ENPH 253 Design Proposal

AutoMated PEt REscue System (A.M.P.E.R.E.S)

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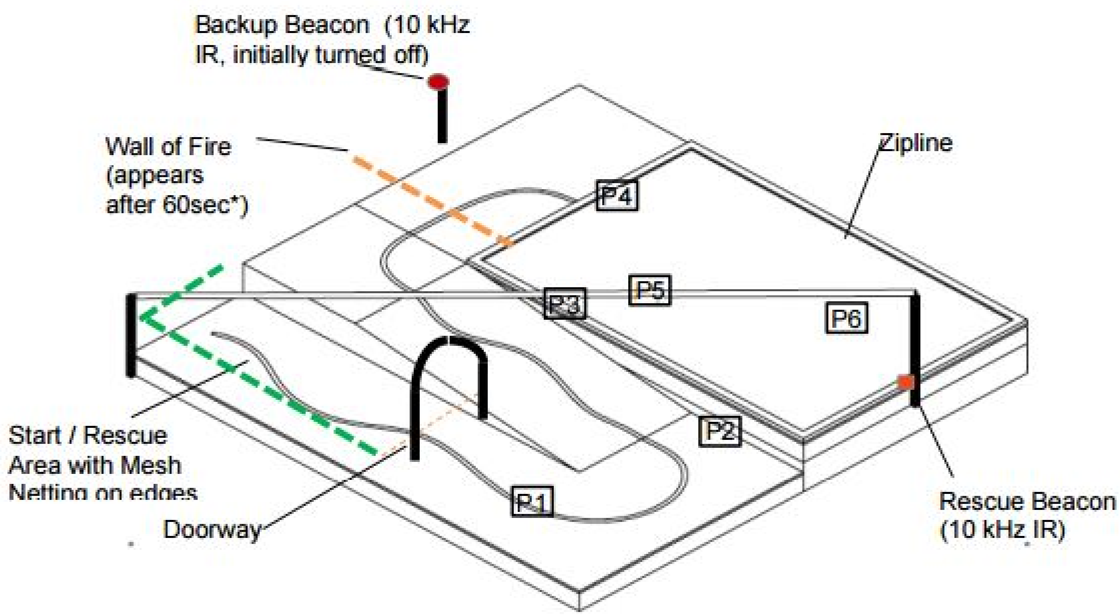
Executive Summary

This document contains the proposed specifications of a robot designed to complete the 2015 ENPH 253 Pet-Rescue Bots challenge. The robot should be able to navigate through an 8' by 8' course by following a tape path and infrared beacon, collect "Pets", which are Beanie toys of height 6", with magnets attached to them and return to the start area. Our robot will transport itself and the toys to a "start area" via the zip line of height 19", which spans the course.

The robot must be able to go through a doorway which is 14" wide and 18" tall. Most pets will be placed 8" to the right of the tape path, one will be placed on a platform 6" above the playing surface, and the last pet will be located in a container and covered with Styrofoam bricks. All will be unattached from the playing surface.

Our robot will be controlled by a TINAH Board using a ATMega128 processor. The proposed design for the robot has an upper bound of 5 kg and a lower bound of 3 kg mass. The design has a length of 15.75", a width of 11.5", and a height of 14.5" when fully retracted.



The Competition Course, Pets marked P1-6

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1 Preface

This report was written in collaboration by Kevin Zhang, Scott Fjordbotten, Johnson Liu, and Anne Lim, in the hope of identifying and addressing potential issues with the design. Work was begun on this document in the beginning of June 2015. We would like to thank the teaching assistants and professors of ENPH 253 for their support and advice throughout.

In the process of preparing this proposal, all major design decisions were agreed upon by unanimous consent. Listed below is a summary of the work done by each team member on this report.

FJORDBOTTEN	Typesetting, Mechanical Design
LIM	Letter of Transmittal, Editing
LIU	Electronics and Sensors
ZHANG	Software, Editing

2 Overview of Basic Strategy

The robot will contain a meshed in area at the front for carrying the payloads. Pets will be picked up by a plastic arm with a steel bracket on the end which will move along a circular path in the plane parallel to the front of the robot to magnetically attach and collect the pets. Below the steel bracket will be attached a hinged aluminium plate that will be sandwiched between the steel plate and any attached magnet, triggering a micro-switch when a magnet is attached. A rod fixed to the chassis will be located at the end of the arm's path such that the load will be sheared off the metallic plate in order to land in the meshed area.

The robot will start following the tape in the starting location and follow it using a single QRD sensor connected to an analog input on the TINAH board and a proportional-integral-derivative controller. Upon detecting tape markers perpendicular to the main tape path using a side QRD connected to a LM311 comparator and a digital input, the retrieval arm will then be lowered until the attachment signal is received from the micro-switch. At this point, the arm will retract until the load is sheared off using the fixed rod, which can be detected by the falling signal from the micro-switch. The pet located in the middle of the path will magnetically attach to a steel bracket at the front of the robot and will remain attached to this bracket for the duration of the heat. The pet located on the elevated rafters will be located using the IR beacon and the rotary encoders on the wheels to determine the distance travelled since the end of the tape.

After collecting the elevated pet, the robot will continue to follow the IR beacon until the intensity from the beacon reaches a certain threshold, to be determined empirically. Based on encoder data, the robot will pivot 90 degrees to position the retrieval arm along the edge of the box. The retrieval arm will be used to push the Styrofoam rubble aside and retrieve the last pet.

At this point, the robot should be positioned below and facing away from the zipline. An arm located on the left side of the robot, opposite the pet retrieval arm and containing a magnetically attached zipline trolley, will swing in the plane parallel to the side of the robot to attach the trolley to the zipline. A sensor will be used to determine when the trolley is on the zipline (sensor type to be determined). A winch in the centre of the robot and attached to the bottom side of the trolley will simultaneously detach the trolley from the zipline arm and lift the robot off the ground. Once off the ground, the robot will roll down the zipline to the Safe Area by virtue of gravity.

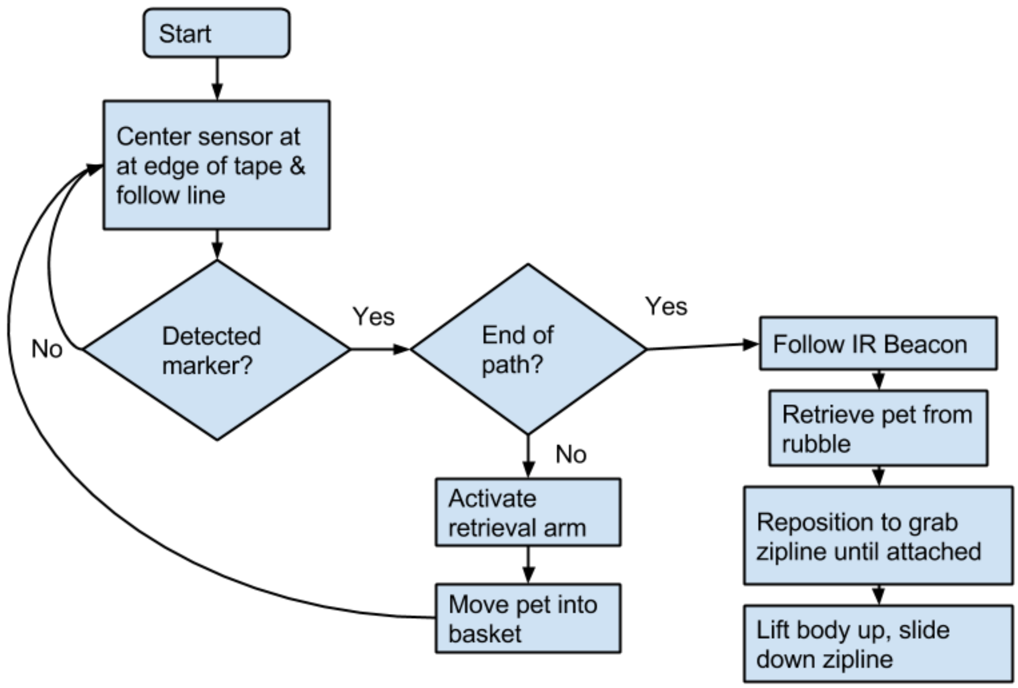


Figure 1: Strategy Flow Chart

3 Mechanical Design

Our robot will consist of three main mechanical sub-assemblies: The Chassis, The Retrieval Arm, and The Zipline Apparatus. These assemblies have been designed such that they are independent modules that can be built and tested at a basic level in parallel. This design section has been broken into sections to show each element individually before being combined into the complete version of the robot.

3.1 The Chassis

The Chassis is the base for the robot. The Chassis consists of the Chassis Plate and two supports for the rear drive motors and axles. The Chassis Plate includes two vertical sections at the rear that support the components of the Board Storage Space. These sections will be discussed in more detail in the 'Board Storage Space' subsection. Circular holes have been integrated in the front portion of the chassis plate to allow for wire routing to the tape following and tape detection QRD1114 reflectance sensors. The Chassis Plate and motor supports will be manufactured from 20 gauge aluminium to limit the overall weight of the robot. Additional brackets may be fabricated to reinforce the edge flange joints if necessary. The complete Chassis and Board Storage module is shown in Figure 7.

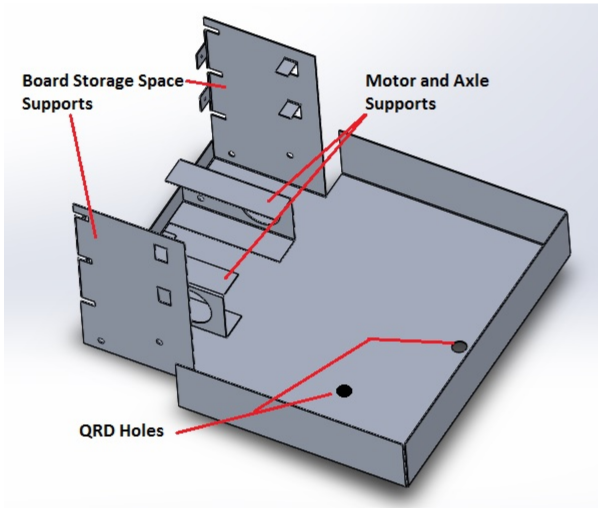


Figure 2: The Chassis Plate and Drive Supports

3.1.1 Pet 4 Pickup Arm

The fourth pet (in the middle of the path) will be picked up without the arm. To accomplish this, there will be a steel bracket mounted to the front of the chassis via an acrylic plate (See Figure 6). The steel bracket will be at the height of the pet's head and magnetically reinforced to ensure the pet does not fall off during the IR-following and zipline phases of the course.

3.1.2 The Sled

Rather than building structures to support wheels at the front of the robot, we will construct a sled and attach it to the front of the chassis via two axle mounted brackets (See Figure 5). The sled will be free to pivot about the mounting axles to improve the flexibility of the robot. The sled will also have a support (not shown) and hole for the tape-following QRD. Both the sled and its mounting brackets will be constructed from 20 gauge aluminium.

3.1.3 Board Storage Space

The Board Storage Space is integrated into the rear of the chassis. The vertical sections of the chassis contain slots and tabs to support the three shelves in the Board Storage Space (See Figure 4). The shelves will be 3.4” deep and 7.8” long and will have a flange at the front to prevent boards from sliding off the shelves. The two bottom shelves will house circuit boards; once the bottom two shelves have been loaded with boards, the back plate will be screwed on to secure the shelves. The top shelf will support the TINAH in conjunction with the back plate. Two mounting features for the TINAH are on the front of the top shelf while the remaining two are on the top of the back plate.

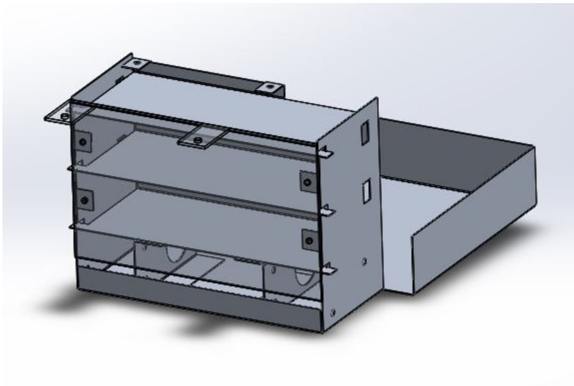


Figure 3: Board Storage Space

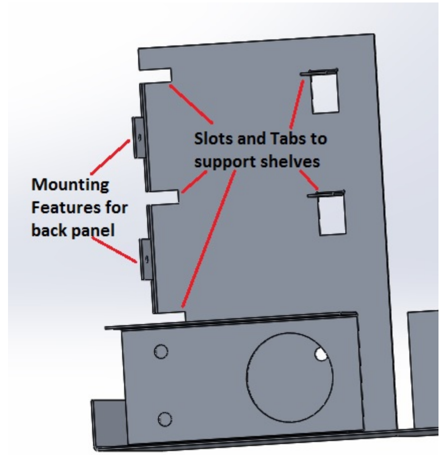


Figure 4: Board Storage Support Features

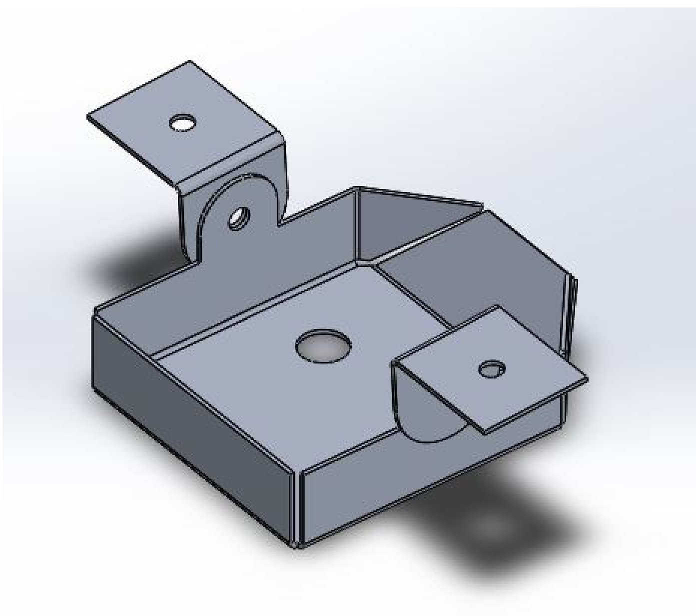


Figure 5: The font sled

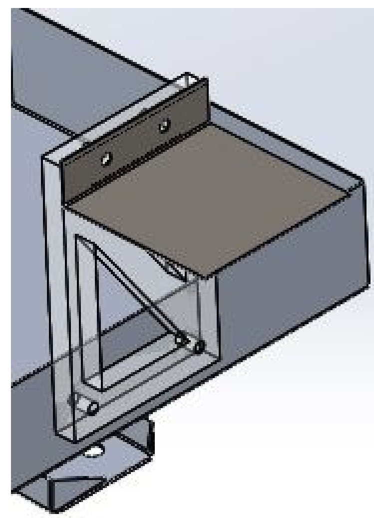


Figure 6: The front arm for statically collecting pet 4

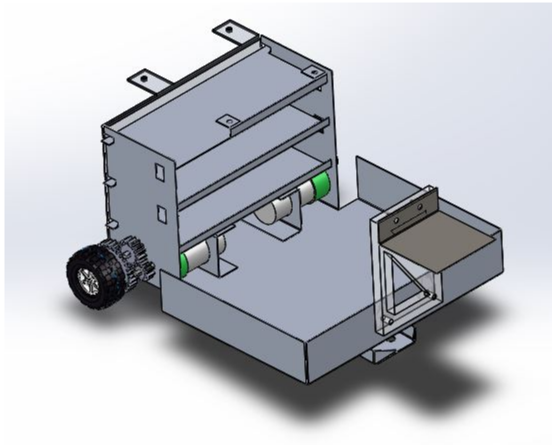


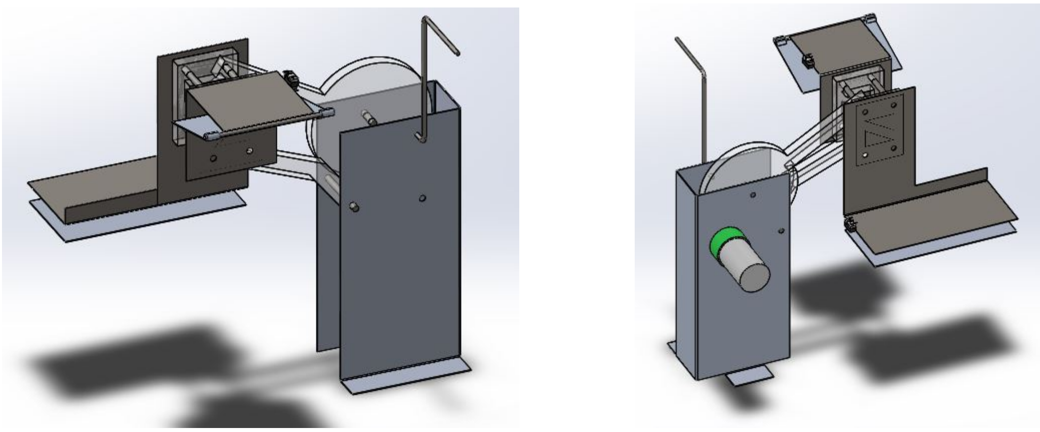
Figure 7: Complete Chassis and Board Storage Module

3.2 The Retrieval Arm

The retrieval arm consists of two main sections: the supporting body (Figure 8) and the arm end (Figure 9). The supporting body is constructed out of 20 gauge aluminium. It houses the arm sections, gears and the knock-off tool (Figure 11)and will attach to the chassis via POP rivet. The two-bar linkage will be cut out of acrylic(Figure 10), and one of the two will double as the driving gear. The gear ratio between the DC motor and the arm gear will be 5:1 as determined in Appendix A. The knock-off tool will be made of 3.2 mm diameter steel rod and positioned so that pets will be knocked off the arm above the chassis. The length and centre of rotation of the arm were chosen such that the arm is the same distance from the chassis centre (8”) when the pick-up surface is 6” and 12” above playing surface so that the same arm can be used to pick up all pets.

3.2.1 Retrieval Arm End

The arm end will consist of a housing made of acrylic and L-brackets made of steel to magnetically attach to pets. To these steel brackets, aluminium sheets will be attached which will trigger micro-switches when a pet is picked up (Figure 9). There will be two such L-bracket assemblies. The smaller assembly, facing the front of the robot, will be used to pick up the pets to the right of the tape path and the elevated pet. This assembly will align with the knock-off tool to deposit pets in the chassis and the aluminium sheet will pivot on a hinge. The larger assembly, facing the rear of the robot, is at the bottom of the body and will be used to collect pet 6 from the box of foam. This assembly will be reinforced with magnets and the 6th pet will remain on the bracket for the remainder of the course. The aluminium sheet will hang below the L-bracket.



(a) Front View (b) Rear View

Figure 8: Retrieval Arm Module

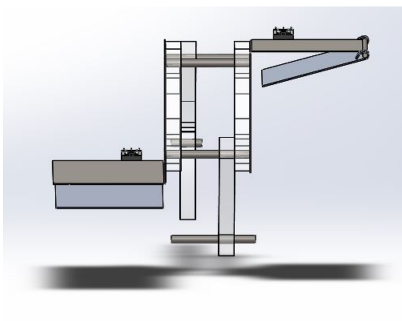


Figure 9: Retrieval Arm End

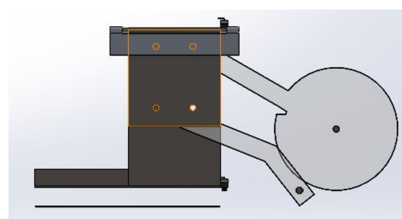


Figure 10: Retrieval Arm Arms

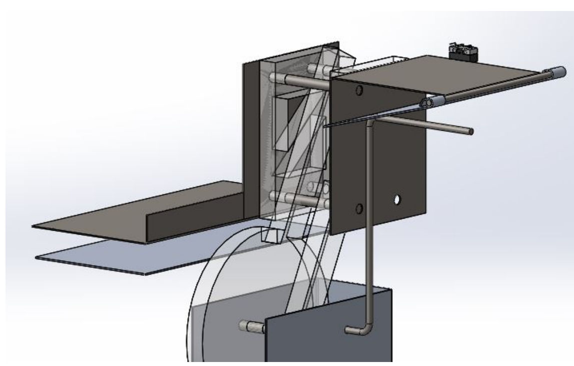


Figure 11: Knock Off Tool

3.3 The Zipline Apparatus

The zipline apparatus is contained in a housing similar to the pet retrieval arm housing. This body contains the motors for the zipline delivery and winch systems, the gears for these systems, the zipline delivery arm and the zipline trolley (Figure 12). The body will be made from 20 gauge aluminium and the gears will be made of acrylic.

3.3.1 Zipline Delivery System

The zipline delivery system consists of a guide that swings the zipline trolley into place. The guide has flanges around all sides to prevent the trolley from falling out before the trolley is deployed. The trolley frame and guide will be made of aluminium and will have small magnets attached to prevent premature separation.

3.3.2 The Zipline Trolley

The zipline trolley consists of a frame, winch attachment axle and roller (Figure 13). The frame was designed with flanges all the way around to improve rigidity. A finite element analysis was carried out in Solidworks. The results showed stresses well below the plastic limit, and deflections of a fraction of a millimetre (See Figure 14). Although the accuracy of the analysis is questionable, the results would have to be off by two orders of magnitude for deflections to be of concern. The winch belt will be attached to the trolley via a pin at the bottom of the frame. The top of the trolley supports the roller which will sit on the zipline, allowing the robot to gravitationally to slide to safety once lifted by the winch. The roller will be lathed out of Ultra High Molecular Weight Polyethylene. The pin bracket and trolley frame will be manufactured from 20 gauge aluminium.

3.3.3 The Winch System

The robot will be lifted off the ground by the winch system, which attaches to the zipline trolley. The winch will be driven by a worm gear system with a 1:40 gear ratio to ensure ample torque and prevent back-driving (Figure 15). The winch will be connected to the trolley by a 1.5" wide material that is yet to be determined.

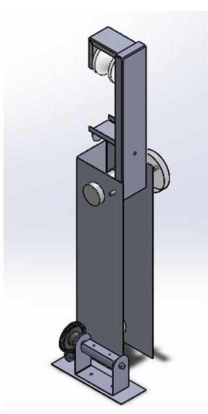


Figure 12: Zipline Module

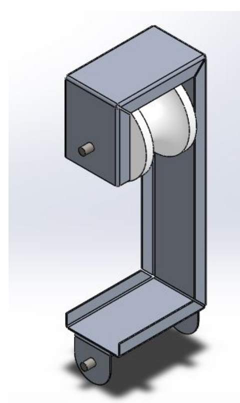


Figure 13: Zipline Trolley

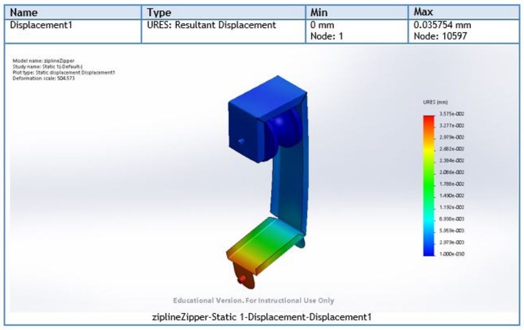


Figure 14: Zipline Trolley FEA

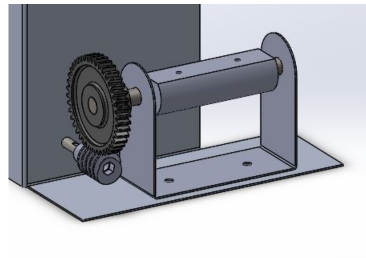


Figure 15: Winch System

3.4 The Robot Assembly

When the sub-assemblies have been constructed and tested, they will be combined to form our robot (Figure 16). The sub-assemblies will be pop riveted to the Chassis Plate.

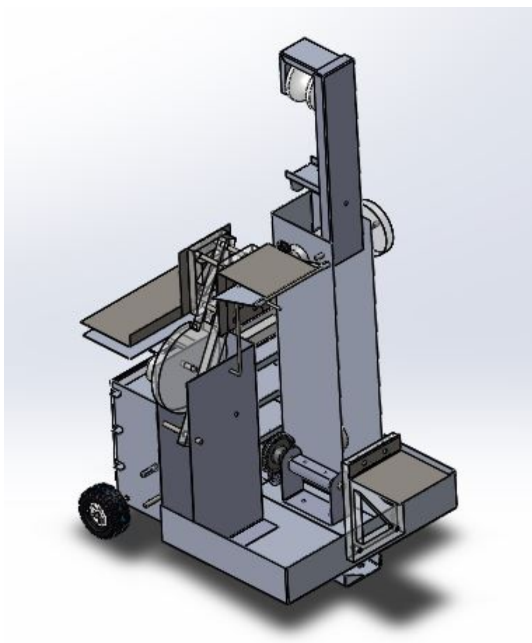


Figure 16: Robot Assembly

4 Drive and Actuator Systems

The drive and actuator systems will consist of five Barber-Coleman geared DC motors. Four of the five will be controlled by H-Bridge circuitry while the winch motor will run unidirectionally on a single MOSFET.

4.1 Drive System

The drive system will consist of two DC motors connected to the drive wheel axles through encoders. Both drive motors will be controlled by H-bridge circuits. The gear ratio between the wheels and the motors will be 3:1 as calculated in Appendix A. All gears will be located in the gap between the vertical section of the Chassis Plate and the inside edge of the wheels. See Figure 7 for the location of the drive system.

4.2 Retrieval Arm Actuation

The retrieval arm will be actuated by a single, H-bridge controlled DC motor. The gear ratio between the arm and the motor will be 5:1 as calculated in Appendix A. The gears for the retrieval arm will be contained within the retrieval arm body.

4.3 Zipline Apparatus Actuation

The zipline apparatus will consist of one actuator for the delivery system and another for the winch. See Figure 12 for the location of these motors.

4.3.1 Zipline Delivery System Actuation

The zipline delivery system will be actuated by a single DC motor controlled by an H-bridge. The motor will be mounted at the top of the body of the zipline system. The gear ratio between the delivery arm and the motor will be 1:1 as calculated in Appendix A.

4.3.2 Zipline Winch Actuation

The winch will be actuated by a unidirectional DC motor. This motor will be located in the bottom of the zipline body and will be controlled by a single MOSFET. The motor will be connected to the winch by a worm gear with a 40:1 ratio to ensure sufficient torque and to prevent back-driving (as determined in Appendix A).

5 Sensor System

5.1 Tape Following

There will be one analog QRD1114 phototransistor at the front of the robot for reading reflectance values to detect the tape on the playing surface. It will work in conjunction with the wheel encoders to ensure efficient tape following. Another QRD will be placed on the side of the robot for detecting the pet marker tape.

5.2 IR Detection

Two front-facing QSD124 IR photodiodes for detecting the 10kHz rescue beacon will be used to triangulate the distance and angle of the beacon. An additional photodiode will be left-facing in order to align the robot with the beacon at the end of the run.

5.3 Wheel Encoders

The wheel encoders will be mounted on the drive train, and will be used to calculate position and also attempt to recover from the loss of tape.

5.4 Microswitches

Two microswitches attached to the actuator arm's will be triggered when a pet is attached to the arm. This will be used to determine whether the pet has been picked up and when it is removed by the shearing pole. An additional microswitch may be used for zipline detection, the type of sensor used for zipline detection has not be finalized.

6 Electrical Design

Wires will be routed along the centre of the robot, up along the front of the board storage space and to the shelf where the circuitry will reside. Wire routes are shown in red in Figure 17. Microswitch wires from the retrieval arm will run along the arms, through the retrieval arm body and to the connection points on the TINAH. Motor wires for the zipline sub-assembly will be kept within the zipline body whenever possible so that the aluminium body doubles as an EMR shield. Motor control circuits will be on the lower shelf of the board storage space while IR detection circuits will be on the top shelf. Shielded wires will be used for sensitive signal wires to further protect against noise from power wires and circuits.

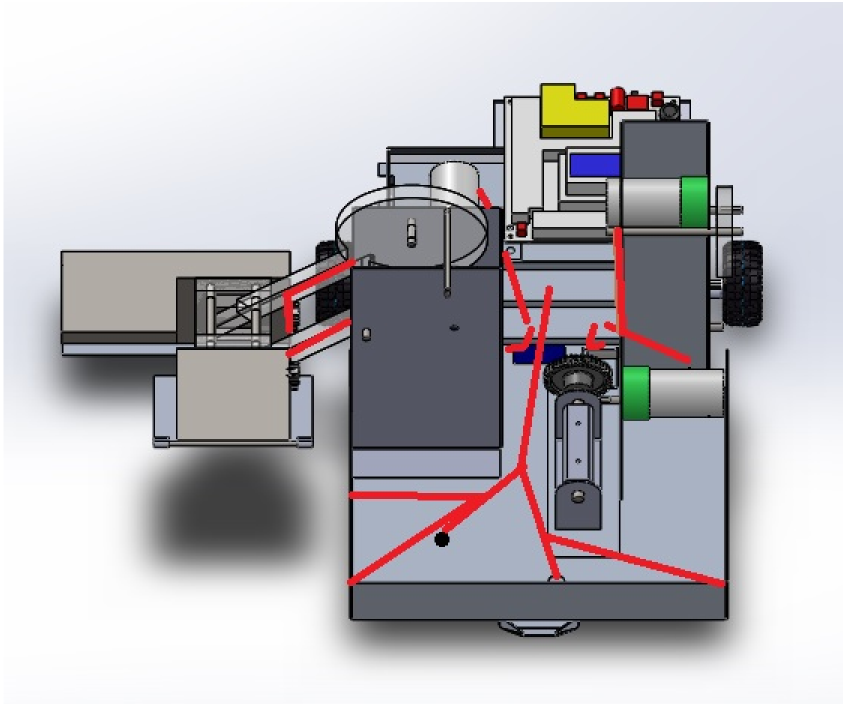


Figure 17: Wire routes shown in red

6.1 Drive

There will be two motors for driving, each powering one wheel using differential steering. Each motor will be connected to a motor output on TINAH via an external H-bridge with a comparator attached. Similarly, another H-bridge is used for actuating the arm for picking up pets, shown in Schematic A.

6.2 Phototransistors

The QRD1114 phototransistor for tape following will be connected directly to an analog input pin on TINAH. Another QRD1114 will be placed on the side of the robot and connected to a digital input on TINAH with an adjustable comparator for detecting the pet marker tape. This is shown in Schematic B.

6.3 Photodiodes

Schematic C shows the circuit for the three identical IR detectors used for detecting the IR beacons during the competition.

6.4 Winch

One N-type MOSFET drives the motor for the winch. Since it does not need to be reversible, a full H-bridge is not needed.

6.5 Pickup Microswitches

The microswitches connected to the lower and upper plates of the retrieval arm are connected as shown in Schematic D

Table 1: Table of TINAH Pin Connections

Digital Pin	Input/Output
0	Pet Marker QRD
1	Pickup Microswitch Lower
2	Pickup Microswitch Upper
3	Winch Enable
4	Wheel Encoder Left
5	Wheel Encoder Right
6	Zipline Detection

Analog Pin	Input/Output
0	IR Sensor Left
1	IR Sensor Right
2	Tape Follower QRD
3	IR Sensor Side

Motor Pin	Output
0	Drive Motor Left
1	Drive Motor Right
2	Retrieval Arm Motor
3	Zipline Arm Motor

Table 2: Table of PCB Information

PCB Number	Purpose	Size (mm)	Components Connected	Rails Needed
1	H-bridges: Drive Motors Left and Right, Retrieval Arm Motor, Zipline Arm Motor	180 x 70	TINAH, 4 DC motors	GND, 5V, 15V
2	IR detection circuitry	90 x 70	TINAH, 2 photodiodes	GND, 5V, $\pm$ 9V

7 Software and Code Algorithms

The software will operate statefully, with one main control loop that handles the primary strategy and execution. At the same time, a 10kHz timer interrupt will run in parallel which will handle the time-sensitive operation of polling input pins. The main control loop will call upon a variety of different modes that describe the current operation at any given point in the program's execution. A summary of the different modes and their transitions is described in Figure 18 below.

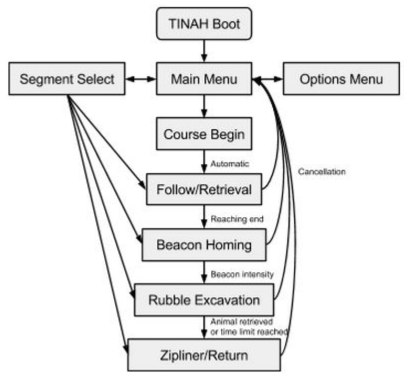


Figure 18: Software Modes

A more detailed description of the modes is shown in Appendix C.

7.1 I/O

On the 10kHz timer interrupt will be attached a procedure that handles pin inputs. Because the standard `analogRead` function blocks until the ADC conversion finishes (approximately a 1000-cycle process), carrying out the conversion in parallel can significantly decrease loop latency. Additionally, polling digital pin inputs on the timer interrupt can provide a better guarantee that changes in digital inputs will not be missed because of latency in the main loop.

Inputs to digital pins 0 to 3 were chosen because of their ability to trigger external interrupts. As a result, we will not poll these pins on the timer interrupt.

7.2 Positional Correction

The encoders, tape-seeking QRD, and side QRD make up the position correction mechanism. Using all of the below methods, we can accurately navigate the course.

7.2.1 Tape Following

Tape following is the procedure of using a positional feedback model to adjust velocity based on a physical track. The analog tape-seeking QRD is read into the following formula which calculates an output value $\delta\theta$ based on the QRD reading Q:

$$-\delta\theta = G_P(Q - Q_T) + G_I \int_0^t (Q - Q_T)\delta t + G_D \frac{\delta(Q - Q_T)}{\delta t}$$

where the gains G_P, G_I, G_D are to be empirically determined, and Q_T is the desired value of Q (in this case, the half-way point between the black and white readings). The robot will then attempt to follow the boundary between the tape and the non-taped area.

7.2.2 Dead Reckoning

Dead reckoning is the process of calculating position based on an initial condition and velocity data over the course of travel. From encoder data, we can derive estimates for the change in position and angle with numerical integration. The number of encoder ticks corresponds proportionally to the instantaneous left and right wheel velocities v_l and v_d. With a distance of l between the two wheels, the instantaneous change in bearing $d\theta$ is

$$\frac{d\theta}{dt} = \omega = \frac{v_r - v_l}{l}$$

and the magnitude of the velocity of point located in centre c of the wheels is simply

$$|v_c| = \frac{v_r + v_l}{l}$$

giving us formulae

$$\frac{dx}{dt} = |v_c| \cos\theta$$

$$\frac{dy}{dt} = |v_c| \sin\theta$$

which we can approximate and discretize into

$$\delta x = \delta t \, |v_c| \cos\theta$$

$$\delta y = \delta t \, |v_c| \sin\theta$$

with v_r and v_l determined by

$$v_{wheel} = sgn(\omega_{wheel}) \frac{\delta E_{wheel}}{\delta t} r_{wheel}$$

where E is the integer number of encoder ticks on a wheel.

7.3 Error Handling

7.3.1 Unable to Retrieve Pet in Loft

We will make several attempts at this, adjusting the position of the robot each time. If after a certain number attempts we have not retrieved the pet, we will move on to the next stage.

7.3.2 Lost Tape

We will adjust proportional, differential, and integral constants to minimize this risk. Additionally, using wheel encoders allows us to have an additional input, which we can use to correct position if the tape is lost.

8 Risk Assessment and Contingency Planning

Table 3: Risk Assessment

Risk Condition	Level of Risk	Impact to Project	Change to Work Plan	Expected Date of Risk Decision
Unable to attach to zipline	High	Robot can't go back to safety zone	Find other ways to attach to zipline	End of June
Pets fall off robot arm as it is being picked up	Medium	Experiment with different magnets strength or find alternative ways to pick up pet	Find other ways to attach to zipline	End of June
Pets stack on-top of each other and fall off basket	Very Low	Unable to save pets	Change shape of basket	Mid July
Unable to detect IR Beacon	Low	Robot may not reach zipline very reliably	Move in a straight line after the tape is finished, until it hits the box. It should be closer to the IR Beacon. OR the robot can drive back to safety zone	Beginning of July
Unable to properly follow tape	Low	Unable to complete the challenge	Test following tape in a variety of lighting conditions	End of June
Robot tilts too much as it slides down zipline	Medium	Unable to save several pets	Adjust shape/size of basket carrying the pets, or change position of zipline arm	End of July
Unable locate pet on loft	Low	Unable to pick up pet	Experiment with using several attempts to adjust location and lowering robot arm	Mid July
Run over pet on middle of path	Low	Unable to collect that pet, cause problems in tape-following and picking up other pets	Adjust height and material metal piece used to pick up that pet	Beginning of July

9 Task Schedule, Responsibilities and Major Milestones

9.1 Tasks

The main tasks will be construction of the chassis, retrieval arm and zipline apparatus sub-assemblies; construction of motor control and sensor circuitry; and software construction for each stage as described in Appendix C.

9.2 Milestones

9.2.1 Tape Following

The first milestone will be reliably tape following. Meeting this milestone will require completion of the chassis sub-assembly, two motor control circuits, wheel encoder and tape following QRD circuit completion, and the tape follow subsection of the 'Follow/Retrieve' software mode.

9.2.2 IR Homing

The second milestone will be reliably following the IR beacon. This milestone will require the completion of the first milestone as well as completion of the IR circuits and the Beacon Homing software mode.

9.2.3 Functional Retrieval Arm

The third milestone will be a standalone arm that is capable of picking up and dropping off pets. This milestone will require the completion of the retrieval arm sub-assembly, the motor control circuit, microswitch circuits, and the retrieve subsection of the 'Follow/Retrieve' software mode.

9.2.4 Pet Retrieval

The fourth milestone will be our robot running through the course and retrieving pets 1-5. This milestone will require the completion of milestones 1-3, the pet marker tape QRD circuitry, and both the 'Follow/Retrieve' and 'Beacon Homing' software modes.

9.2.5 Rubble Excavation

The fifth milestone will be successfully retrieving pet 6. This will require completion of milestones 1-4 and the 'Rubble Excavation' software mode.

9.2.6 Functional Zipline

This milestone will be a standalone zipline assembly that can attach to the zipline. This can be accomplished in parallel with milestones 3 and 4. This milestone will require the completion of the zipline apparatus sub-assembly, motor control circuits for the winch and delivery system, and the swing and winch sections of the 'Zipline/Return' software mode.

9.2.7 Zipline Use

This milestone will be our robot attaching to and using the zipline. This will require the completion of the chassis assembly and drive systems, the 'Functional Zipline' milestone, the side IR sensing circuit, and the 'Zipline/Return' software mode.

9.2.8 Complete Course

This milestone will be our robot successfully completing the entire course. This will require the completion of all other milestones and the integration of all sub-assemblies and software modes.

Table 4: Task Schedule

Week	**FJORDBOTTEN**	**LIM**	**LIU**	**ZHANG**
7	Chassis	Chassis Drive	Drive	Position Correction Retrieval Arm
8	Retrieval Arm	Sensors Arm Circuit	Sensors Arm Circuit	Retrieval Arm Retrieval Code
9	Zipline	Zipline Code Testing Retrieval	Other Circuits	Zipline Rubble Excavation
10	Testing Rebuilding?	Testing Rebuilding?	Testing Rebuilding?	Testing Rebuilding? Dead Reckoning?
11 12 13	Shared Goals: Retrieves pets on ground Retrieves pet on rafters Retrieves pet in rubble Can zipline back intact Integrate dead reckoning into tape following			

A Appendix: Calculations

A.1 Rear Wheel Torque

From Solidworks' analysis of our CAD models, we have an upper bound m of 5 kg on the assembly's weight. The height h_G of the centre of gravity G off the ground is 0.144 m. The horizontal distance l_A from the back (driven) wheels at A to G is 0.085 m. The horizontal distance l_B from the front support B to G is 0.134 m. From our measurements, the ramp has an incline of 8°. The rear motors apply a frictional force F_F on the back wheels, and the front support is estimated to have a coefficient of static friction $\mu = 0.2$. Applying force and moment balancing equations on a static body,

$$\begin{aligned}\Sigma F_x = 0: &\quad N_A\hat{\imath} + N_B\hat{\imath} - mg\cos 14^\circ\hat{\imath} = 0\\ \Sigma F_y = 0: &\quad F_F\hat{\jmath} - \mu N_B\hat{\jmath} - mg\sin 14^\circ\hat{\jmath} = 0\\ \Sigma M = 0: &\quad N_B l_B - N_A l_A + F_F h_G - \mu N_B h_G = 0\end{aligned}$$

Solving these equations, we obtain 9.7 N force necessary to drive the assembly out of stasis on the ramp, which will be the most difficult part of the course. The wheels have radius 2.8 cm, so a gear ratio of 3:1 will be sufficient to sustain movement with less than half of maximum torque.

A.2 Actuator Torque

Again, from the Solidworks analysis, the actuator arm has a centre of mass 9 cm from the pivot and weighs 0.535 kg when it is loaded with a pet. This requires a torque of 48 Ncm, and consequently a gear ratio of 5:1 will allow the motor to run at half of maximum torque.

A.3 Zipline Arm Torque

The zipline arm has a mass of 0.117 kg which is centred 1.5 cm from the pivot. This is a 1.7 Ncm moment required, which the motor can run at one-tenth of maximum torque without any gearing.

A.4 Winch Torque

The robot has an upper bound of 5 kg on mass. The winch pulley has a radius of 1 cm, which can increase to an upper bound of 2 cm when the belt is wrapped around the spindle. This requires an upper bound of a 100 Ncm moment. A gear ratio of 1:40 is used, allowing the motor to run at just over half of maximum torque.

A.5 IR Sensing Circuit Value Validation

A.5.1 DC Block

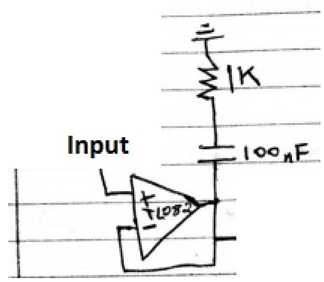
Since:

$$f_{cutoff} = \frac{1}{2\pi RC}$$

With $R = 1k\Omega$ and $C = 100nF$

$$f_{cutoff} = \frac{1}{2\pi(1000)(100 \times 10^{-9})} = 1.59kHz$$

This will allow us to block all frequencies below about $1.5kHz$ which will functionally block DC and unwanted low frequencies.

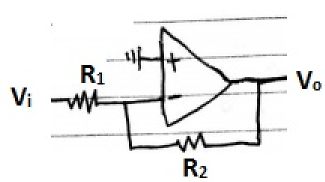


DC Block

A.5.2 Amplifier Calculations

$$\frac{V_o}{V_i} = \frac{R_1}{R_2} = \frac{47k\Omega}{10k\omega} = 4.7$$

This will give us a five times amplification of the signal.



Amplifying Circuit

A.5.3 Band Pass Calculations

A high pass filter and a low pass filter in series (see diagram below) will form a band pass filter with upper and lower limits determined by:

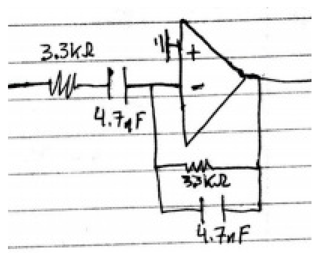
$$f_{cutoff} = \frac{1}{2\pi RC}$$

We want both cutoff frequencies to be $10kHz$ so that the band around the desired frequency is as narrow as possible. Therefore, the capacitors and resistors used in each section of the band pass filter will be the same.

Using $R = 3.3k\Omega$ and $C = 4.7nF$ we get:

$$f_{cutoff} = \frac{1}{2\pi(3700)(4.7 \times 10^{-9})} = 10.26kHz$$

as desired.



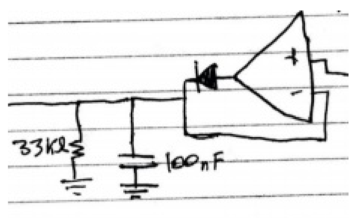
Band Pass Filter

A.5.4 Peak Detector Calculations

So that the input to the TINAH is a non-oscillatory analog signal, we will need a peak detector. This will be a rectifying circuit consisting of a resistor and a capacitor. Since the charge/discharge time of an RC circuit is

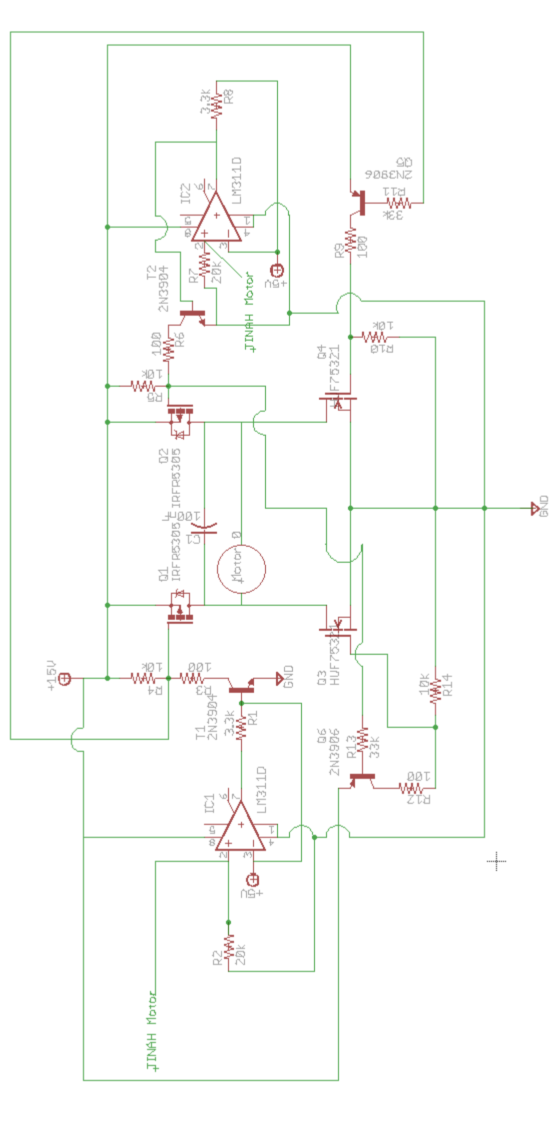
$$\tau = RC$$

we need to pick these values so that the charge time is as short as possible and the discharge time is long enough to compensate for the voltage drop due to the oscillation of the IR signal. We chose $R = 33k\Omega$ and $C = 100nF$ so that $\tau = 33000(100 \times 10^(- 9)) = 3.3ms$ so that the discharge time would be longer than the period of the wave, keeping voltage relatively constant, and short enough that IR following will be functional.

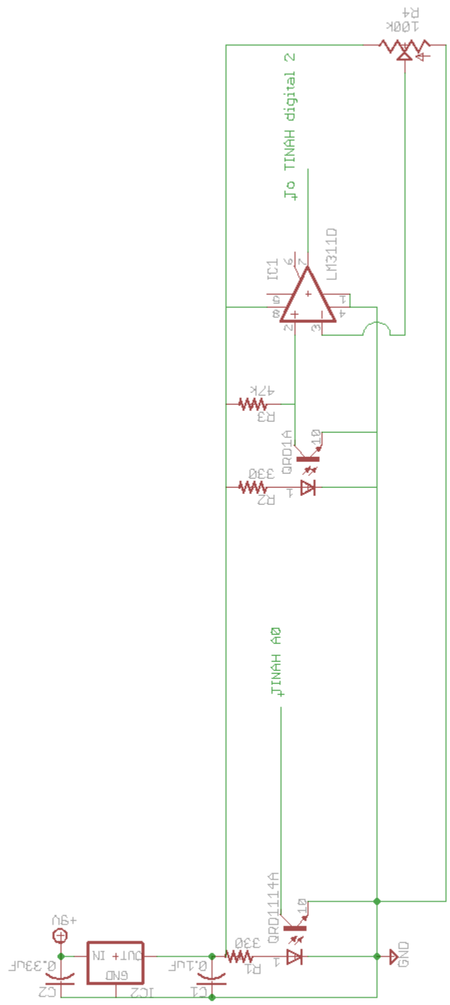


Peak Detector

B Appendix: Circuit Schematics

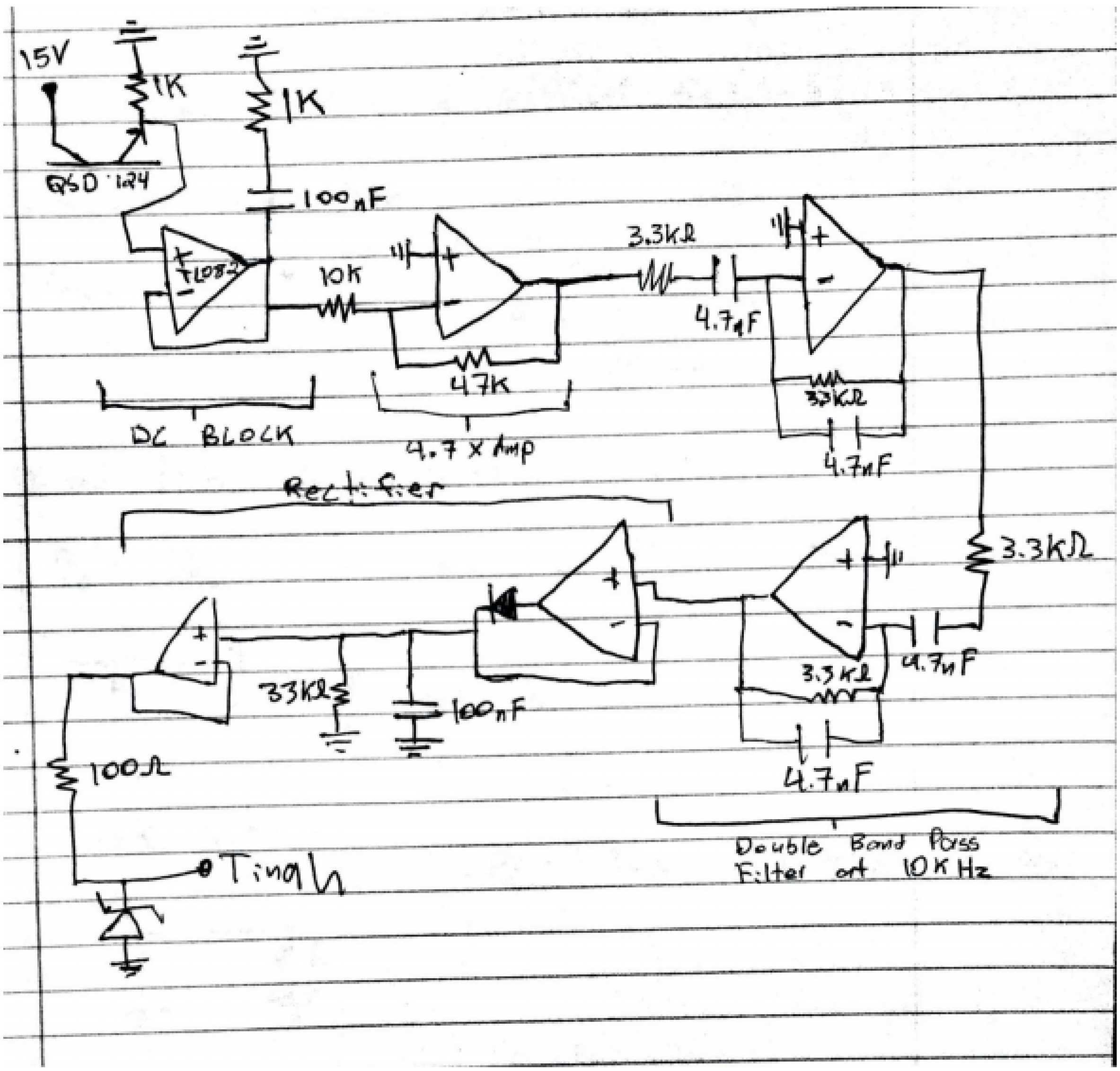


Schematic A: H-bridge circuitry for controlling motors for driving and arm actuation

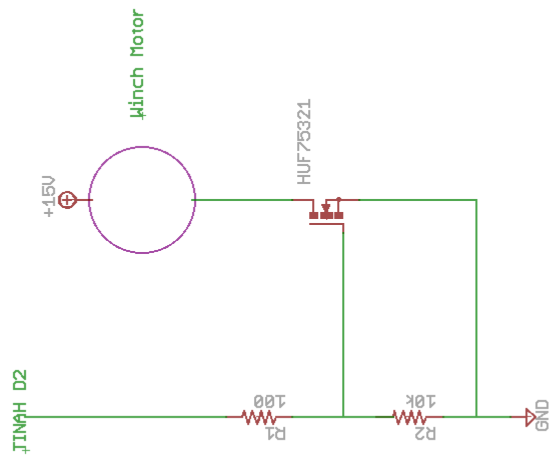


Schematic B: QRD1114 circuitry for tape following

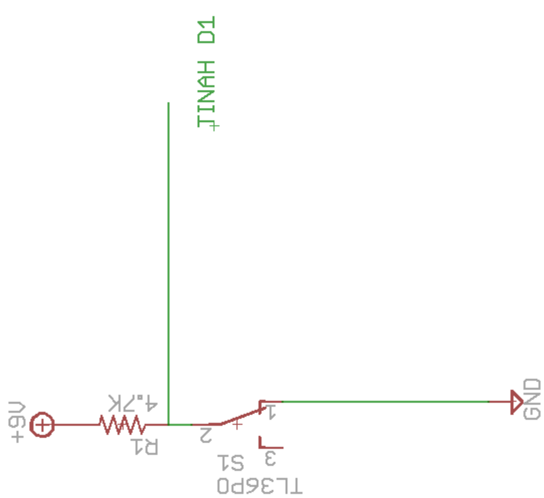
Left QRD1114 is for general tape following; right QRD1114 is for detecting tape leading to pet.



Schemtic C: Circuitry for 10kHz IR beacon detector



Schematic D: circuitry for controlling winch



Schematic E: circuit for microswitch detecting pet pick up

C Appendix: Software Modes

Table 5: Table of Software Modes

Mode	Description
Main Menu	This is the mode automatically entered when the board boots. The knobs are used to cycle between menu options. Additionally, any mode can be canceled to return to the Main Menu.
Options Menu	Allows runtime parameters to be modified using the second knob.
Segment Select	Starts the selected mode from a list containing modes during program execution.
Course Begin	Transitions to the Follow/Retrieval mode.
Follow/Retrieval	Follows the tape and picks up the first three animals. Upon reaching the end of the tape (once all horizontal marks have been detected), switches to the Beacon Homing mode.
Beacon Homing	Using the two forward IR sensors, navigates towards the IR beacon. Picks up the elevated pet on the rafters by measuring distance from the end of the tape. Switches to Rubble Excavation upon IR sensor intensity reaching a threshold to be determined empirically.
Rubble Excavation	Turns 90 degrees and brushes off the top layer of foam using the arm. Attempts to find and retrieve the pet buried in the foam, and upon retrieving it (or on approaching the 2 minute time limit), switches to Zipline/Return.
Zipline/Return	Uses the side IR sensor to align the robot with the beacon, raises the zipline arm, and cranks the winch up to return to the Safe Area. Returns to Main Menu afterwards.