be avoided. The following principles will be used to guide development and avoid infinity.

Timeouts:
Timeouts will restrict all states, so that the robot does not remain in any one state forever.

Randomness:
The robot's decision-making process will be made non-deterministic by including the influence of random numbers. This is key to avoid remaining in repetitive loops between states, which is much more difficult to monitor with timeouts. Furthermore, this can be used cleverly (e.g. increasing influence with time) to add an effective timeout to any meta-loop.

Simple, well-defined structure:
The general structure of the robot's modes will be sound, and the paths from one mode to the next will be clearly attainable.

Chapter 6

Risk Management and Contingency Planning

6.1 Risk Assessment

The primary risks anticipated to arise in our design are:

Central wheel placement
This could lead to instability in turning and difficulty in tape following due to the wide wheel separation and close proximity to the tape-following sensors, making the control system unnecessarily difficult.

Use of the passenger bin
Using the arm of the robot to lift and dump the passenger bin may be too difficult for our hardware to accomplish, so alternative options must be considered.

Use of the double jointed arm
The central joint on the arm may pose problems due to underperformance of available hardware or creation of too much of a challenge for control within the given time frame.

Detection of drop-off zone
Once a passenger has been acquired, if the hardware cannot detect where the drop-off zone is due to great distance or interference from external infrared sources, then the robot will not be able to finish the drop-off.

Finding passengers/navigation
If the robot's navigation algorithm does not lead the robot to check all possible locations or traverse the entire competition surface, then it may not be able to acquire any passengers.

6.2 Contingency Planning

The contingency plan is documented in Table 6.1.

Table 6.1: Contingency plans

Risk	**Prob.**	**Severity (1-5)**	**Change to plan**
Wheel placement	0.2	4	If by July 8 the robot chassis cannot be controlled to accurately and quickly follow tape to our standards, we will scrap the bottom half of the chassis, which will be built separately according to modular design principles, and redesign with wheels placed in the back for increased control in forward movement but reduced control in reverse.
Passenger bin	0.2	1	If by the competition day the bin cannot be accurately and consistently used, then it will not be used, and the robot will instead just hold a single doll in its claw and carry it directly to the drop-off point. This functionality will be written into code initially to account for the possibility.
Double-jointed arm	0.1	5	If by July 13 the arm as a standalone module cannot perform under test conditions, then a new backup single base-jointed arm will be used instead. Loss of variable length will be accounted for by software, and the passenger bin will not be used.
Drop-off detection	0.4	2	Failsafe software will be added to the base code regardless of issues seen so as to ensure that the robot will search for the drop-off beacon if it is not found initially, and the robot will search randomly for the drop-off zone if the beacon is not found within a reasonable amount of time.
Navigation	0.1	2	If robot bottom chassis cannot be programmed to effectively traverse the entire arena in a reasonable time frame by July 20, then algorithms involving randomness will be added to the navigation code so that the robot cannot get stuck in any infinite loops or completely neglect any regions of the completion area due to systematic error.

Chapter 7

Major Milestones, Team Responsibilities, and Task List

7.1 Team Responsibilities

Tasks will be spread out so that team members are always being productive. Dilyn will be our software lead, but otherwise work will be distributed relatively evenly, according to timeline need. (And Dilyn will not work exclusively on software).

7.2 Task List

Lower chassis:

- Fabricate lower chassis
- Mount wheels and motors
- Design and fabricate H-bridge circuits

Arm:

- Fabricate arm
- Attach motors to arm components
- Control arm using TINAH

Sensors:

- Mount sensors
  - Tape following
  - Collision sensing
  - Passenger sensing
- Build sensor circuits
- Control arm through sensor input

Upper chassis:

- Fabricate upper chassis
- Fabricate passenger bin
- Fabricate TINAH and batter mounts
- Mount beacon sensors

Lazy Susan:

- Establish motor control of Lazy Susan
- Mount arm to Lazy Susan

7.3 Major Milestones

2016-07-08: "Lower chassis" and "Arm" sections are completed.

2016-07-18: "Sensors" and "Upper chassis" sections are completed.

7.4 Minor Milestones

Rigorous testing will follow the completion of every independent objective. Particularly, the following minor milestones specify independently-testable achievements.

- Robot successfully tape-follows
- Speed and agility of robot meet course needs
- Arm successfully picks up passengers
- Robot responds to collision sensors
- Robot can pursue and find passengers
- Beacon sensor detects and tracks drop-off beacon

Appendix A

Document Contribution Summary

Contribution to this document is recorded in Table A.1.

Table A.1: Document contribution summary

Section	**Writers**	**Editors**
Letter of Transmittal	Brunette, Jacob	DY
Executive Summary	Yao, Dickson	JB, DF, RW
Preface	Yao, Dickson	JB
Overview of Basic Strategy	Fullerton, Dilyn	JB
Chassis	Brunette, Jacob	DY
Drive System	Watt, Ryan	JB, DY
Electrical Design and Sensor System	Yao, Dickson	JB
Software and Algorithms	Fullerton, Dilyn	DY
Risk Management and Contingency Planning	Watt, Ryan	DF
Major Milestones, Team Responsibilities, and Task List	Brunette, Jacob	DF, DY
Formatting/layout	Fullerton, Dilyn	
References/appendices	Fullerton, Dilyn	DY

Appendix B

Descriptions of Software Modes

Major modes

Major mode (I): Locate passenger

Goal: Find the first passenger.

Ordered tasks:

1. Follow course tape.
2. Detect passenger signal.
3. Stop across from passenger.

Minor modes:

- (a) Tape follow / watch
- (b) Passenger seek / watch
- (c) Collision watch

Failure modes:

- (i) Tape lost
- (ii) Dead end / no path
- (iii) Collision

Exit modes:

- (II) Pick up passenger: Passenger found

Major mode (II): Pick up passenger

Goal: Pick up the adjacent passenger.

Ordered tasks:

1. Track passenger location.
2. Adjust vehicle, if necessary.
3. Rotate arm to face passenger.
4. Extend and lower arm over passenger.
5. Grasp passenger.
6. Lift passenger.

7. Rotate passenger over bucket.
8. Drop passenger in bucket. (If room, else hold in claw)

Minor modes:

- (a) Tape follow / watch
- (b) Passenger seek / watch
- (c) Collision watch
- (d) Loose arm operate
- (e) Passenger holding / moving

Failure modes:

- (i) Tape lost
- (iii) Collision
- (iv) Passenger signal lost
- (v) Passenger not grabbed
- (vi) Passenger dropped

Exit modes:

- (III) Drive to dropoff: Passenger successfully loaded

Major mode (III): Drive to dropoff

Goal: Drive to dropoff location, acquiring addition passengers as possible.

Ordered tasks:

1. Find dropoff beacon, and begin tracking.
2. Move vehicle towards dropoff location.
3. Align vehicle with dropoff beacon signal.

Minor modes:

- (a) Tape follow / watch
- (b) Passenger seek / watch
- (c) Collision watch
- (d) Loose arm operate
- (e) Passenger holding / moving (if in claw)

Failure modes:

- (i) Tape lost
- (ii) Dead end / no path
- (iii) Collision
- (vi) Passenger dropped (if held in claw)
- (vii) Dropoff beacon lost

Exit modes:

- (II) Pick up passenger: Addition passenger found
- (IV) Drop off passengers: Dropoff zone reached

Major mode (IV): Drop off passengers

Goal: Remove passengers from claw/bucket onto dropoff zone.

Ordered tasks:

1. Align vehicle with dropoff zone.
2. Drop passenger from claw into zone (if holding one).
3. Engage claw with bucket.
4. Tip bucket to release passengers.
5. Return bucket to upright position.

Minor modes:

- (a) Tape follow / watch
- (c) Collision watch
- (d) Loose arm operate
- (e) Passenger holding / moving (if in claw)
- (f) Dropoff seek / watch
- (g) Bucket dump

Failure modes:

- (i) Tape lost
- (iii) Collision
- (vi) Passenger dropped (if held in claw)
- (vii) Dropoff beacon lost

Exit modes:

- (I) Location passenger: Dropoff successful

Minor modes

Minor mode (a): Tape follow / watch

Tape sensors will be watched on the side of the robot's heading. If static, all tape sensors will be watched to improve the chance of detecting the orientation of the robot with respect to the tape in the event of a collision.

Minor mode (b): Passenger seek / watch

IR sensors on the sides of the robot will be continuously monitored, watching for the signal of a passenger. If the robot is static, these will continue to be engaged to ensure the robot is still across from the passenger.

Minor mode (c): Collision watch

Switches on the sides of the robot will be watch so that the robot can appropriately react if a collision switch is triggered.

Minor mode (d): Loose arm operate

Arm is rotated, extended, etc. to a desired position (if static) or to keep the dropoff beacon sensor tracking with the beacon.

Minor mode (e): Passenger holding / moving

Claw switch is monitored to ensure passenger is being grasped. Arm is operated with the consideration of the added torque.

Minor mode (f): Dropoff seek / watch

In cooperation with Minor mode (d), IR sensor at the arm's elbow is rotated in seek of dropoff beacon. If the beacon is found, arm is rotated to attempt to continuously track it.

Minor mode (g): Bucket dump

Arm engages in pre-defined sequence to rotate the bucket (dumping passengers) and restore it to its upright position.

Failure modes

Failure mode (i): Tape lost

Trigger: Primary tape signal lost.

Procedure:

1. Engage all available tape sensors
2. Slow down robot speed
3. Oscillate robot attempting to find tape
4. Following timeout, reverse robot direction
5. Oscillate robot attempting to find tape
6. Engage dropoff beacon sensor
7. Move towards beacon until tape found

Failure mode (ii): Dead end / no path

Trigger: Front end tape signal lost, with no intersection detected.

Procedure:

1. Stop robot
2. Switch to opposite side sensors
3. Find tape
4. Store dead end location?

Failure mode (iii): Collision

Trigger: Collision sensor(s) activated

Procedure:

1. Stop robot
2. Evaluate last tape sense, orientation with respect to tape
3. Evaluate location of collision
4. Attempt to move robot in opposite direction of collision

Failure mode (iv): Passenger signal lost

Trigger: IR detector stops showing passenger

Procedure:

1. Move robot back and forth slightly, watching for signal
2. Turn robot about central axis, watching for signal
3. Give up if timeout

Failure mode (v): Passenger not grabbed

Trigger: Claw switch not activated, following grab attempt

Procedure:

1. Slowly lift and retract arm
2. Realign robot with passenger signal, if necessary
3. Reattempt to grab passenger (how many times?)
4. Give up if passenger cannot be grabbed

Failure mode (vi): Passenger dropped

Trigger: Claw switch deactivates while passenger is being held

Procedure:

1. Finish the motion, in hopes that the passenger is still in claw

Failure mode (vii): Dropoff beacon lost

Trigger: IR dropoff beacon stops detecting dropoff location

Procedure:

1. Continue towards last seen location
2. Rotate arm, in seek of beacon
3. If timeout reached, stop robot and rotate in seek of beacon
4. If timeout reached, continue tape following again