F.R.O.G. & F.L.Y.: Field Retriever Outdoor Grandpa & Frequently Lost Youngster

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Figure 1: F.R.O.G. & F.L.Y.

Abstract

Events in robotics history have raised the challenge of how to rescue disabled robots. Our team decided to research and try to answer this problem. One application of this is when a robot is stuck in an environment where a person can not find and retrieve the robot, such as in toxic atmospheres or difficult-to-reach places, the surface of Mars for example. At this point in history, no one could go and retrieve the robot, so we would need a way to do this autonomously. Our inspiration came from the European-Russian Mars Schiaparelli Lander, which crashed on the surface of Mars after losing communication with the team. With our project, we are exploring the beginnings of autonomous retrieval, which could be used to solve problems similar to this. Our project consists of two fully-autonomous robots, one in the 4kg category and one in the 1.5 kg category. These robots will navigate the sand dunes and all of the obstacles that come along with the challenge. The larger robot will use a detachable retrieval system, to recover F.L.Y., which will be stranded in a pit to simulate system failure. We have gone through several design changes and have ultimately decided to use a detachable arm system using a Pixy2© camera to detect the disabled robot and have the arm raise the robot via an electromagnet. We are excited to be working on this task and hope that our project not only challenges us to grow in our knowledge of autonomous robotics but that it also challenges others to experiment with autonomous retrieval.

Inspiration

This project idea came from the European-Russian Mars Lander, the Schiaparelli Lander. In 2016, the Schiaparelli Lander entered the atmosphere of Mars. The team lost the launcher's signal before the lander touched the ground. Without the communications systems, all knowledge of the landing and aftermath was lost, and there was no proof of survival. This is not the only time a situation like this has occurred. There are other robots that have failed, and are stranded on Mars's surface. This has led our team to attempt the construction of an autonomous retrieval system, to explore this problem and begin the creation of a tangible solution to retrieve robots stuck in inhabitable environments.

Materials and Methods

There are three major aspects of our project: our retriever robot F.R.O.G., our retrieval system, the Frog tongue, and our rescuee robot, F.L.Y.. Our robots will each be able to autonomously navigate the courses at the COSGC Robotics Challenge at the Great Sand Dunes National Park. As an additional challenge, the detachable Frog tongue that is mounted on F.R.O.G. will locate F.L.Y. and rescue it from a pit.

F.R.O.G.: Our Retriever

F.R.O.G., the larger of the two robots, currently weighs 3.34 kg, without the Frog tongue. The remainder of the 4kg limit will be used for the retriever and the necessary counterweight needed for the retrieval challenge.

Building

The retriever robot body is cut from sheets of acrylic material, using Fusion 360 to make the template using a GlowForge laser cutter. The acrylic pieces were glued using Cyanoacrylate Insta-Cure glue. The first Retriever, had poor structural integrity, and did not survive testing. The angles on the front of the robot required more support, and the joints would detach after being glued, and the shaft holes were uneven. The retriever body needed to be remade due to the lack of care in its construction.

After revisiting the new design, new mechanical drawings were made with alterations to the hole placement for motor shafts and axles. A new body was cut from acrylic, and the team made sure all of the holes were drilled in the correct places. The new body was assembled by using a fast set acrylic solvent cement that was better suited for keeping the acrylic together. The new design allows for the robot to run both right side up and upside down; in addition it can better accommodate the gear chain system. The original plan was to use a hinged lid design, but the team decided to switch to a sliding lid because of its practicality. The structure of our robot includes a gear chain system that is separated from the electronic components using an acrylic divider. Originally we planned on using a worm gear system, to limit the power of the drill motors. After some testing, the team realized that the mass of the drill motors was adding too much mass to the robot and switched to vex motors to conserve that mass.

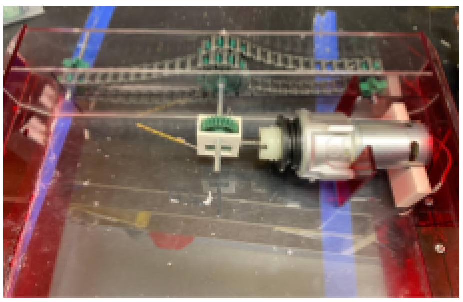

Figure 2: Original F.R.O.G. body with drill motors and worm gear system.

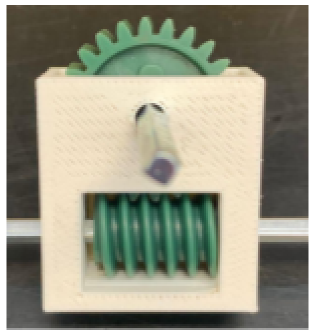

Figure 3: Worm gear system

Figure 4: Drill motor vs Vex motor

While making this change, we also switched to a 6:1 gear ratio. This gear chain ratio would work better with Vex motors, especially since we did not need to limit the power as we did with the drill motors. One thing special about our F.R.O.G.the 6 infrared (IR) sensors. Usually we use 3 IR sensors for the purpose of detecting pits, but these additional IRs allow F.R.O.G. to navigate while upside down.

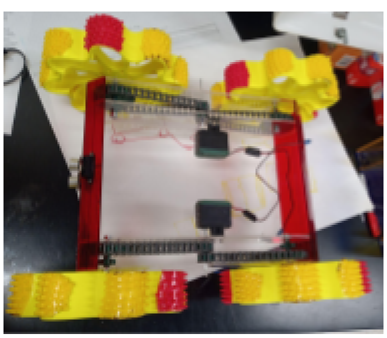

Figure 5: 6:1 gear chain system with Vex motors

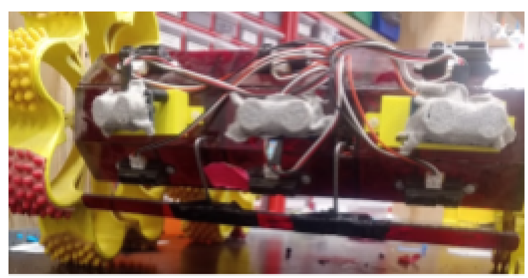

Figure 6: 6 Infrared Sensors for navigation both rightside up and upside down.

3D Design

The panels for our robot body were designed using Fusion 360 to create dxf files, and then cut out using a Glowforge CNC laser cutter. Our wheels for F.R.O.G. were taken from the design of TSC's Sable 2016 robot. We adjusted them to be slightly larger in diameter to work better with this year's design. This adjustment adds more clearance for driving over rocks, and through the sand. The larger diameter also improves F.R.O.G.'s ability to work both upside down and rightside up. After the adjustments the wheels were printed in ABS material on the UPrint SE plus 3D printer. The PING)))™ mounts were taken from last year's design and reprinted using Fusion 360.

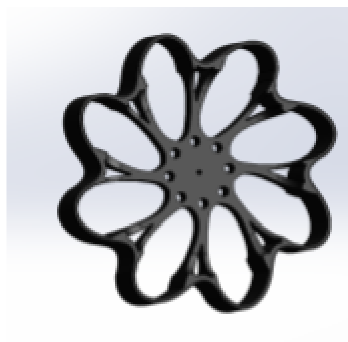

Figure 7: F.R.O.G. retriever wheel design

Electronics

Our circuit board is a double-plated through-hole board, which includes a micro:bit, Propeller Flip controller, and an AD converter. F.R.O.G. makes use of 6 IR sensors, 3 PING)))™ sensors, 2 bump sensors, 1 Sparkfun compass, 2 Vex motors, and a motor driver to control the power going to the motors. Our robot is powered using a Thunder Power RC 55c 3 cell 11.1V lithium polymer battery.

The circuit board for both of our robots was designed using DipTrace, an electronic design automation software that is used to create schematic diagrams. There were two original ideas for the circuit board, one of which was a more compact design, used to save space in the robot body. The other idea was a board that was more integrated with F.R.O.G.'s systems, making it easier for all of the sensors to be connected to F.R.O.G.. We decided to go with the board that was more integrated into the robot, because it would make connecting everything smoother and we had plenty of space in our large robot.

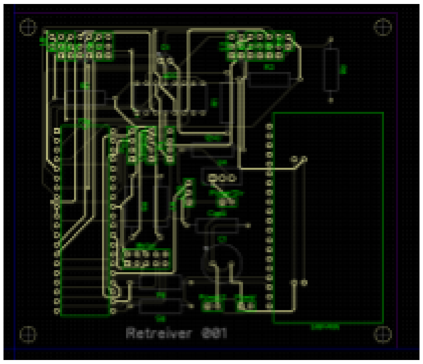

Figure 8: Circuit board design for both robots.

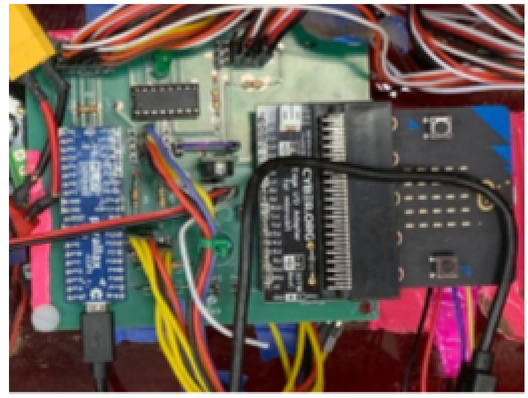

Figure 9: Circuit board mounted in F.R.O.G.

Programming

Our code is written in Propeller C, this language was chosen because of its capability to run different cogs at the same time. One of the cogs is set aside for our main program which runs the navigation. When F.R.O.G. begins its navigation program, it waits for a signal to say that the bump sensor has been pressed.

The robot then checks the infrareds to determine if there is a pit to avoid. If the infrared sensors are triggered, the robot will stop, then back up, and turn in the opposite direction of the triggered sensor. The infrareds use a threshold to determine if there is a pit or not. Our threshold is at 9 centimeters. If a reading is beyond the threshold value, then that triggers a pit detection. This threshold will change in relation to the roll and pitch of the robot. The roll is how much the robot is tilted side to side, and the pitch is how much the robot is tilted front to back. When the robot is upside down it reads the top infrareds, and while right side up it reads the bottom IRs. The accelerometer Z axis reading determines if the robot is upside down. A level pitch reads 100. If the pitch is greater than 50, it determines it is rightside up, and if than -50, it determines it is upside down. When the robot is navigating upside down, all functions in the program are inverted from when the robot is rightside up, for example if the robot would turn right when rightside up, if upside down it would turn left. The only code where this does not apply is the compass code. This is due to the fact that the compass corrects the degree angle if it is upside down, meaning there is no direction correction needed. If the pitch or tilt is greater than 17, for 400 loops of the navigation function, then the robot determines that it is high centered. The robot will then shut off the wheels on the right side, and run just the wheels on the left side. It will do this for 5 loops to try to dislodge itself and then switch to the other side and repeat the same thing. After that, the robot will start driving backwards and turn in a random direction to continue on with its navigation.

The next step is to check the ultrasonic PING)))™ sensors for walls. The PINGS)))™ have a far threshold of 40cm, and a short threshold of 30 cm. If both the right and left PINGS)))™ see something within the close threshold, the robot will back up and go in a random direction. If one side is triggered, the robot will back up and turn in the opposite direction of the obstacle. If the middle PING)))™ detects an obstacle farther out than the close threshold, but within the far threshold, the robot will simply turn in a random direction to avoid the obstacle. The PINGS)))™ only back up if the middle one is triggered or if the robot is really close to an obstacle. If not, it will just turn away from the perceived obstacle.

After this, the compass is checked. This tells the robot if it is going in the correct direction or if it needs to make a correction. The programmers set a desired heading and, the robot will decide if turning left or right will get it there quickest. The program checks the compass every 7500 milliseconds the program runs. The compass will only be checked, if the robot is close to level. If the robot is tilted too far in any direction, the compass will not be checked.

After the robot checks the compass, the tilt sensor is checked to make sure the robot is not high centered. If this goes well the program tells F.R.O.G. to go forward. This sequence then repeats until the course is completed.

Parallax's Flip microcontroller uses 8 cogs (or brains). The first cog or mastercog is constantly getting values from the compass, and the accelerometer. This is to make sure that the robot is going in the correct direction, and is not tilted too far in any direction. The z-axis value determines if the robot is upside down and navigation needs to be employed. The second cog is always checking the PING)))™ values. Since these are ultrasonic sensors, the data takes longer to get back to the robot than any of the other sensors. Having the PINGS)))™ constantly checked in this cog allows for the program to run faster and not interfere with other tasks. The third cog is a millisecond timer cog. It keeps track of how long the program has been running in milliseconds. This is used to determine when to check the compass for a correction. If there is something detected through either the PING)))™ or the infrareds, this timer is reset to a lower value so that F.R.O.G. will not attempt to correct too soon after running into an obstacle.. The fourth cog holds our main navigation program, which tells the robot which direction to go and how to avoid obstacles. We also have separate cogs for the Pwm motor driver, which is running the motors for F.R.O.G.. The Full-Duplex Serial has a cog to keep communication with the small robot using a UART system, however this is not currently in use. The final cog is for our servo commands, which run our motor for the retrieval system.

Frog Tongue, Retrieval system

The retrieval system was our biggest challenge this year. Inspired by the Schiaparelli Lander, we came up with the plan to have F.R.O.G. rescue F.L.Y. from a pit at the Sand Dunes challenge. The first idea was a scoop at the end of the arm to pull the robot out of the sand. This was rejected because there were concerns about the scoop and robot dragging in the sand and hindering the retrieval. Another idea was to deploy a net with a bar attached to the bottom; the bar would be attached to a winch system inside F.R.O.G.. In this design, the sand would be able to fall through the net without causing resistance as F.L.Y. was being retrieved. We realized that with the net based retrieval system we could only get the robot out of the net using human intervention. After further consideration, we had the idea of using an electromagnet to retrieve the robot. We switched to this plan because it allowed us to detach the robot from the retrieval system easily and reliably. While researching the best electromagnet to use, the team rigged a temporary trial system to a previous year's robot to test the magnet system. This prototype of the electromagnetic system consisted of a yardstick attached to TSC's 2019 GRIFFIN, it used a drill motor to reel in a paracord line tied to S.C.O.R.P.I.O.N. from 2022. While the concept worked great for lighter test loads, heavier loads required a counterweight. This necessitated reorganizing the internal components to put as much weight as possible near the back.

Figure 10: Prototype Retrieval System

Soon after this mostly successful test, the retrieval team created the actual retrieval arm. This arm consisted of two thin, three-walled aluminum pieces facened together in the middle by a wooden block. On the back of the arm, we mounted a square piece of acrylic material with a cutout for our drill motor. Spooled on the shaft of the drill motor is the paracord casing, that has been hollowed out and then threaded with wires to power the electromagnet. Through testing we discovered that the electromagnet has the capability to lift and hold 1.5 kg. At the end of the aluminum shaft is a 3D printed mount for the Pixy2© sensor made from ABS material.

Figure 11: Retrieval arm with drill motor.

The Pixy2© sensor is what scans for the disabled robot, by checking for certain colored boxes in an area of 300 pixels by 200 pixels. The Pixy2© then returns the coordinates for the center of this box back to the program. The Pixy2© sensor assigns signatures to each of the different colors that it sees, and we are specifically looking for the pink plate on F.L.Y.. The Pixy2© sensor detects blocks of this color and chooses the block with the greatest area. This is done because the Pixy2© tends to see boxes that aren't the ones we are looking for. It checks to see if the area of color is greater than a certain threshold. If it is less than the threshold, it's not seeing any boxes or it's not seeing the correct ones. If the Pixy2© does not see a large enough box, the robot will go forwards a little bit and check left and right for boxes. Once it finds a reasonably sized box it adjusts itself to see if the box is in a specific set of the Pixy2© sensor's coordinates.

When the Pixy2© aligns the magnet with the plate on the F.L.Y., it will activate the electromagnet, and drop it to attach to the metal plate on F.L.Y.. It will then raise the magnet a small amount so the Pixy2© can check to see if the area is larger, meaning the robot is closer, it will repeat this until the area is larger than a threshold. Once the small robot has been rescued. Then F.R.O.G. will rotate 180°, and power down the magnet. F.L.Y.'s programming will note the change in position and resume navigating.

A bit later on in the project we realized that F.R.O.G, with the retrieval system, would be over the weight limit for the Sand Dunes Challenge. The decision was made to use a Vex Motor instead of a drill motor to save weight, since the vex motor could also lift the small robot. The retrieval system receives its instructions and power from the circuit board of F.R.O.G.

Figure 12: Updated retrieval arm with Vex Motor

F.L.Y., Rescuee Robot

Design

F.L.Y.'s design was modeled after the 2022 TSC S.W.A.R.M. robots. To make the modifications to improve our design, we examined what didn't work last year. Some changes we needed to make included a higher clearance, improved placement and design of the infrared mounts, motors, the bump sensor, and the internal placement of all of the electronics in the robot. Last year's crowded placement created many sensors and boards getting shorted out.

Starting with the robot body we created a preliminary design. Gathering the list of electronic components, our first body included front holes for the PING)))™ mounts and Infrared mounts. It also included holes on the side for placement of the switch, fuse, and battery testing terminals. At this point, we were unclear which motors would work best, our most likely options were Vex motors which were too big and heavy, the motors from last year which did not have enough torque. Or new motors similar to the ones from last year, would have to be ordered from abroad. Testing indicated that the motors from last year, with upgraded gearing, worked with our robot. They were lighter than the vex motor option, and functioned better than the other new small motors. We also had an ample supply of the motors from last year because we bought a 200 pack. After that, we modified the body of the robot to fit the electronics comfortably with no chance of crossing wires. A battery mount was positioned in the center, using a basket design, and a motor driver mount added to the side wall. Infrared hole sizes were enlarged on the front and moved the switch, fuse, and battery testing ports were moved to the back of the robot to avoid interference with the wheels. The circuit board was mounted on the bottom of the lid to save space and make the board easier to access. On the lid of the robot, we added a mount for the bump sensor, which connects to an arm that hangs over the front of the robot. Last year's bump sensor only detected obstacles that hit the very front middle of the robot. A new modification was to add wire whiskers extending from the bump arm to the outside edge of the wheels to detect more obstacles. External motor mounts placed under the body add more clearance. With this, we added holes on the bottom of the robot for wires to the motors. That snake inside and connect to the circuit board.

Figure 13: Small robot body

Figure 14: Bump Sensor

Electronics

F.L.Y. uses the same circuit board as F.R.O.G.. Connected to this circuit board are 2 IR sensors, 2 PINGs)))™, a bump sensor, 1 compass, 4 motors, and 1 motor driver. F.L.Y. is powered by an E-Flite 3S 11.1V 300mAh lithium polymer battery.

Programming

F.L.Y. starts by initializing all of the sensors. It immediately checks the compass to make sure that it is going in the correct direction, after which it reads the other sensors to make sure that there are no obstacles in each path. If the robot does not sense any obstacles, it will move forward while repeatedly checking all of its sensors. If there is an obstacle, the robot will back up and turn slightly, then go forward again and repeat until the path is clear. During the retrieval process, the small robot will read the compass while it is in the pit, to get a reading of which direction it is facing. After the large robot picks up the small robot it will make a 180° turn. 15° before the robot is back at the starting direction the small robot begins a 1500 millisecond countdown. After that the small robot begins navigation.

Testing

Our team is currently in the testing portion of all aspects of our project.

F.R.O.G., Our Retriever

Initial problems included the compass not working, the robot stalling out in a turn, and sand getting inside the robot body. To fix this, the building team tried gluing and filling in any seam that sand could penetrate. The programmers needed to find appropriate thresholds for all of the sensors and then test those thresholds and make sure the sensors were detecting properly. Numerous tests were needed to fix the infrareds for both robots to make sure the robots did not give false pit detections on slopes, as well as making sure that pits were being detected correctly. While the testing process had many ups and downs, F.L.Y. eventually navigated around obstacles.One thing discovered was that the retrieval system on top of F.R.O.G. was over the weight limit. Making the bump sensor lighter was one way to fix this. Our original bump sensor was made using brass, however that was too heavy of a design to work within our weight limit, so the team began redesigning the bump sensors to make it lighter. The next attempt used a 3d printed bump sensor system but in testing found out that it was too brittle and kept breaking. The team is currently working on an acrylic piece attached to a metal hanger. Sofat this works for the robot. In testing F.R.O.G. it was necessary to cut out some of the original plans. For example, the UART system for communication between F.R.O.G. and F.L.Y. during the retrieval process. The original plan also used both the micro:bit and the Propeller C flip controller, but at this stage, none of the code is written in Python. We were going to originally use the micro:bit for the compass, tilt sensor, and an LCD screen to show what the large robot was doing without needing a computer. We decided to not use the micro:bit's compass because it requires manual recalibration every time it is used, or reprogrammed. The tilt sensor was very inaccurate on the micro:bit. It worked fine until it was placed in a jiggling robot.

Figure 15: Upside down testing

F.L.Y., Rescuee robot

Numerous problems came up in F.L.Y.'s testing. During the navigation testing, F.L.Y. fell into pits because the infrared mounts were at the wrong angle to accurately detect those pits . This began a long process of designing proper infrared mounts. There were six different versions of the infrared mounts, over the course of that redesign, the team slowly added holes for each of the different wires, improved the method of mounting the sensors, and - the most important change - modifying the angle of the IR mount from 30° to 60°. This gave the IR sensor a clearer and more accurate field of view.

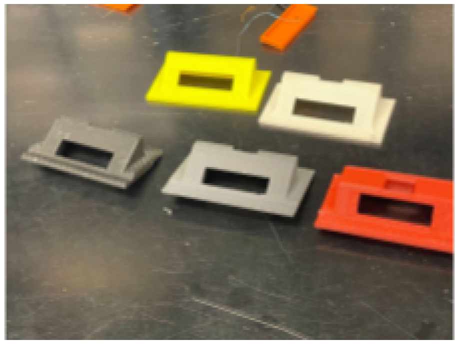

Figure 16: Evolution of infrared mounts

Another issue was the bump sensor. Because it was a bar going down the front of the robot, it would detect any obstacle if the robot hit them head on, but there were issues with the bump sensor not detecting an obstacle if the robot came in at an angle. The team decided to fix this problem by using wire from some coat hangers to make “whiskers” for our bump sensor. This helped it to catch a wider range of obstacles.

Figure 17: Picture of F.L.Y. with new bump sensor

Later testing of F.L.Y. ran into a different problem; sand getting into the motor mounts of the robot and inside the motor gearboxes. To fix this problem, the team decided to use heat shrink tubing around the gearboxes to try and sand-proof them. During the testing in the sand pit, the wheels kept falling off of the robot. To fix this, the wheel and the axle were held together by jumper wires running through the wheel and through the axle, making it nearly impossible for the wheels to fall off. The wheels also interfered with the field of view for the IR sensors. The wheels were too far forwards on the robot. To fix this, the team had to rework the design and move the motors slightly back on the robot slightly enabling pit detection at an angle.

One of the most recent changes to F.L.Y. because of testing was implemented another new and improved wheel design. The wheels were made slightly larger, wider, and with thinner spokes or wells. With the larger wheels also came better traction in the sand. The width modification to the wheel to prevent the robot from digging itself into the sand as often because it increased the surface area in contact with the sand. The wheels were redesigned with thinner walls to save on weight and add more flexibility and suspension to the robot. A parabolic concavity was added to the the wheel spokes to cut down on weight and prevent sand from building up in the wheel spokes. More traction nubs were added to the outer edge of the wheels to increase traction. The wheel treads themselves were redesigned with a wave forward design to help better grip the sand and rocks. Multiple versions of these wheels were created over the course of this year, starting with a very basic and rigid wheel. This design was very heavy due to the large size and thick walls. As the year progressed, we ended up with the previously mentioned wheel design.

Figures 18 and 19: Old small wheel design (left) New small wheel design (right)

Frog Tongue, Retrieval system

In testing the Frog Tongue, numerous difficulties arose, one of the most problematic was that the wire inside the paracord was too thick for the arm to be able to reel in the electromagnet without getting stuck or snarled.Switching to 30 GA silicone wire allowed for less tangling and the system worked. Another challenge was getting the cord to spool on the motor shaft. The retrieval team originally had the idea to base the system on a tape measure. Upon opening one up however, they noticed that the shape of the metal was what allowed the tape to coil up. In order for the arm to work, the team needed to redesign something that would do the same thing but with string. A retractable dog leash came to mind. The team bought one, took it apart to inspect the internal mechanism, and then tested it out with our retrieval arm. It worked out really well. Testing the autonomous part of the retrieval system came next. After tweaking the code and attempting to get the magnet to pick up and drop the test robot, everything seemed to be going well. There are still numerous issues getting the Pixy2© sensor to decipher where it should drop the magnet, and the robots are not able to communicate with each other during the retrieval process due to lack of time for testing this component.

Figure 20: Retrieval Testing

Results

Through much testing, testing, and more testing, the team has managed to make immense amounts of progress towards autonomous retrieval. While there is still more to do, the two robots are mostly prepared to persevere through the challenges set in front of them. Learning from previous years, the small robot design is a vast improvement. The design of the bigger robot with its capability to navigate flipped upside down was a goal met. The team has also had fun and learned quite a bit about the dynamics of autonomous retrieval.

Conclusion

While the process of completing the project is still continuing; hopefully everything will work by the Sand Dunes challenge. The autonomous retrieval concept is still progressing for this team, we have created two functioning autonomous robots and a retrieval method that will function with minimal outside assistance. Even though our time management could have been better, we have definitely had great successes and learning. With more time and research the autonomous retrieval idea will hopefully spur future teams to continue this process.

Discussions

Even with all of the delays and mistakes that we have made throughout this year, we have made quite a lot of discoveries and have definitely learned from our mistakes. Some of our biggest challenges included time management and communication. Most of our team this year was new to robotics, so we had many things to learn and challenges to face throughout our project, but we all learned so many things along the way and have grown, not only in engineering, but also in teamwork and communication.

Acknowledgements

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Trinidad State Robotics Youtube.