Assignment: Black Box

Team Name: LOST

Course: ENES100 - 0301

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Executive Summary

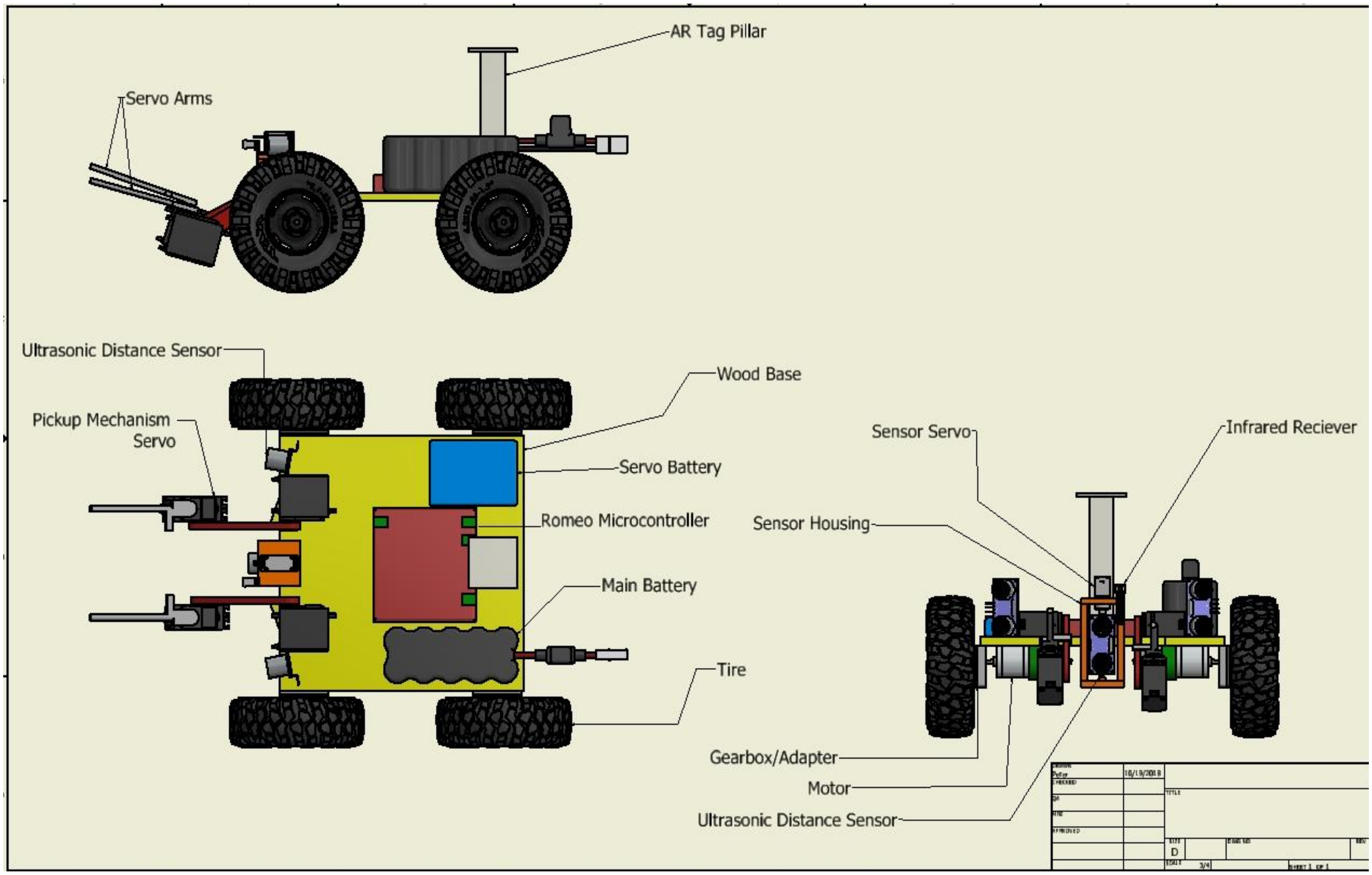
Our team is tasked with creating an over-sand vehicle (OSV) that can locate and retrieve an aircraft's black box from an undisclosed location within an obstacle area. The OSV and everything on the OSV is required to cost no more than $350, have a mass of no more 2.50 kilograms, fit within a 300 mm x 300 mm footprint, and run all systems at full power for at least 10 minutes without recharging. The base of the vehicle is a sturdy, rigid sheet of plywood. Attached to the chassis are four motors connected to rubber tires with reasonably deep treads. On top of the OSV lay two batteries -- one for the servos, and one for the the rest of the electrical components -- a Romeo microcontroller, three ultrasonic distance sensors, an IR sensor, and our mechanism to pick up the black box. The OSV is designed to maneuver to the center of the four quadrants, and use its IR sensor to pick up on the black box's infrared 50 ms pulse, four per second, at 38.0 kHz. Once it locates the black box, it will transmit its coordinates and then use its ultrasonic distance sensors to position itself in front the black box with the arms under. The mechanism to pick up the black box is composed of four 3D printed arms, and four servos (two for each arm) as well as a fifth servo to orient the mechanism to face the box. The OSV will then move towards the box with its arms lowered, bring the arms closer together until secured firmly against the sides of the box, and lift. It will then maneuver itself back towards the original landing site, with the box in tow, to complete the mission.

Introduction

The objective for our engineering firm is to design an over sand vehicle that can search and transmit the coordinates of an airplane black box from an unknown location on a "remote island." Once landed on the Landing Zone (LZ), the vehicle will travel to the center of the given four quadrants. It will utilize its IR sensor and ultrasonic distance sensors to navigate to within 250 mm of the black box, which will be emitting an infrared pulse of 50 ms at 38.0 kHz. When the OSV arrives at the black box location, it will measure and transmit the coordinates of the box to the command center, using its APC220 Radio Communication Module. In addition, as a part of its advanced objectives, the OSV will retrieve the black box by lifting it up using its 3D printed arms and deliver it back to the given landing zone coordinates. Both the basic and advanced objectives are required to be completed within 5 minutes as soon as the vehicle lands on the island. While traveling to the mission site, the OSV is also expected to navigate through rocky terrain, as well as avoid various obstacles using the ultrasonic sensors mounted on the vehicle.

The design of the OSV is constrained to the following specifications: The vehicle must weigh equal to or less than 2.50 kilograms, must fit within a 300 mm x 300 mm footprint, must cost no more than $350, and cannot have any purchased pre-built assemblies perform more than two vehicle functions. The OSV cannot be powered by lithium or lead acid batteries, and at full power is expected to last for a minimum of 10 minutes without recharging. Our OSV is a 4x4 wheel drive vehicle, with four drive motors connected to one of the four wheels. To complete the advanced mission, we have constructed a mechanism composed of servos and 3D printed arms that, when in close enough contact to the black box, will lower the arms until lined up against the sides of the box, and move inwards, pressing against the sides of the box until the box is secured firmly. We will be using a potentiometer to measure feedback on how firmly the box is secured by the arms, and once secured, will lift the arms in order to be able to freely travel back to the landing site.

The OSV must travel on sand, have motors that are powerful enough to provide the necessary torque to propel through rocky terrain, and navigate around obstacles. We addressed the issue of moving through sand by utilizing tires with deep treads, which will allow the OSV to avoid digging into the sand. For the motor requirement, we determined appropriate calculations of torque and tractive effort in order to purchase a motor with a torque that fits in our desired range. As for navigation, we decided to use multiple ultrasonic sensors to detect the distance of the black box and surrounding obstacles, as well as an infrared sensor to pick up on the frequency being emitted by the black box. After transmitting its coordinates using the APC220, the OSV would then use its arms to press against and pick up the black box, and then navigate back to the landing site.



Preliminary Design Details

The OSV is essentially designed with a 4x4 wheel drive, with four motors, each connected to one of four wheels. The OSV is built on a 200x200mm plywood base with a thickness of 6.34mm. The motors are connected to the wheels mounted underneath, and the electrical components -- including the batteries, microcontroller and sensors -- are on top of the vehicle, as well as the pick up mechanism made up of the 3D arms and the servos. In addition, we decided on two separate batteries, one for the main motor propulsion and for the sensors, and another, smaller battery for the pick up mechanism's servos. Our mission actuator is comprised of servos connected to 3D arms that function as prongs that will lift it by pressing against the box's sides and moving upwards.

Structure and Design Drawings

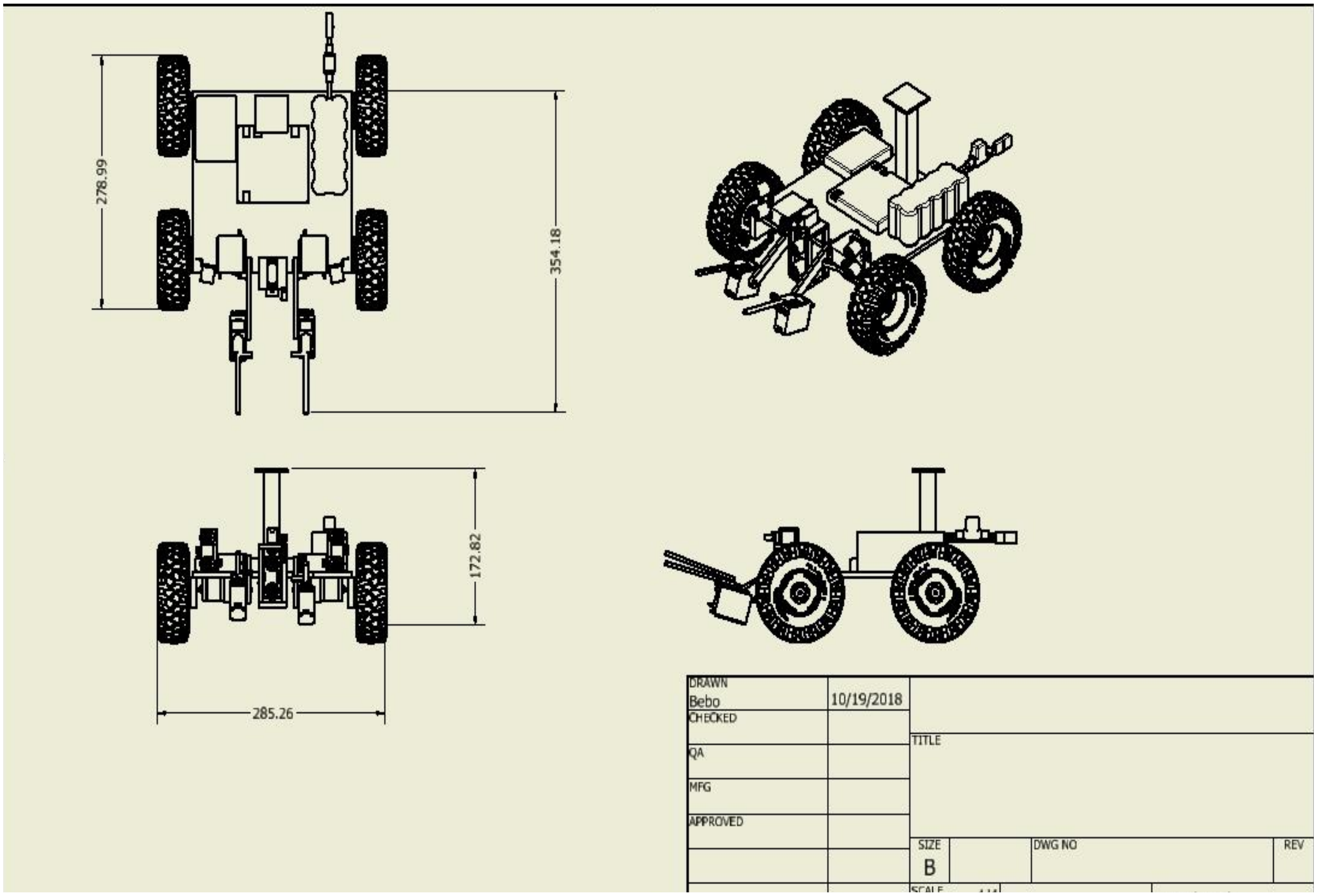


Figure 1. General Dimensions, including the dimension from wheel to wheel to display footprint when arms are fully raised. The OSV is built around a 6.34mm (.25 in) plywood base that measures 200mm by 200mm.

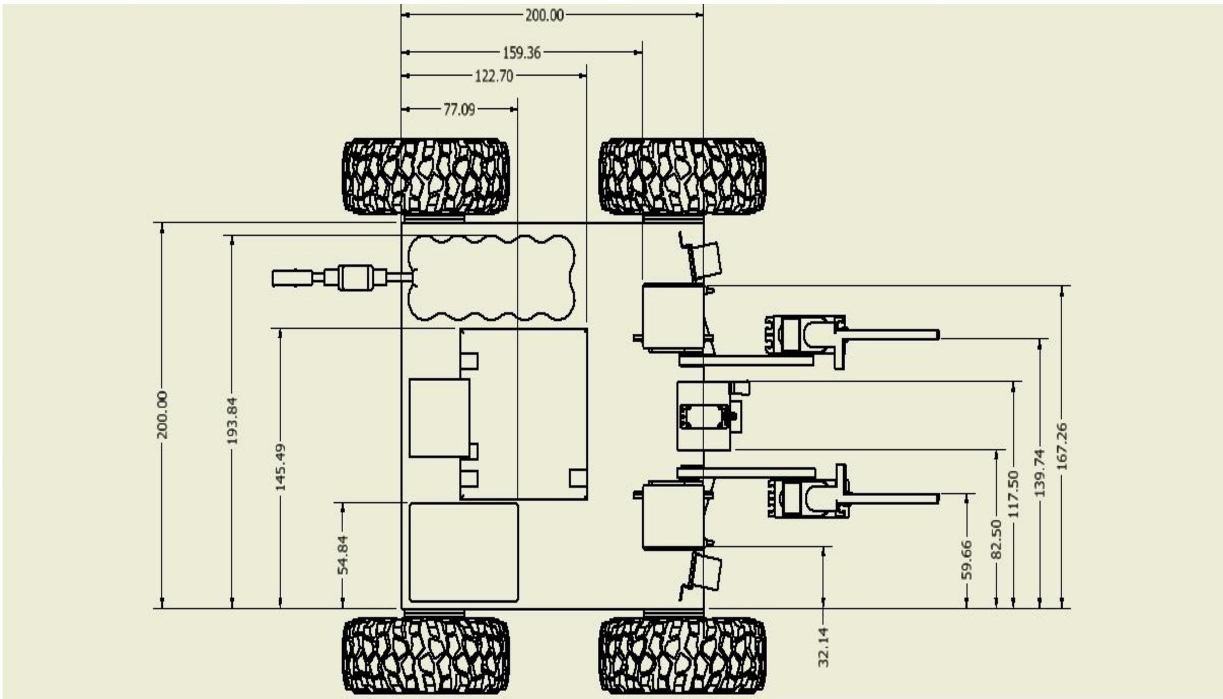


Figure 2. The dimensions showing the spacing of all components on the chassis of the OSV

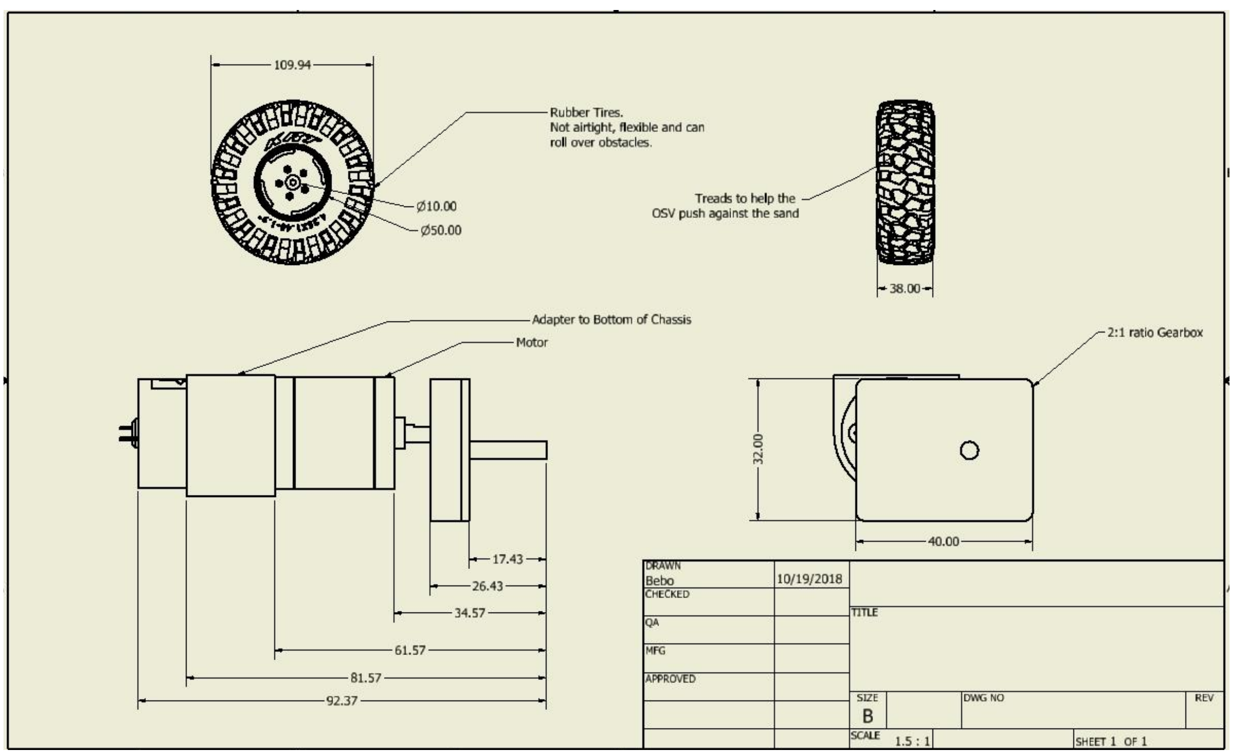


Figure 3. Tires and Motor systems. The protruding cylinder of the 3D printed gearbox will fit into the center of the wheel in the final assembly.

Mass Chart

Items	Estimated Weight (kg)
APC220	0.032
Wheels	0.2
Infrared Sensor	0.005
Romeo Microcontroller	0.0816
Ultrasonic Distance Sensor	0.027
Battery (12V)	0.607
Forklift Servos (4x)	0.080
Forklift Arms (2x)	0.05
Battery (6V)	0.1410
Motors	0.1880
Gearboxes (4x)	0.1
Wiring & Housing Units	0.15
Wood Base Plywood	0.161
hex wheel adapters	0.02
gearmotor bracket pair	0.034
Total:	1.8766

Figure 4. Total mass chart of all components of the OSV.

Propulsion

Our team opted for malleable tires with deep treads to go over the rocky terrain and through the arena's sand. We then calculated a Tractive Effort (TE) range needed to overcome the resisting force of the sand while not applying too much force so that the wheels begin to slip on flat ground ($2.35N < TE < 4.29N$). We then calculated the TE range at 35° as this is the resting angle for sand($3.66N < TE < 5.97N$). We do not expect the OSV to move along a 35° slope (as the sand will be pushed down from that angle before the wheel rises to it), but this means that every angle from 0° to 35° will be operable. From these ranges we combine the bounds creating the smallest range ($3.66N < TE < 4.29N$). Moving away from motor calculations, we decided on a conservative distance and time the OSV will take to travel (15m in

180s, or 60% of the mission time requirement). From this we obtained a desired linear velocity and angular velocity of 8.3cm/s and 1.66rad/s. From this, we obtained an acceleration to create a desired Tractive Effort, which fit inside our range (3.73 N * 5cm = 18.6Ncm). Our mission desires a 1.66 rad/s angular velocity, so we required a motor with a high torque and a low no-load speed. So with the motor we opted for (see Power section for specifications), we decided we needed a 2:1 gearbox ratio to obtain a radial speed of 1.8 rad/s from the motor's linear torque to angular velocity curve $\tau = \frac{-41.78 kg*cm}{1.887 rad/s}\omega + 20.88 kg * cm$, which was agreed upon as optimal for our OSV.

OSV Mission

Our OSV must be able to measure and transmit the coordinates of the black box within 75 mm of the actual value, and then navigate to within 250 mm of the box's locator beacon. Upon arriving at the site, the OSV must lift the black box off of the sand and bring it back to its starting point in the landing zone. To accomplish the mission, our vehicle is equipped with a variety of sensors. There is one infrared sensor attached to the center pole of the OSV that will detect the infrared signal that the black box emits, which enables it to read the coordinates transmitted by the black box and locate it. The OSV is also equipped with three ultrasonic sensors which enable it to sense obstacles in its path as it navigates to the black box. Once at the location, the OSV will orient itself to pick up the black box with the forklift mechanism at the front of the vehicle and lift it to slide into the tabs in each arm. After acquiring the box, the vehicle will turn around and head back towards the landing zone to complete the mission.

Power

Power for the Romeo V2 microcontroller, the 4 motors, and all of the sensors will be supplied through a 12V 2.8A rechargeable 3000mAh NiMH battery pack. The 4 servos will have a seperate power source connected to the Romeo which is a 6V NiMH 2200mAh with a continuous discharge of 2.2A. As for our propulsion system, each wheel will be powered by a DC motor (391:1 Gear Ratio, 36 rpm no load, 90mA no load current, 290 oz*in stall torque, 1.6A Stall Current). In an ideal situation, all 4 of the motors would be placed in parallel, so that if one motor were to stall the rest of the motors would be able to continue without fault. However, placing all of the motors in parallel would increase the total current which could potentially be harmful if something went wrong. As shown in Figure 5, our team has decided that it would be best to place each *pair* of motors in parallel with each other so that they operate at the same voltage and share the current. This also allows for each of the side wheels to rotate in opposite directions, creating a system for the OSV to turn. At 12V, the current draw of each motor will be 161mA, allowing for a current draw of 644mA in total for all of the drive wheels. The sensors max current draw of 200mA in supplement to our motors also creates a total current draw of 844mA. We opted for a 2.8A continuous and 5.6A burst current draw, so if 3 of our motors stall out, the battery will not be fried. According to the data sheet of the battery we have chosen for our propulsions system, the total capacity of the battery is 2948.4mAh. This indicates that the OSV should be able to run for 3.5 hours without recharging. However, this does not account for the areas of rocky terrain that the OSV will have to overcome which would result in a lower run time since the motors will need extra power to achieve the same torque. As for our mission specific actuators, the servo motors we have chosen are expected to draw 737mA for our two lifting servo motors, and 150mA for our two gripping servos as well as the orientation servo for a total current draw of roughly 1.95A. The battery chosen for the servo will continuously discharge 2.2A so, as seen in Figure 6, there will be no need for any resistors. Each input pin on the servo will be directly connected to one of the PWM digital output pins.

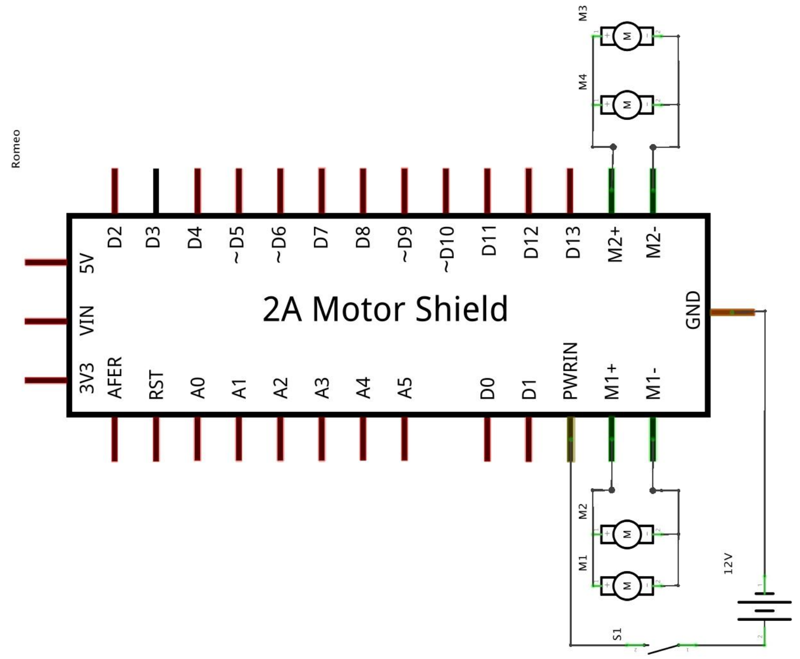


Figure 5. Wiring schematic of the 4 DC motors for the drive wheels. Two motors on each side of the Romeo V2 microcontroller will be connected in parallel in order to maintain a constant voltage.

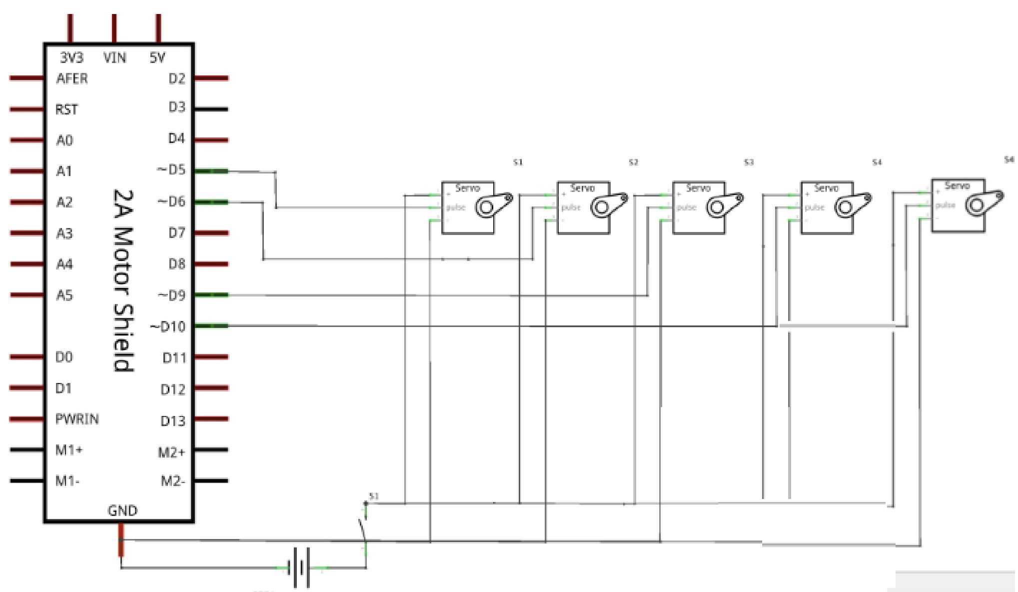


Figure 6. Wiring schematic of the 4 servos connected to the Romeo V2 microcontroller. Each servo will be connected to a PWM digital output pin in order to allow for control of the direction of the servo.

Sensors and Actuators

Our OSV will utilize three ultrasonic sensors to detect obstacles and an IR sensor to detect the black box. The ultrasonic sensors will be evenly spaced from each other on the front side of the OSV with the servos. The angling of the side ultrasonic sensors enables them to detect objects in front of the OSV's tires, eliminating a large blind spot. Also, having three sensors allows the OSV to detect an obstacle with one sensor and turn away from the obstacle in a specific direction. The ultrasonic sensors will communicate with the Romeo board using analog pins (Figure 8). The IR sensor is placed in between the two servos located on the front of the OSV. Positioned here with a funnel to limit the IR signal emitted from the OSV to a narrow physical range. Once within the range of the black box, the OSV will rotate until the IR sensor picks up the signal from the black box. The IR sensor will communicate with the Romeo board using the analog pins. The servos used to pick up the black box will communicate with the Romeo using the PWM digital pins.

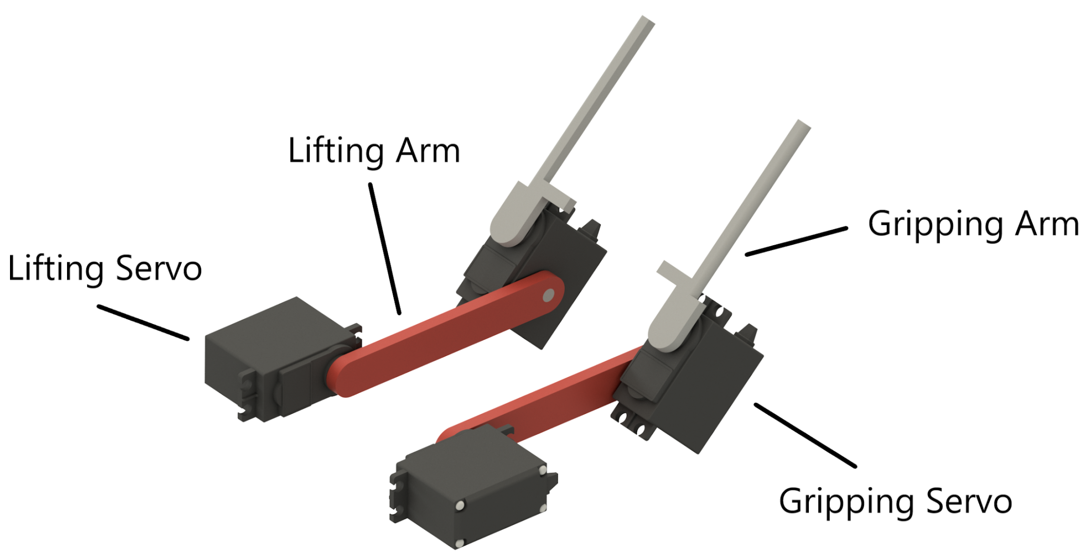


Figure 7. Labeled diagram of the OSV pick up mechanism.

In order to lift the black box off the ground, we will utilize a pair of PLA 3D printed arms, each mounted onto a servo which will allow them to move up and down. At the end of each arm is a second set of servos which will grip under the lip of the black box. The lifting arms will lower themselves in order to get under the lip of the box. Once under the lip, they will briefly clamp down as the lifting servos raise the gripping arms (and black box by proxy) until they are parallel with the ground. At that point, the gripping arms will stop applying force to the box, and the pickup mechanism is complete.

<u>Subsection 1: Justification for length of arms</u>

The lifting arms will be 9.7 cm long (Figure 7) . This length was determined based on three parameters. First, the lifting arms must be at a 45 degree angle relative to the ground while in its lowered position. This angle was chosen as it simplifies our calculations while also ensuring that the black box clears the ultrasonic sensor mounted to the front of the OSV while the arm is in an upright position. Second, the gripping arms must be extended at a height 3 cm from the ground. This is distance was chosen because it is the measurement from the bottom of the black box to the lip of the box. Thirdly, the gripping arms will be 12 cm long. This length was chosen to provide 2 cm room for error on both sides of the 8 cm base of the black box. Given these parameters, we were able to identify the components that made up the height from the base of the OSV to the ground which include the distance between . By finding the distance between the center of the servo to the arms to be negligible, we were able to calculate the length the arms must be when situated at a 45 degree angle.

<u>Subsection 2: Torque and Mechanism</u>

Taking into account that the desired torque must be for the combined strength of two lifting servos, the mass of the two gripping servos, and the mass of the black box, we were able to identify a desired torque of 31N for our lifting servos. This desired torque is conservatively calculated based on the max torque scenario — when the center of gravity of the box is directly across from the lifting servos. This situation occurs when the angle between the lifting arm and the parallel with the ground is 17 degrees. By accounting for max torque scenario, we can ensure that the lifting servos will be able to keep the black Box off the ground in all circumstances. The gripping servos will briefly grip onto the box to lift it up into the air before simply maintaining its position, essentially operating as if it has no load. This is possible due to design of our gripping arms, which have small sideways extrusions so that the corners of the black Box can be held secure without exerting additional force onto the sides of the box.

Subsection 3: Orientation and Fifth Servo

The purpose of this front-mounted, middle oriented sensor is to act as a passive object detector while traveling, and to allow us to orient the OSV in manner that allows us to lift to black box (Figure 8) . The top mounted servo will be mounted facing down in a 3D printed enclosure that sits inside of the base of the OSV. The vertically oriented ultrasonic sensor will be attached to a free spinning pole, fixed by the top servo and the bottom donut-like extrusion. With some lubrication, this will allow the top mounted servo to rotate the sensor to take distance measurements, which will be utilized to orient the OSV in a preferable position.

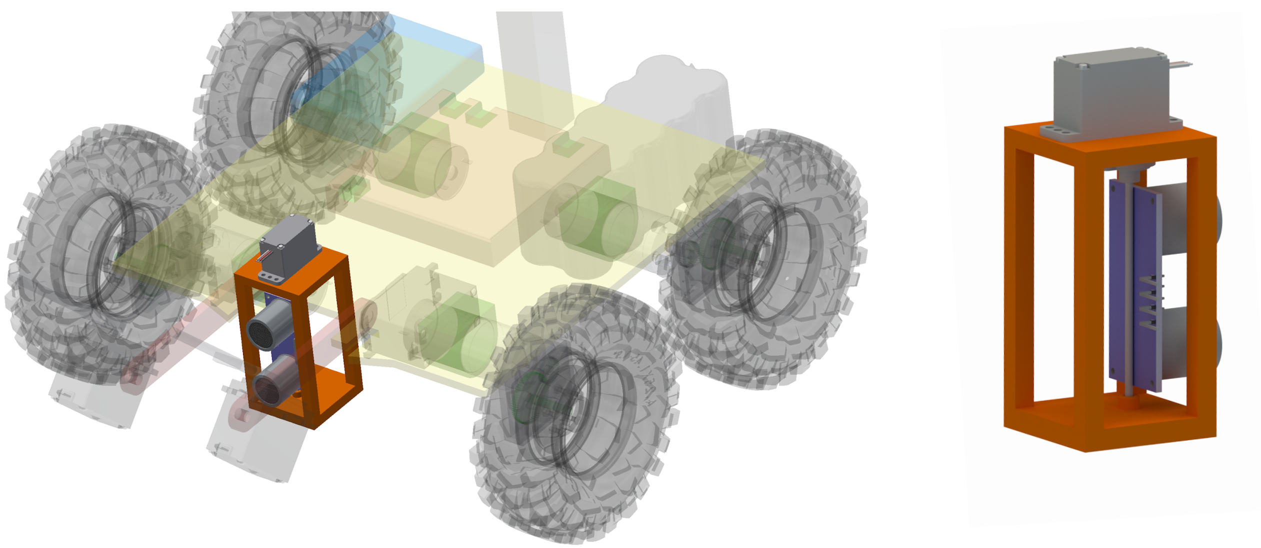


Figure 8. CAD of our middle oriented servo which will orientate the arms to

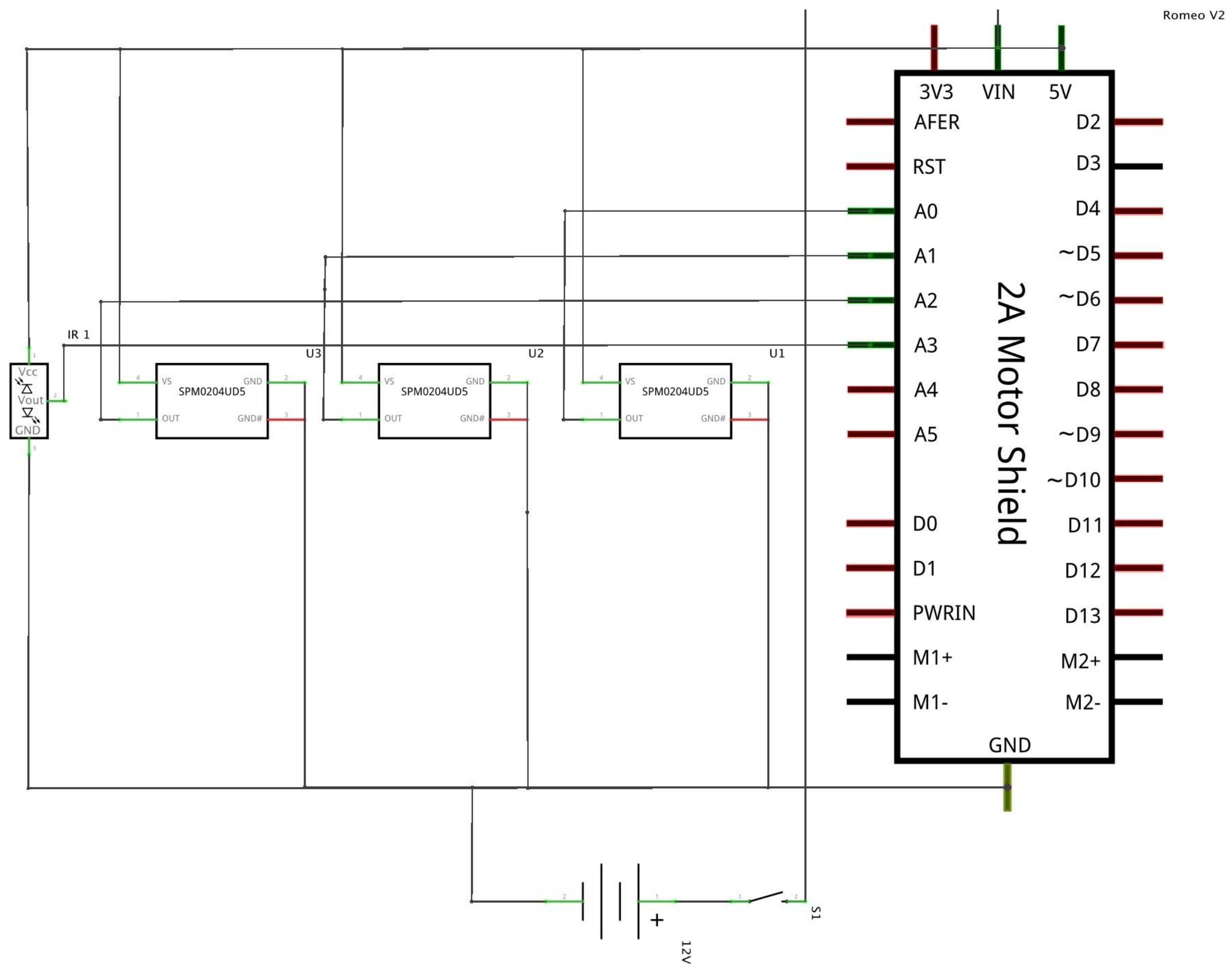


Figure 9. Wiring schematic of the three ultrasonic sensors and the infrared sensor. All of the sensors will be connected in parallel and will be connected to the Romeo Microcontroller through the analog pins.

Control Algorithm

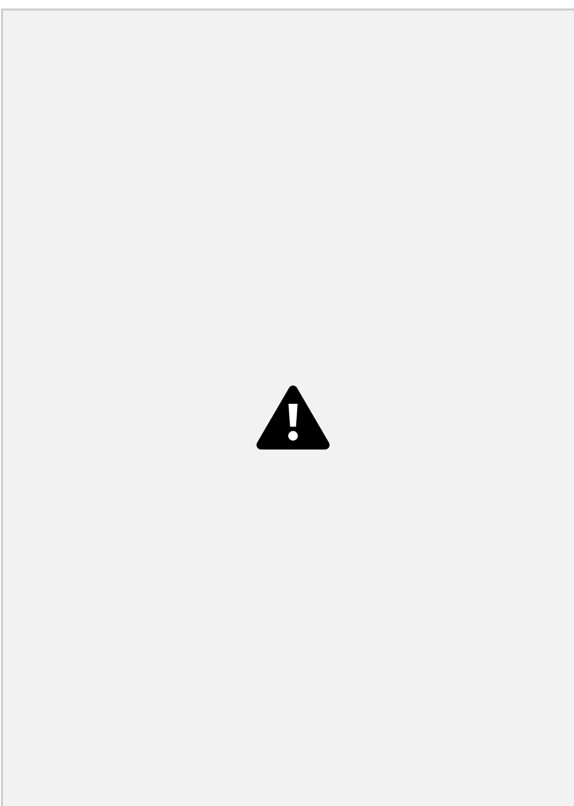
The OSV will be drop off in the landing zone and from there it will calculate the distance and the angle it is from where it is at to the center of the arena. After calculating the angle it needs to turn to face the center, it will turn to that angle to face the center and then move forward. Next it will have complete two checks, one of the check will be an object detection. The object detection will have two inputs, one input comes from the front sensor and it will tell if check if there is an object in front of it and the second input is from the two side sensors. If neither of the sensors detect an object then it will go back to the move command. If an object was detected from any of the sensors, then it will stop movement and determine the given distance away and calculate the specific angle and determine if the wall was close. When the wall is close, it will choose an angle away from the wall and continue back to the move forward command, but if it is not then it turns using a smaller angle and redo the object detection algorithm. The other check it will do will be to determine if it has arrive at the center. If it has not then it will keep moving forward and repeat the object detection step, but it has reach the center then it will move to the next part of the control algorithm.

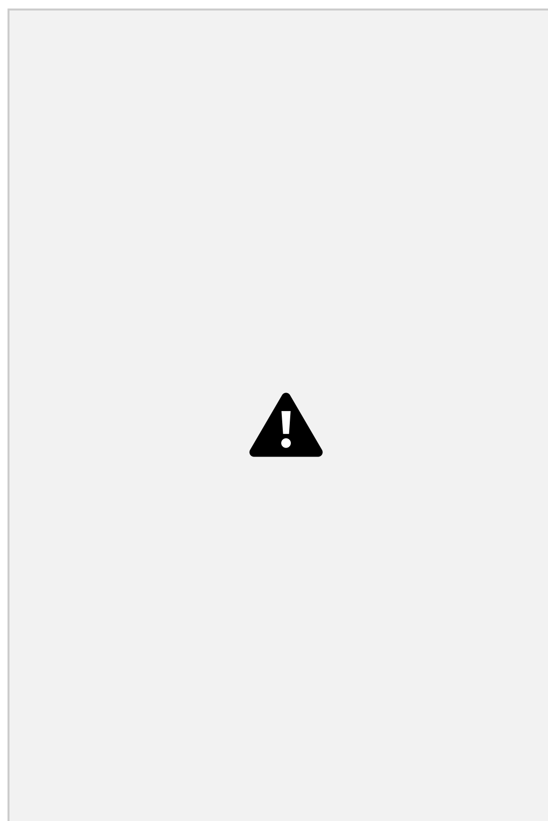
The next part of the control algorithm is detecting the black box by spinning. Once the OSV has reach the center it will input every 200 milliseconds to spin until it does not detect the black box's infrared signals anymore. It will next spin 360 degrees and record when the signal is and is not recorded. The average of the starting and ending angle will be taken and the OSV will turn toward this average angle heading towards the black box. It will continue the move forward command and object detection algorithm until it arrives at the black box location where it will begin its next set of algorithm.

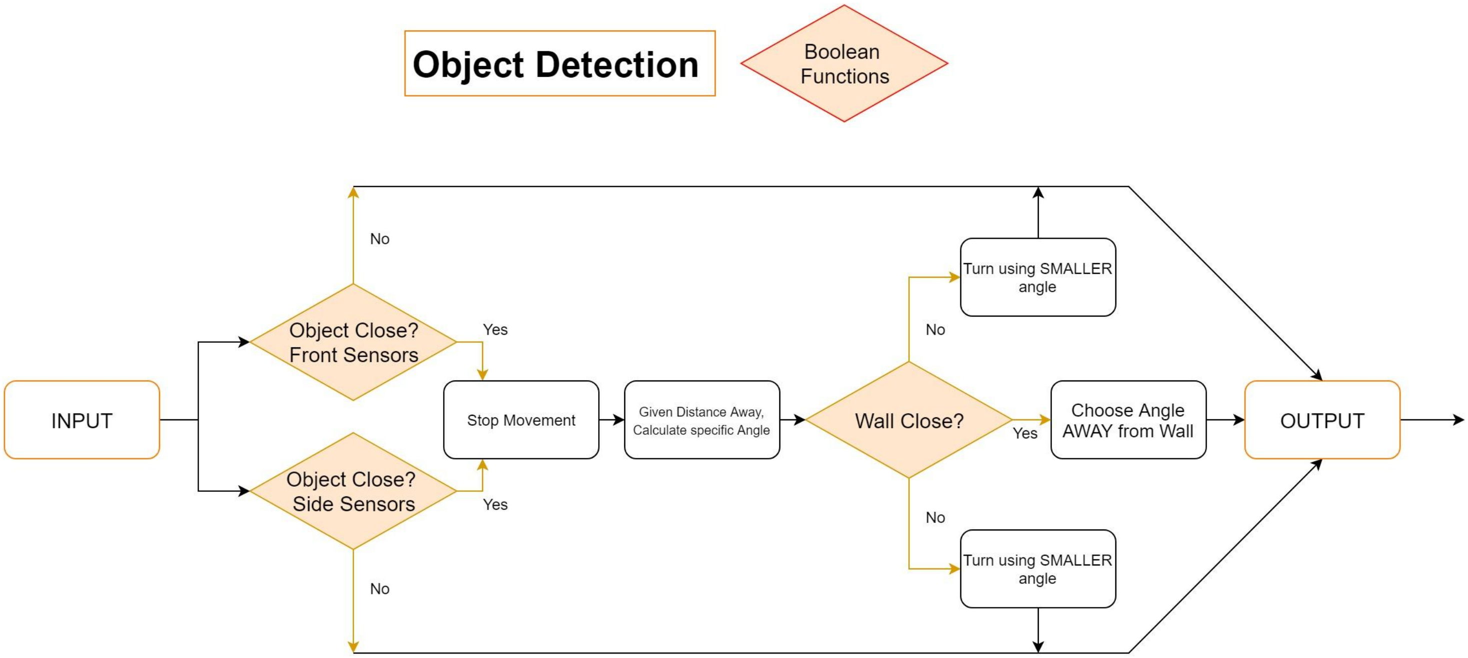
The OSV now must orient itself to the black box. With the sensor that detected the object, it will first turn left until nothing is sensed and then turn right until nothing is sensed by the sensor and find out the total angle in between where the sensors does detect an object. It will also store every distance measurement; by finding the x (left bound), the y (smallest distance), and the z (right bound). Turn sensors from left side until the smallest distance measurement is found and store the angle, and do the same from the right side. Then compare the two angles to find the smallest angle to determine if x=z. It will determine if x is greater or less than z and if x>z, then calculate the angle to turn with the equation 90-cos^{-1} [(x*ycos(θsmallest))/side length of the black box] and calculate the distance to travel with x*sin(θcalculated) or if x<z then calculate the angle to turn with the equation 90-cos^{-1} [(z*ycos(θsmallest))/side length of the black box] and calculate the distance to travel with (longer side: x or z)*sin(θcalculated). Then move this distance and turn 90 degrees toward the black box and start the Orienting to black box algorithm again. But if x does equal z then check if x*cos(θ) = y and if z*cos(θ) = y, if yes use this as the

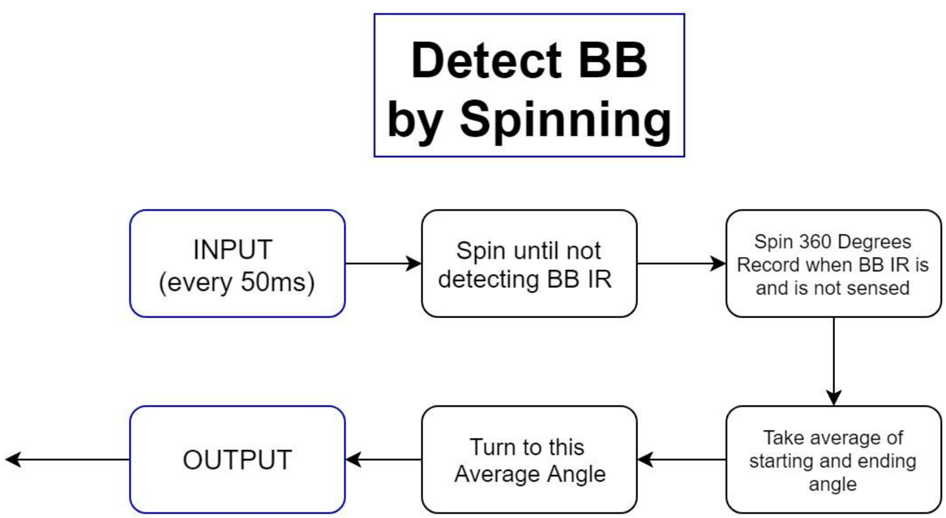
output, but if it does not then use the x or z equation and follow the same step as when x does not equal z after their calculated angle to turn when determined.

After the OSV has oriented itself with the black box, then it will move to pick it up. The input will be every 200 milliseconds. The OSV will deploy its arms by lowering from its upright position all the way to the sand and then raise it up 2.5 centimeters. The arm will move until they are underneath the black box's lip and lift its arm slightly (10 degrees above normal) to determine if there is any resistance by measuring how long it takes to lift it up 10 degrees. If there is no resistance then it will lower its arm by 12 degrees and backup 10 centimeters and measure its distance away from the black box and move its arm underneath the black box again and repeat the test for resistance. When it encounters resistance, then the arms will lift the black box to 45 degrees above the normal. The OSV will turn toward the landing zone, utilizing the object detection algorithm again, until it reaches the landing zone, where it will lower the black box.

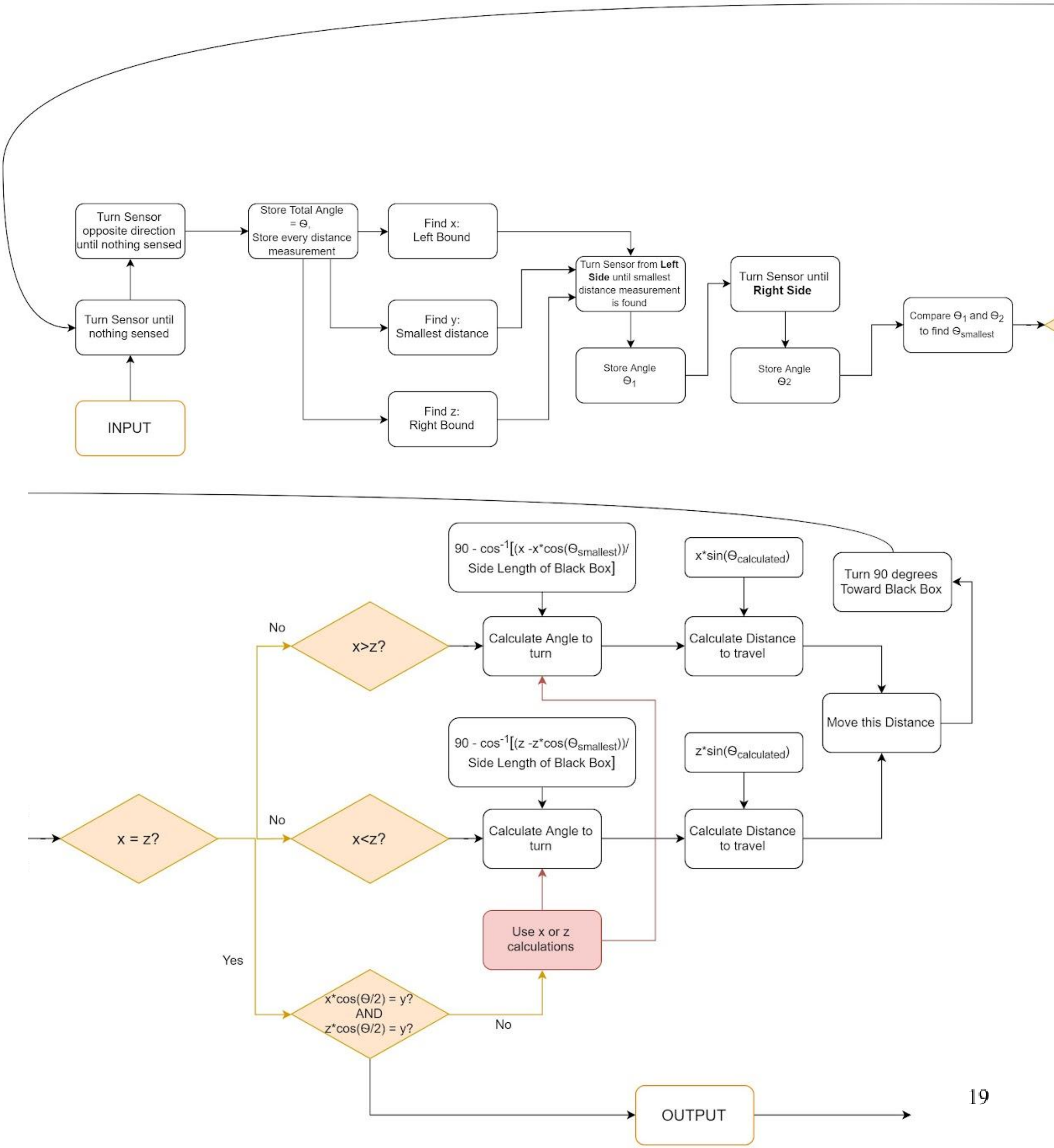


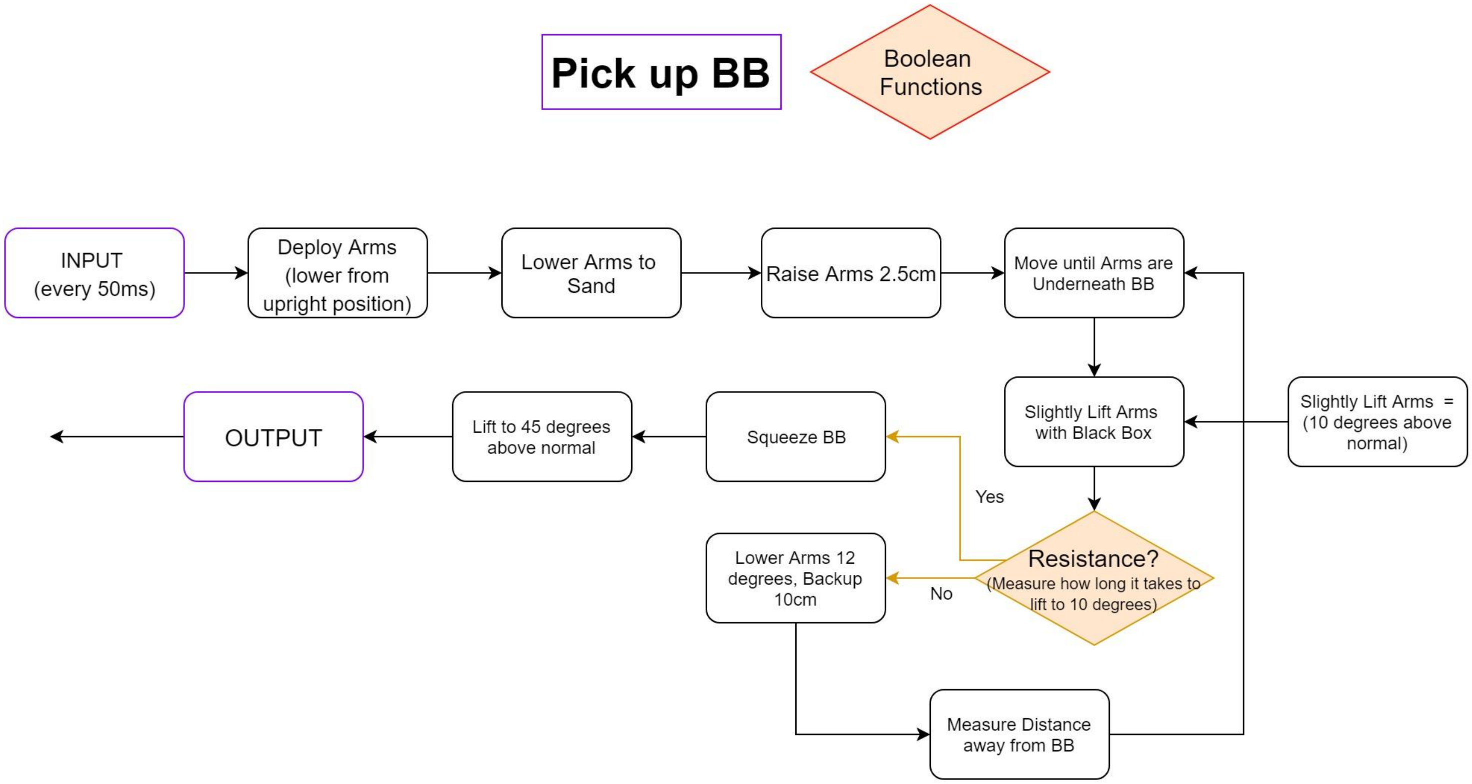


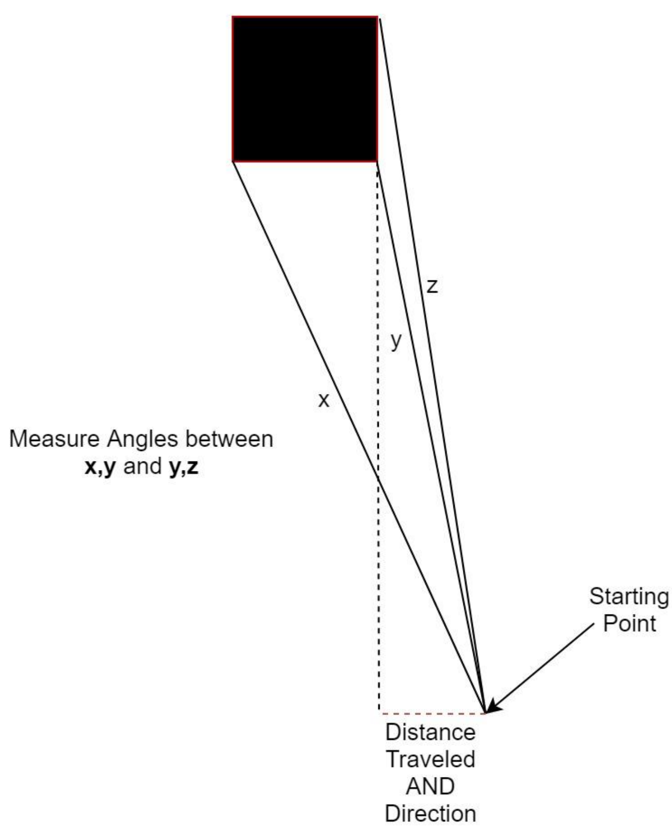

Object Detection
Boolean Functions
INPUT
Object Close? Front Sensors
Object Close? Side Sensors
No
Yes
Yes
No
Stop Movement
Given Distance Away, Calculate specific Angle
Wall Close?
No
Yes
No
Turn using SMALLER angle
Choose Angle AWAY from Wall
Turn using SMALLER angle
OUTPUT


Detect BB by Spinning
INPUT (every 50ms)
Spin until not detecting BB IR
Spin 360 Degrees Record when BB IR is and is not sensed
Take average of starting and ending angle
Turn to this Average Angle
OUTPUT

Orient To Black Box




Pick up BB
Boolean Functions
INPUT (every 50ms)
Deploy Arms (lower from upright position)
Lower Arms to Sand
Raise Arms 2.5cm
Move until Arms are Underneath BB
Slightly Lift Arms with Black Box
Slightly Lift Arms = (10 degrees above normal)
Resistance? (Measure how long it takes to lift to 10 degrees)
Yes
No
Squeeze BB
Lift to 45 degrees above normal
OUTPUT
Lower Arms 12 degrees, Backup 10cm
Measure Distance away from BB


z
y
x
Measure Angles between **x,y** and **y,z**
Starting Point
Distance Traveled AND Direction

Preliminary Bill of Materials

Items	Cost	Manufacturer	Description
APC220	$ 26.44	QixinStar	Radio communication module
Wheels (4x)	$ 24.43	RC-Hub	Wheels for OSV
Infrared Sensor	$ 7.49	Vishay	Detects black box frequency
Romeo Microcontroller	$ 31.99	DF Robot	Programmable microcontroller with h-bridges
Ultrasonic Sensor (3x)	$ 16.14	SainSmart	Distance sensor
Battery (12V)	$ 24.99	Tetrix	Battery for motors/sensors
Forklift Servos (4x)	$ 31.80	Pololu Robotics	Regulates movement of forklift
Forklift Arms (2x)	$ 8.00	3D printing	Enables forklift to pick up black box
Battery (6V)	$ 15.15	RobotShop	Battery for servos
Motors (4x)	$ 91.80	Pololu Robotics	290 oz*in stall torque, 1.6A Stall Current
Gearboxes (4x)	$ 10.00	3D printing	Transmission for OSV
Wiring & Housing Units	$ 10.00	3D printing	Covers for wires
Wood Base Plywood	$ 10.48	Midwest Products	Wooden base for OSV
Hex Wheel Adapters (4x)	$ 7.90	Pololu Robotics	Screws to attach things to base
Gearmotor Bracket Pair (2x)	$ 14.90	Pololu Robotics	Mounting for gearmotors
Total:	$ 331.51		

Project Management Plan

In our construction phase, we envision three distinct stages in which we complete physical construction of the preliminary base and layout, propulsion system, and sensors. The estimated date of completion for these components are October 22th, October 26th, and November 2nd respectively. The completion status of these tasks are managed in the Build Phase Gantt chart, and the members of the team assigned to each part of the building process are directly responsible for that task getting completed in a timely fashion (although other members of the group can help with the assembly).

The date for the base and layout task is the first that we have set for ourselves because it is the easiest and least error prone task that we will accomplish, and will most likely not need much trial and error after building the original design. The propulsion system is our next assigned building task as this is a level up from the base and layout task, but is also something that we can accomplish during the week after we've made the base. The servo construction phase is the most complex and error prone, and also relies heavily on how the other parts of the system are operating, and therefore is the last task that we have outlined in the Build Phase of the Gantt Chart. Even though it is due last, we have still allocated enough time for the servo build phase to deal with any issues that will most likely arise in our implementation of the current design.

After a task is completed, it is crossed off in the shared Gantt chart by one of the members of the group that has completed the task. This ensures that everyone in the group is up to date on what still needs to be done by when, and what has already been completed when it comes to building.

Construction and Testing Plans

Construction on the OSV will being on Monday, October 22, 2018, when all preliminary materials are purchased and ready to use. The team will be divided into two subteams, one focused on the actual construction of the OSV vehicle body, and another group that will be focused on the programming code for the OSV's movement. The programming team will be composed of three people, whereas everyone else will be in the construction team. In regards to 3D printing, one person will be designated to 3D print the arms, either during class hours, or during other available hours. In terms of the three construction stages that we will need to complete, the construction team will start by building the base and connecting the motors to the wheels, using hex adapters and motor mounts. Once that is finished, and the propulsion system is added, the team will test the propulsion of the OSV vehicle, before adding the sensors and actuators. Once the full vehicle is constructed, the team will test the sensors and actuators, to make sure they work. It is estimated that propulsion testing and adjustment will only require a few days, so that if there is a need to change the design or buy new materials, there is enough time to do so without having to rush the rest of the construction process.

Anticipated Difficulties

A setback that the team may come across while making the OSV is that the 3D printed parts may be too brittle or not working properly. To deal with this issue, the 3D printing process will be started as soon as possible so that there is enough time to make multiple revisions if need be and to also get help from any of the lab teaching fellows. Disagreement over the design or the process for how the OSV will be put together might occur especially if something does not go well, but this can be resolved in a mature and orderly fashion through a majority vote since the team is composed of an odd number of 9 members. The team also has to take into account the possibility that the 3D printed arms cannot orient themselves around the black box, but this can be solved by adjusting our orient to the black box algorithm to allow the OSV to have a greater scope of navigation that will allow it to have a smaller margin of error. Another challenge that may come up is that there is a chance of the black box falling off of the OSV while returning to the Landing Zone, so the team has decided on an idea that involves increasing the angle of the servo arms so that the black box will lean into the OSV.