Final Project Lab Report

Slugs vs Bugs II

ECE118 - Introduction to Mechatronics
University of California, Santa Cruz

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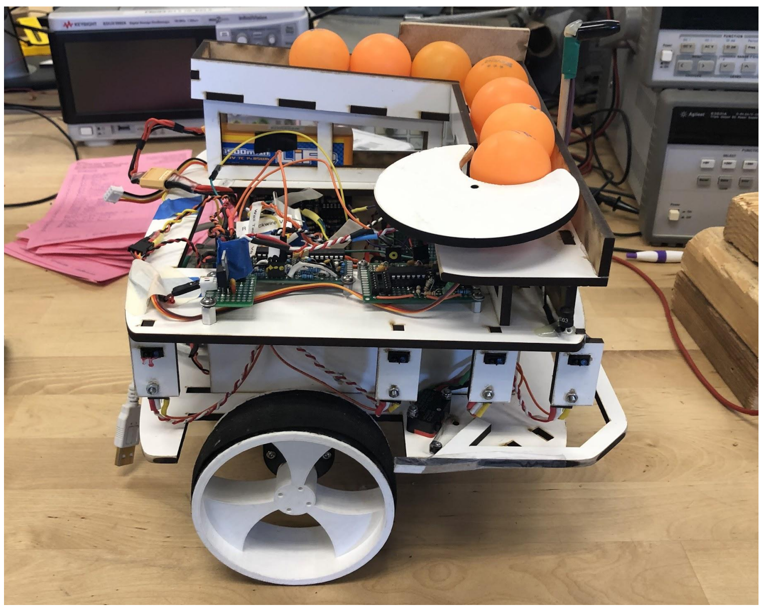

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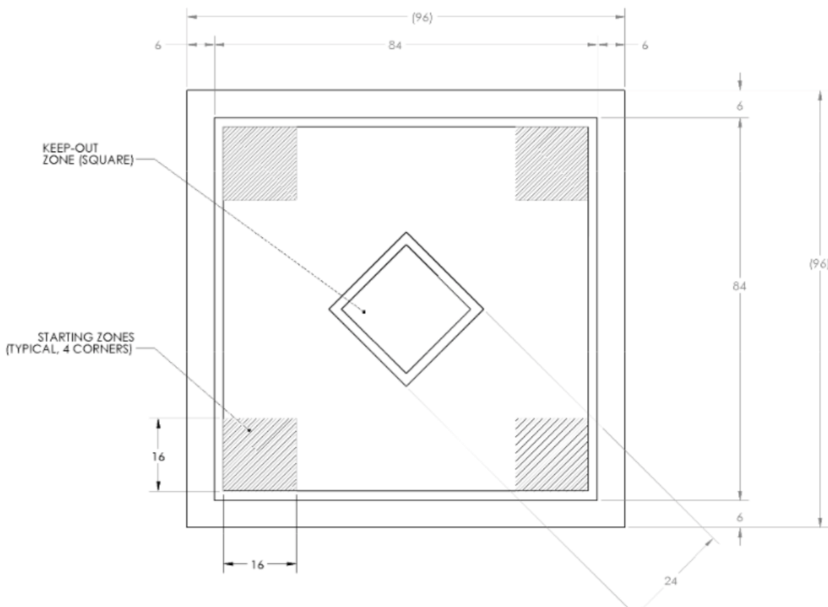
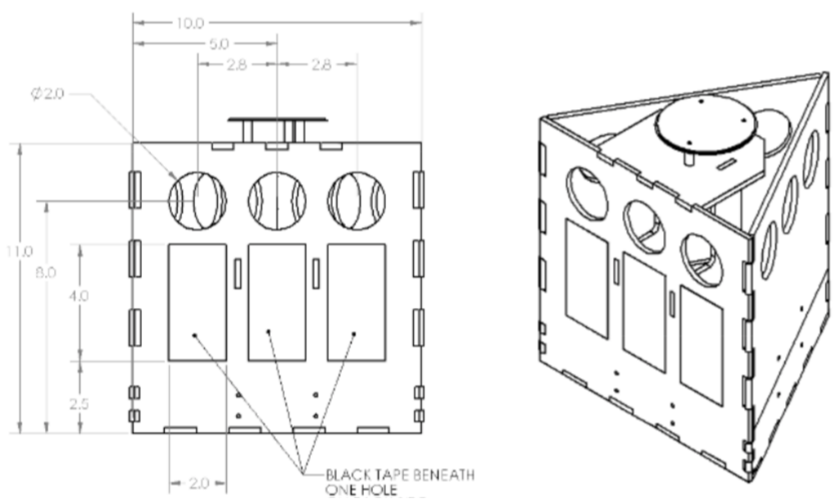
I. Early Planning

A. Background Briefing

The basic goal of this lab is to create an autonomous ground robot to effectively and robustly navigate a standardized 8’x8’ field and avoid obstacles. The robot must also locate randomly placed triangular vat towers around the field, marked with a 2kHz beacon on the top; identify the correct side, marked with a 25kHz trackwire; and identify the correct hole on that side, marked with black tape; and drop a ball into it. It should also be noted that a dead robot (modeled with a 11” black cube) will also be randomly placed within the field, and the robot must be able to properly ignore and avoid it. Points will be lost if more than half of the robot goes into the out-of-bounds portion or the edge of the field, again marked by black tape, or if a ball is dispensed into an incorrect hole. In order to properly meet minimum specification, the robot must fit within an 11” cube and be able to drop a ball into the correct holes of at least 2 different vat towers in less than two minutes. Both the field and the randomly placed vat towers are shown below.



Field of Play for Slugs vs Bugs II



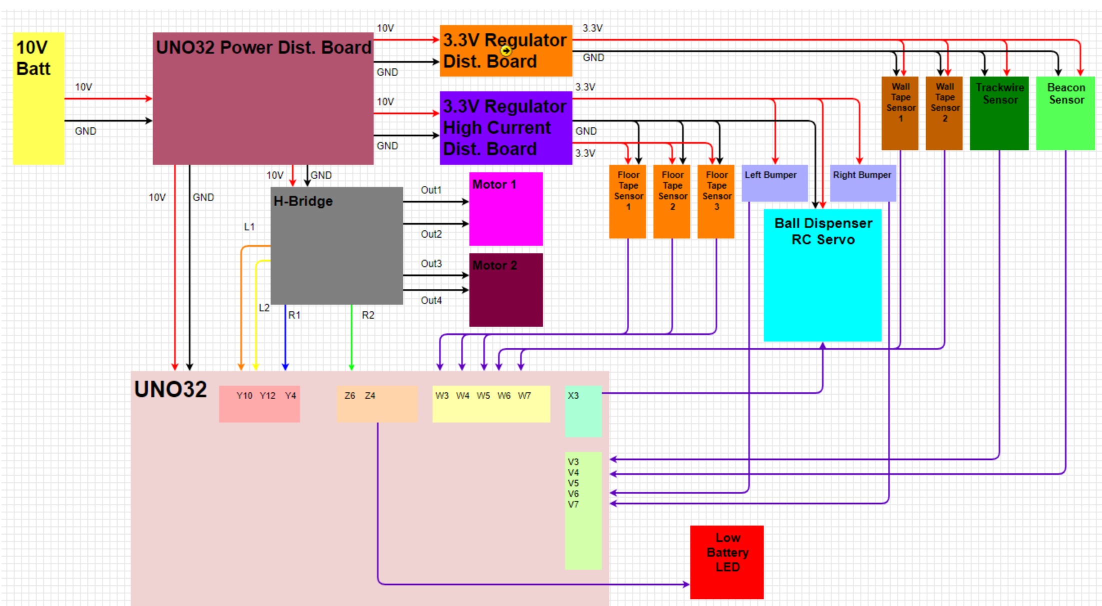
Vat Towers are 10” wide and 11” tall and are marked with a 25kHz trackwire on the active side

B. Hardware Design

The course midterm covered many topics necessary for this lab, including brainstorming both the hardware design and state machine design of the robot. Because of this, the group was able to heavily base their initial hardware and CAD design off of the various combined ideas from the group's midterms. With this in mind, the group landed on a simple differential drive two-level design, with a gravity-based ball deployment mechanism. The ball dispenser utilized a 3 degree ramp leading to a circular door with a ball-sized slot to allow one ball to pass at a time. This "door" was controlled by a servo and would rotate to allow one ball at a time to be released into the correct hole.

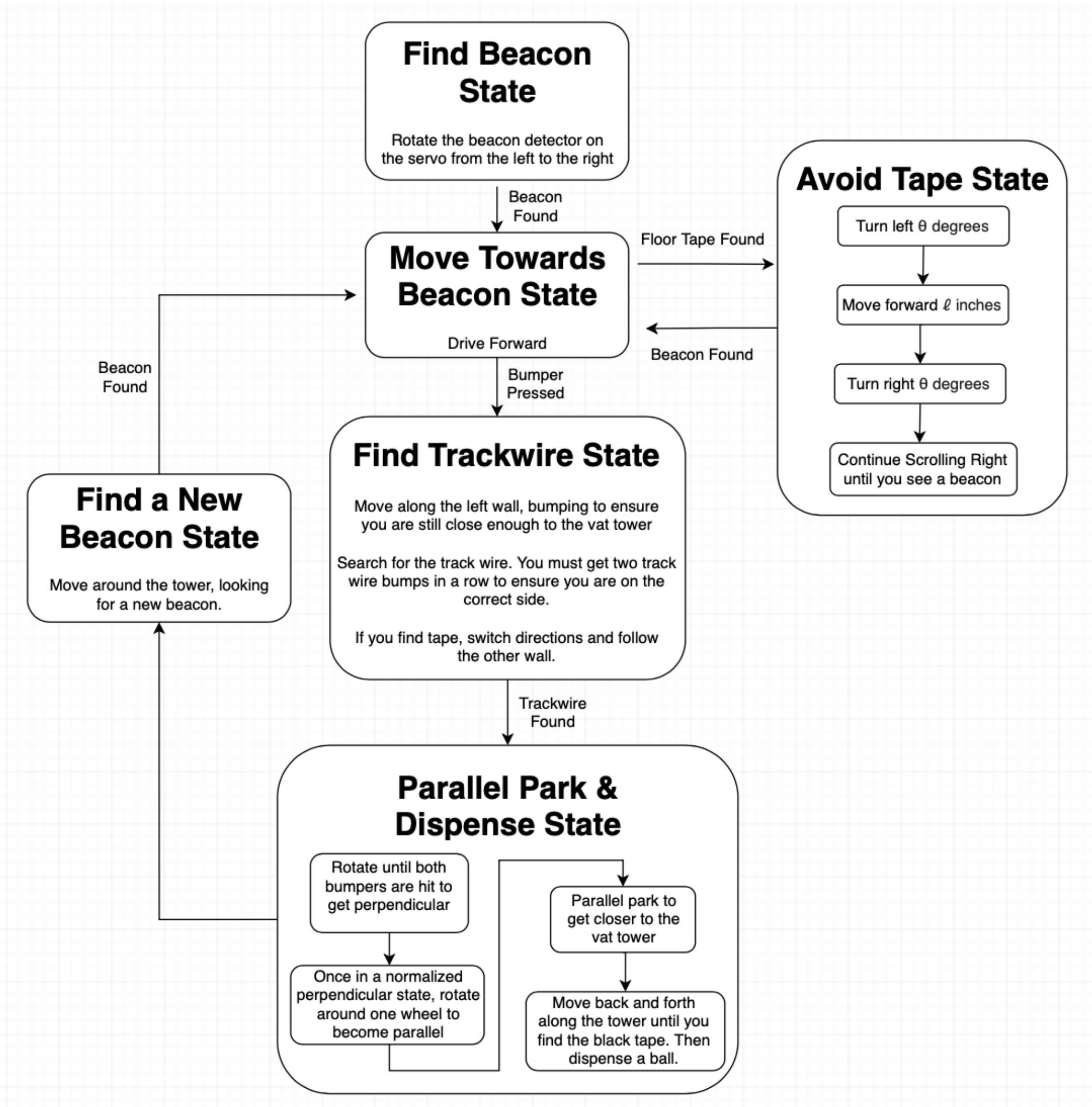
The robot also utilized a wide variety of sensors to navigate properly around the field and complete the assigned challenge. This includes bumpers on each side of the front of the robot to allow it to bump wall follow around the various obstacles on the field as well as trackwire sensors on the front corners to find the correct side during the wall bump. Three tape sensors on the bottom, two towards the front corner and one in the back, would also be used to ensure the group's robot does not leave the playable portion of the field. There would also be two tape sensors on the side of the robot to allow it to determine whether or not the ramp was properly lined up with the black tape of the correct hole. Note that later into the project more tape sensors would be attached to the side, bringing the total to four. Finally, the group wanted to put the beacon detector's phototransistor attached to a servo at the top of the robot, acting as a periscope to find and follow the vat tower beacon.

Although there would be definite altercations to both the CAD design and the electronics used, this design was relatively unchanged during the entirety of the project. Additionally, the same pinout would be used throughout the entire project, with the addition of a select few sensors.



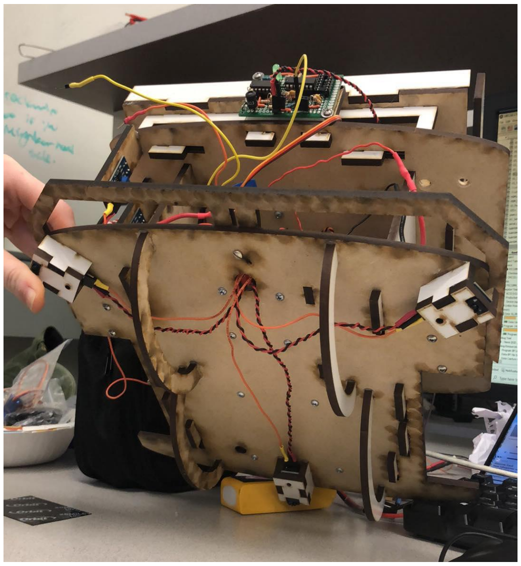
C. State Machine Design

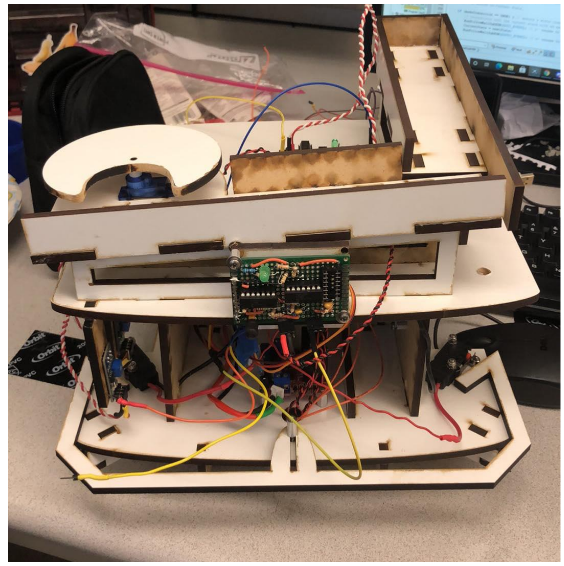
The initial state machine relied very heavily on a bump-based wall follow technique. This would include pivoting on one wheel until the corresponding bumper hit the vat tower, unpivoting about 60 degrees, and moving forward a small amount before repeating the process. This would ensure that the robot would remain close to the vat tower and be able to navigate corners fairly well. During this state, if the vat was too close to an edge of the field and the robot found floor tape, it would simply turn around and repeat the process, bumping along the other side of the robot.



II. CAD Prototyping

A. Robot Body

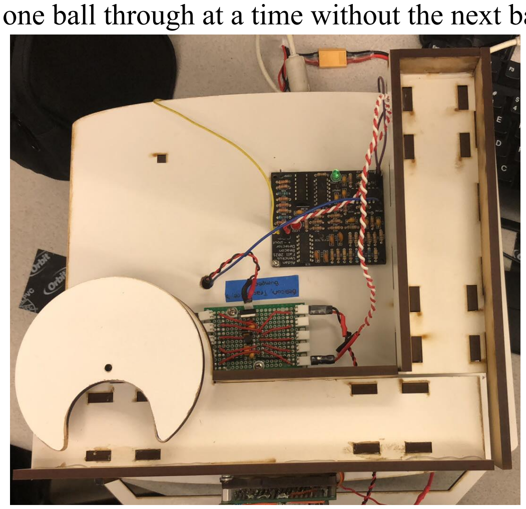




Early on, the robot body was very simple with a front bumper capable of detecting left or right bumps, a trackwire detector in the front of the bot, as well as two tape sensors under the shooting ramp in order to detect the correct hole. The bottom of the robot is equipped with 3 tape sensors on the bottom outer edges in order to detect out of bounds. The body features holes for wires and has fully detachable walls, top layer, and ramp, with notches they snapped into to be held securely.

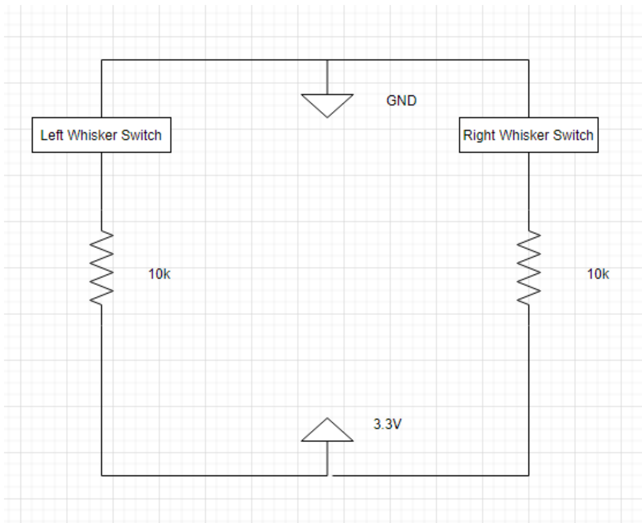
B. Ball Dispenser

The ball dispenser is designed to be as simple and effective as possible. Using only a single servo with a revolving door, the servo swings from its minimum position to its maximum, flawlessly dispensing only a single ball at a time. The dispenser is loaded using a 3 degree angled ramp and is capable of carrying 9 balls. The group had to make slight adjustments to the servo door as sometimes the servos, which were sometimes lacking in quality, did not always make uniform angle changes as the PWM input changed. This meant the door opening had to be wide enough to account for slight differences in angle and thin enough to still allow only one ball through at a time without the next ball getting caught or stuck.



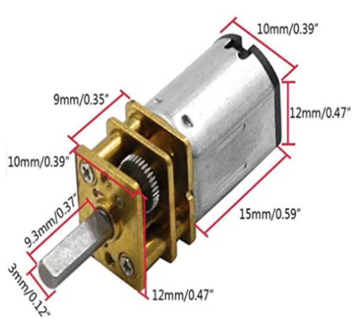
C. Early Changes

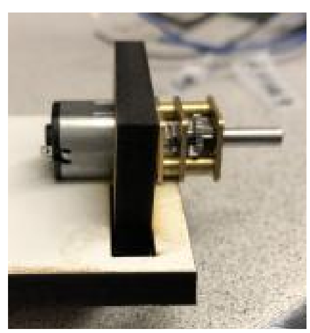
Early on, the plan for object detection was to use simple whisker sensors to navigate the towers. The design utilizes two thick wires which act as limit switches when pushed against two pins on either side. The whiskers output 3.3V when not pushed and 0V when pushed.

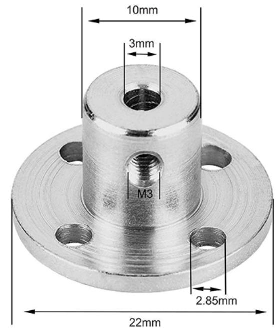


The design was abandoned early on due to the need for more consistent switches. With no mechanism to spring back, the whisker sensors have difficulty remaining in a consistent angle when the bumpers need to surround the front of an 11 inch body.

The group also originally planned to have the beacon detector's phototransistor rotate independently to allow the robot to continue to track the tower even when avoiding tape and obstacles. However, it was rather difficult to get this functionality without tangling the wires of the phototransistor; an electrical slip ring was needed to get this functionality. Maintaining consistent reliable angles would require a significantly more costly servo than the group preferred. At this point the level of intricacy, price, and work outweighed the benefits of a rotating phototransistor so the idea was dropped from the design. A static phototransistor was instead placed at the top center of the robot in the front to allow it to easily see new VAT towers.





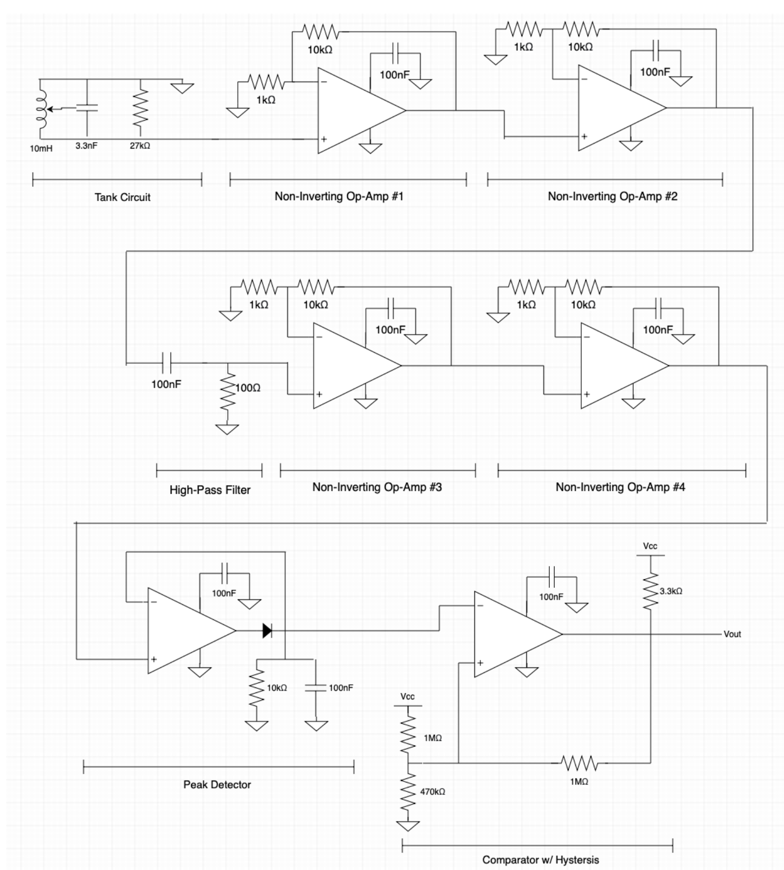


The final early change was that the group originally planned on using micro 12V 100RPM DC motors, but because of the lack of both torque and consistency, the group decided to switch over to larger 12V 100RPM DC Motors. This change means the group had to reorder DC motor adapters, changing from 3mm diameter adapters to 6mm adapters.

III. Hardware

A. Trackwire Circuit

Inside each vat tower, the correct side has a trackwire circuit which carries an oscillating current with peak-to-peak amplitude of 150mA at a frequency of 24-26kHz. The current generates an oscillating magnetic field around the wire which can be detected as a voltage using a solenoid in the correct orientation.



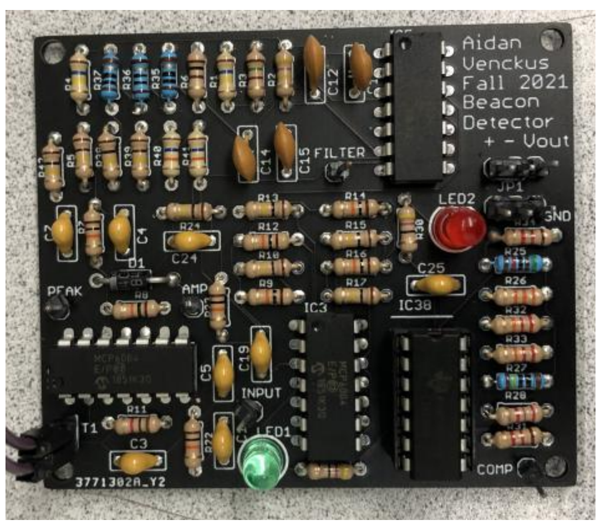
Since the signal directly from the solenoid is too weak to be of any use, it must be amplified so that it can detect the trackwire within 2 inches. The first stage of amplification is the passive stage, which consists of only a RLC tank circuit. The RLC tank circuit, which includes a solenoid which detects the trackwire magnetic field and a capacitor, passively amplifies the signal by setting the resonant frequency of the tank circuit close to the trackwire circuit frequency of 25kHz which produces large oscillations in the tank. The resistor lessens the gain of the tank circuit, but widens the bandpass of the amplifier.

While the LC tank circuit passively amplifies the desired signal of 25kHz, it may still be too small to distinguish the trackwire from high noise sources. Operational amplifiers are needed to further amplify the signal to a more useful range. Since the goal after this stage of active amplification is peak detection, the goal is to rail out the signal to 3.3V. That way, the largest hysteresis gap can be established when detecting the trackwire. Three stages of active amplification using non-inverting amplifiers are used to accomplish a total gain of 1331.

Next, the signal goes through a peak detector which is essentially an active rectifier which holds the highest voltage. The capacitor holds the charge while the resistor slowly drains it. The diode prevents the op amp from discharging voltage, but allows it to charge up. The peak detector raises the voltage output as the tank circuit nears the trackwire circuit and drains the voltage when it is not near it. In this way, the output of the peak detector is the analog output of the sensor.

While the analog signal of the peak detector can be converted to a digital signal using a comparator, the analog signal is better suited for detecting different towers. Since every tower may carry a slightly different signal, setting the hysteresis bounds in software makes it easier to adjust for than if it was set in hardware.

B. Beacon Detector



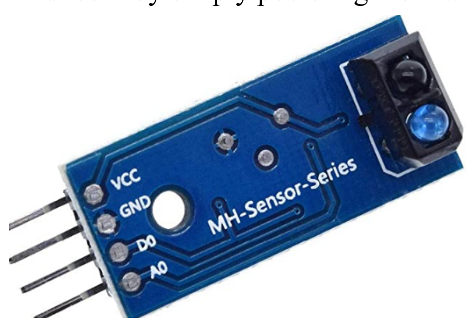
On top of each vat tower sits a beacon which sends out an infrared signal of 2kHz in every direction. The beacon detector sensor uses a phototransistor to detect the beacon signal from 6 feet away while rejecting other signals at 1.5kHz and 2.5kHz. The beacon detector first goes through a trans-resistive stage, where the primary goal is to linearize the signal from the phototransistor. Then, it goes through a 4th order Butterworth filter stage in order to attenuate the signals of non-interest. After filtering, the signal goes through amplification and peak detection in order to present a signal to the UNO. This beacon detector was prototyped in a previous course lab, and with the help of another classmate, the group was able to order and use a PCB. A banana clip was used as mechanical shielding to ensure extra light was not read and that the sensor could be aimed accurately.

The phototrans-resistive input is first filtered by AC coupling which removes any DC bias or drift before the amplification stage. Then, in order to magnify the signal to a usable range, the signal is passed through four stages of non-inverting amplifier gain. Each amplifier has a gain of 11x resulting in a total gain of 11^4 or 14641. Then, the amplified signal is inputted to the 4th order bandpass filter. The bandpass filter is a 4th order Buttersworth filter centered at the signal of interest, 2khz. The lower corner frequency and upper corner frequency are set to significantly attenuate signals at 1.5kHz and below or 2.5kHz and above. The circuit is buffered before and after the filter to prevent the load on either side from affecting the filter's impedance. The trans-resistive circuit, amplifiers, and filter all use a virtual ground or split rail buffer to center the signal at 1.65V. Since the op-amps are being operated from 0-3.3V, centering the signal at 1.65 allows the full signal to swing instead of half being cut off by the 0V rail.

After the filter stage, the circuit is then converted into a signal for the UNO with a peak detector. The same way the peak detector held the high voltage for the trackwire sensor, the peak detector will jump to the high value as the beacon is detected and hold that voltage while the signal is high. Using the peak detector output, the beacon can be tuned to be more or less sensitive given the amount of noise or other signals present.

C. Tape Sensors & Bumpers

The tape sensors work with TCRT5000 IR sensors which utilize an infrared emitter and phototransistor to measure the amount of light reflected off a material. There are cheap drivers which have an analog and digital output and work by simply powering them with 3.3V.



After testing them, the optimal distance for the clearest readings is approximately 3cm away from the floor or wall. The analog output is generally better than the digital output since it is more versatile, although the digital output is acceptable for the floor-aimed sensors, as the group does not need as precise information. Using the sensor at its optimal distance, the sensor can tell the difference between black tape, white floor, and the void. This means these sensors can be used both to avoid the out of bounds black tape on the floor, as well as to gauge the distance from the VAT tower using sensors on the side of the bot, and to line up the ball dispenser ramp with the vat's black tape.

With these applications in mind, the last concern is the current draw. Since there will be 7 tape sensors running, it is very important to make sure enough power can be distributed to all 7 boards. By connecting the sensor boards to the lab power supply which has an internal ammeter, the current draw for the boards is approximately 20mA. Seven of the sensors drawing 20mA results in 140mA total at 3.3V.

The bumpers were similarly bought sensors, and consisted of two limit switches, one for the left side and one for the right. The switches are used with MDF laser cut bumpers which cover the front of the bot as well as part of the side. The switches are powered with 3.3V and the ground is connected to the UNO pin.

D. Motors & Servo

The motors are standard 12V 100RPM DC motors driven by the L298N Dual 3A H-bridge module. The L298N is capable of driving two motors in both directions with two enable pins and 4 PWM pins. Driving the correct pins at the correct PWM speeds allows the bot to make tank turns, gradual turns, sharp turns, and move in either direction. The module also features external clamping diodes which counteract the dangerous inductive kickback from the motors.

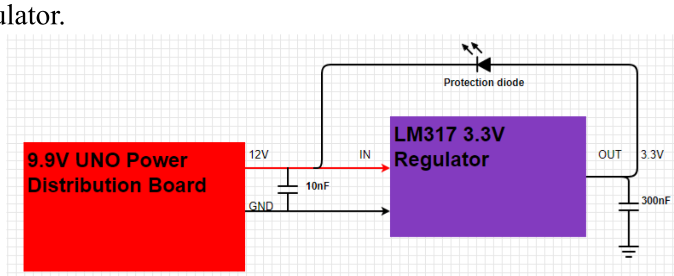
The servo used for the ball dispensing mechanism is a micro servo with a turn rotation of 180 degrees. They can be driven with 3.3V and are strong enough to easily rotate with the MDF swinging door attached. The RC servo swings the full 180 degrees when changed from its minimum PWM to its maximum PWM. When in use, the servo can draw up to 1A of current.

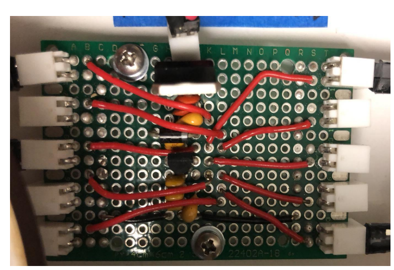
E. Power Distribution Boards

In order to effectively distribute power to all 7 tape sensors, the beacon sensor, two trackwire sensors, the H-bridge, and the servo, several power distribution boards were needed. Having multiple distribution boards ensures that the voltage regulators, uno power pins, and other components are not overwhelmed by the current supply needed for all the different sensors and actuators. The motors are the only piece of hardware not powered by a distribution board.

The voltage regulators can source up to 1.5A and output 3.3V. The servo draws the most current and should be on a separate board. Each tape sensor draws approximately 20mA so they are not much of a concern. Likewise, the beacon detector and trackwire sensors draw very little current.

The voltage regulators each have a diode to protect the regulators against backwards voltage stored in the capacitors. The input capacitor is there to serve as a bypass capacitor to reduce the circuit's vulnerability to input line impedance and the adjacent capacitor prevents any ripple from being amplified by the regulator.

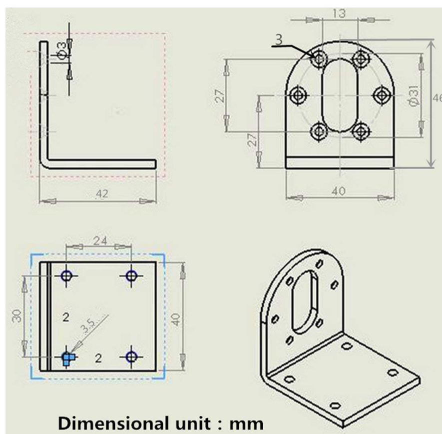




IV. Prototype Changes

A. CAD Updates

As was previously mentioned, the group's original design was made with the idea that two 12V micro DC motors would be used to drive the wheels. This was rather challenging as the mounting holes on the motors were too small to be very functionable, so an alternative way of mounting them had to be found. The group designed a bracket to anchor the motors down by clipping into the base of the chassis. However, when the drivetrain was tested, the brackets were not able to hold the motors in place against all the torque being generated. This hindered the robot's ability to drive in a straight line. As the group continued to test and try to resolve this issue, the gearing in one of the motors stopped working. Without the gear ratio, the motor was not able to provide enough torque to rotate the wheel with the weight of the robot; with only one working motor the robot only spun in place. As the group considered replacing the broken motor, the possibility of running into this issue again if the same model of motor was used was too great and we decided to switch to the other 12V 100RPM DC motors they had on hand. This means, however, that the new motor would not fit in the same hole that had been designated for the micro motors. We instead had to mount the new motor to the bottom of the base in order to continue to have room for the remainder of the electronics.



Larger DC Motor Mounts attached to the bottom of the robot base

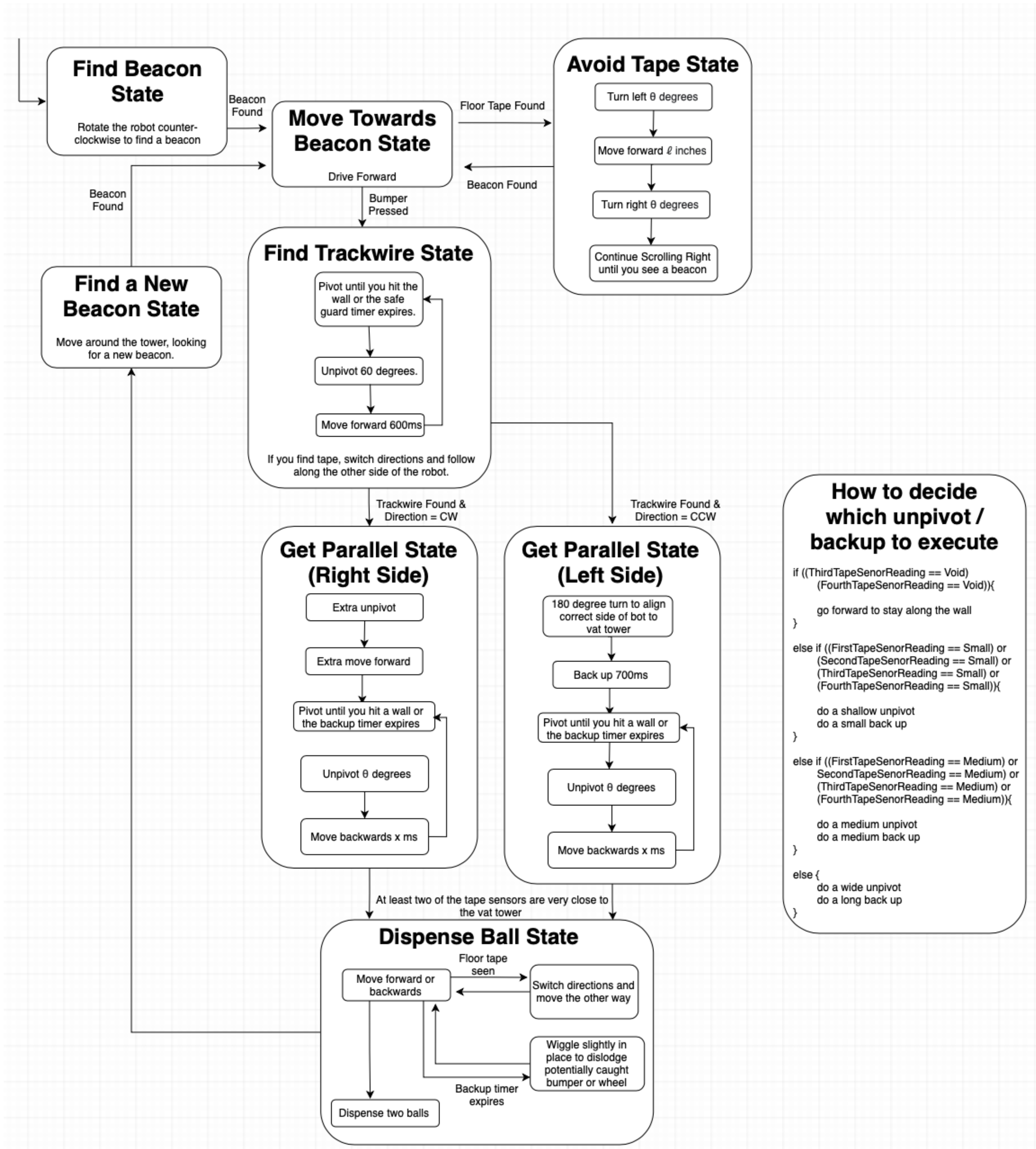
This would raise the height of the robot by more than an inch. To continue to have the ball dispenser at the correct height to shoot a ball into the holes of the vat towers, significant height had to be removed from other parts of the design. The ball ramp itself was already relatively low sitting on the top platform, so the best option was to shorten the two side walls that connected the base to the top platform. Shortening the wall however, would make it impossible for the group to reach into the chassis to adjust connections, and the jumper cable connections to the UNO board would be squished. To resolve this, we cut a large hole on the top platform that would allow them to reach in and adjust connections and allow more space for wires.

B. Circuity Updates

The original design had two tape sensors mounted vertically to the side of the robot to help the robot align with the tape marking the correct hole. As the group began programming the robot to complete the tasks, however, they found it difficult to "parallel park" well enough to align well enough with the side of the tower. The group realized that they needed more information on the position in relation to the tower than just what they were getting from the front bumpers. Using the tape sensor's analog signal, fortunately, allowed the robot to tell the distance from the wall of the tower, however this was a limited functionality, as it could not be used if the two tape sensors were directly over the black tape or not over the wall at all. To remedy this, the group decided to add two extra tape sensors along the ramp side to help the robot read distance when some of the tape sensors were over black tape or not along the wall at all. An extra 3.3V regulator was made for the new tape sensors to ensure the sensors do not overdraw from one particular power distribution power.

Another change included the group adding a second trackwire circuit. This is because the original robot design only had one with the tank circuit sensor attached to the middle of the front of the robot. In reality, however, when the robot follows the bump follow wall method, it would pick up the oscillating magnetic field much easier in the corner, and it would need one in each corner depending on which direction it is circling the vat tower. This was quickly soldered up and attached to one of the many power distribution boards.

V. Software



The final iteration of the state machine was fairly similar to the first draft, with major differences only appearing in the steps involving getting parallel. "Parallel parking" with standard turns was very difficult, and would either take far too long or not get close enough for the ramp to correctly dispense the ball. To remedy this issue, the group used the two additional tape sensors on the side of the robot to help customize the unpivot and back up timers to ensure it is able to get as close and parallel to the vat tower as quickly and efficiently as possible. In order to do this, the group read the values while the robot stood at various angles and distances from the vat tower and recorded the thresholds for which they would like to do different movements. It should be noted, because the robot would sometimes get stuck on either the bumper or the wheels, each state has a back up timer that would jolt it out of its current state and position to help it become dislodged.

VI. Final Alterations

One of the last problems the robot struggled with involved getting stuck while trying to scan the wall for the correct hole on the tower. The bumpers and wheels, which slightly stood out, would sometimes get caught on the sides of the towers or on the mounting screws sticking out the walls. Even though a "jiggle" implementation would sometimes unstick the bot, it would often cause the bot to stray from the wall and miss the shot.

In order to remedy this, the group sanded down the bumpers to make them smooth and catch less often. In addition, they moved the wheels inwards about 4cm so they did not stick out as far when searching for the correct hole. Both these additions allowed us to gain consistency. Still, sometimes the bot would be slightly too far away so the group implemented a software change so that the robot would fire two balls, hoping the second one would help push the first one in, and give a slight pivot after dispensing the ball to help push them into the hole after shooting. These three solutions in combination solved the dispensing issues and allowed the robot to make consistent runs around the randomized field.

VII. Appendix

A. BOM

Part Name	Date	Description	Link	Cost
DC Motors	11/4/21	2X 12V DC Motors 100rpm	https://www.ama:	13.99
RC Servo	11/4/21	4X 4.8-6V RC Servos	https://www.ama:	10.99
Cont. RC Servo	11/4/21	2x 4.8-6V Cont. rot RC servo	https://www.ama:	13.79
Tape sensor drv	11/5/21	10x TCRT5000 drivers	https://www.ama:	10
DC Motors	11/8/21	2x 12V Plumia DC Motor	https://www.ama:	26
Slip ring	11/8/21	Slip ring for beac det	https://www.ama:	5
		12x 3 mm screws		
		4x 1 mm screws		
		8x 2 mm screws		
MDF	11/12/21	MDF for initial prototype	BELS	5
Shaft Adapter	11/16/21	4x 3mm DC Motor Shaft Adapter	https://www.ama:	8.18
DuctTape	11/23/21	DuctTape to wrap the wheels	ACE	3
Motor Mounts	11/23/21	2x 37mm DC Motor Mounting Bracket	https://www.ama:	9
Shaft Adapter	1/23/21	2x 6mm DC Motor Shaft Adapter	https://www.ama:	9
TOTAL:				113.95
Amount Left:				36.05

Please note, the objects highlighted in yellow ended up not being used in the final iteration of the robot, and were either returned or discarded (if they were broken over the course term).

B. I/O Pin Layout

UNO I/O BOARD PIN LAYOUT			
#define	Pin	I/O	Use
PORTW03_LAT	W3	Digital Input	Front Left Floor Tape Sensor
PORTW04_LAT	W4	Digital Input	Front Right Floor Tape Sensor
PORTW05_LAT	W5	Digital Input	Back Floor Tape Sensor
AD_PORTV8	V8	Analog Input	First Wall Tape Sensor
AD_PORTW6	W6	Analog Input	Second Wall Tape Sensor
AD_PORTW7	W7	Analog Input	Third Wall Tape Sensor
AD_PORTW8	W8	Analog Input	Fourth Wall Tape Sensor
AD_PORTV3	V3	Analog Input	Left Trackwire Sensor
AD_PORTV5	V5	Analog Input	Right Trackwire Sensor
AD_PORTV4	V4	Analog Input	Beacon Detector
AD_PORTV6	V6	Analog Input	Left Bumper
AD_PORTV7	V7	Analog Input	Right Bumper
BAT_VOLTAGE		Analot Input	Battery Voltage Reading
PWM_PORTY12	Y12	PWM Output	Left Wheel 1
PWM_PORTY10	Y10	PWM Output	Left Wheel 2
PWM_PORTZ06	Z6	PWM Output	Right Wheel 1
PWM_PORTY04	Y4	PWM Output	Right Wheel 2
PWM_PORTX03	X3	PWM Output	Ball Dispensor Servo Door