The Innovation and Advancement of A.X.O.L.O.T.L. and A.X.O.L.

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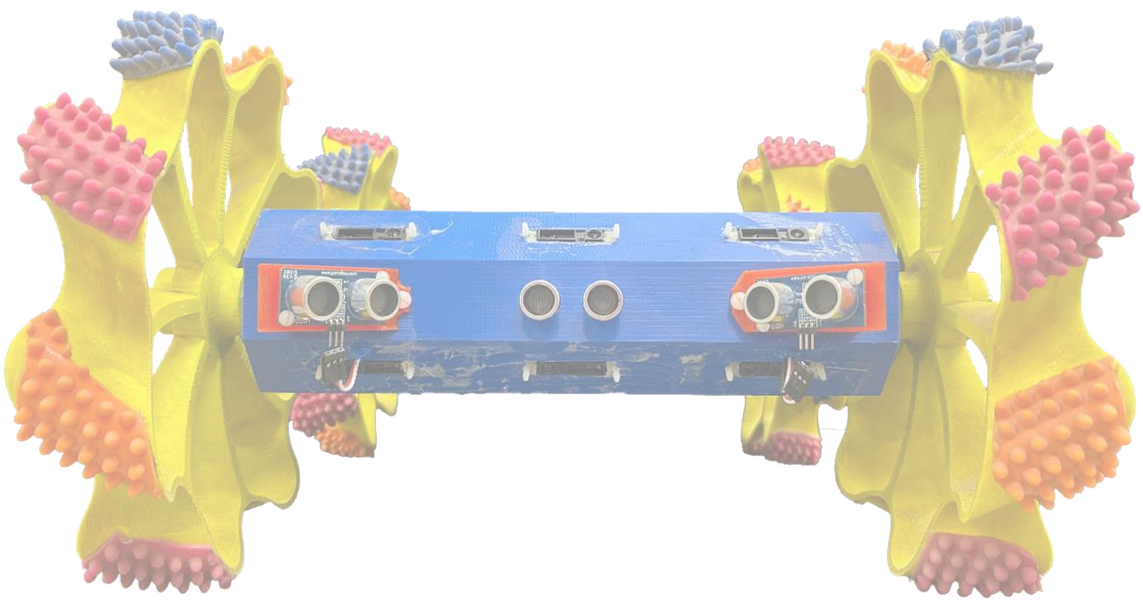

ABSTRACT

A.X.O.L.O.T.L. is Trinidad State College's entry into the 4 kg weight category at the Great Sand Dunes Robotics Challenge. This year the team has set out to improve the capabilities and mechanics of the robots by creating A.X.O.L.O.T.L. Great strides have been made in the advancement of the standard navigation capabilities, the structural integrity of the rover body, the revamped electrical system, and the new twisted wheel design. Each intricate part of this rover is specifically designed to advance maneuverability and obstacle avoidance while on the Sand Dune's courses. The team created a new sensor array that mitigates blind spots by inverting the direction that the ultrasonic sensors look to allow the rover to have a larger field of view. For the central pivot system, the body of the rover is split into two separate pieces that are joined by a flexible tube made from 3D printed thermoplastic polyurethane (TPU). This allows the robot to maintain four points of contact at all times with the ground and can assist in preventing high-centering issues and with the traversal of difficult terrain.

A copper pour ground plane was added to the circuit board to provide better conductivity and minimize any chance of a brownout. The twisted wheel is something that the Trinidad State Robotics team has attempted in the past but this year the team improved and perfected the design. The slightly twisted wheel design allows the rover to turn smoothly over rough terrain while always maintaining traction with the ground. A.X.O.L.O.T.L. focuses on building upon the years of research done by this team and inventing new solutions to previously unsolvable problems. Combining these two aspects have laid the foundation for the creation of the most highly advanced rover to come out of Trinidad State's Robotics team, A.X.O.L.O.T.L.

Introduction:

The goal for the Trinidad State Robotics team this year was to design and fabricate two robots - one in the 4 kg weight category, and one in the 1.5 kg category. Both robots were designed with a modular front section that allows for a variety of uses. A.X.O.L.O.T.L is the entry into the 4 kg weight category, and A.X.O.L is in the 1.5 kg weight category. Both designs brought their own challenges to the table but also new innovations and major improvements.

The team implemented a systems engineering approach to the fabrication of the robots. This allowed the workload to be divided amongst the different sub-teams (Building, Electronics, Programming, and 3D Design) for each to effectively accomplish their part with maximum efficiency and minimal setbacks. Each team was given a portion of the robot to work on and once they finished, all the parts were combined to create the finished robot. With this method the robot was completed as early as January 18th so programming could begin testing.

A.X.O.L.O.T.L:

The 4 kg robot this year is A.X.O.L.O.T.L, which stands for Autonomous eXploratory Optimal Lightweight Operational Twisting Lad. A.X.O.L.O.T.L currently weighs 3.4 kg. The team only had one iteration of A.X.O.L.O.T.L, but the modularity and adaptable nature of this design allowed for the making of large adjustments quickly and with minimal changes. Some major design features that were crucial was a flipping design, a central pivot, an external programming port, and a predominantly 3D designed body.

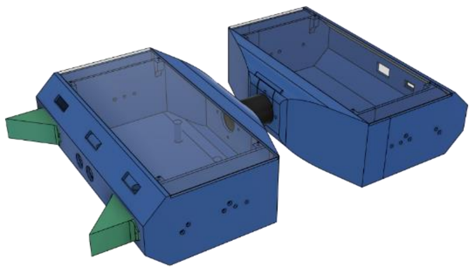

Figure 1.1 **Figure 1.2**

Central Twist:

At the beginning of this year, the building team did some testing with last year's robot T.O.A.D to determine the weaknesses of the previous designs. One weakness that was discovered was a wheel losing contact with the ground when going over hills or climbing out of pits, which increased the likelihood of high centering. This problem was due to the rigid body design used previously. To solve this, the team designed a central pivot section on the robot's body made from TPU. This section allowed the front and back halves of the robot to flex independently, allowing all four wheels to remain in contact with the ground.

Central Pivot Hinge: Prototype 1:

The first prototype consisted of a solid block of TPU with two ridges on the sides that attached to each half of the robot and a hole through the middle to allow the electrical wiring to run between the two modules. This prototype ultimately failed because the block was too stiff and would not flex. The ridges on both sides of the hinges were also too weak to support the middle of the robot, so they tore. Also, due to the solid TPU design, this prototype added an unnecessary amount of weight. Figure 1.3 is a diagram of this prototype.

Figure 1.3

Central Pivot Hinge: Prototype 2:

This prototype was a TPU tube that had a circular flange on either side. The tube was reinforced with a 1-inch PVC pipe that ran through the TPU tube. This prototype ultimately failed because the TPU tube was like a tight sleeve that slid over the PVC pipe. The friction between the PVC and TPU made this prototype unable to flex. Also, the walls were extremely thin and fell apart, allowing sand to enter. Figure 1.4 represents prototype 2.

Figure 1.4

Central Pivot Hinge: Final Product:

The final product used the design from prototype two but made the inside diameter of the TPU tube wider. This worked much better because it was able to flex against itself and pivot. It also couldn't over rotate when pivoting because the TPU only had a certain amount of room to flex. Finding this information required an extensive amount of testing. One of the main concerns when testing was the central pivot hinge seizing up when exposed to sand. To test this, sand was placed in between the central twist section and a piece of supporting PVC. After rigorous twisting the TPU showed signs of wear, so a seal was implemented to minimize the amount of sand particles that slipped into this system.

Wheel design:

The wheel design this year had to advance greatly to coexist and work with the central pivot hinge. A design was created that put less stress on the central pivot of the robot when turning but still had the traction to get over hills and pits.

The 2020 twisted wheel design (Figure 1.5) consisted of a wheel with eight spokes and eight lobes. The lobes were thin and twisted in a way that allowed them to slide through the sand while turning. This made turning much easier on the motors and drivetrain and did not put as much stress on the chassis. However, the thin lobes didn't have enough traction and thus would not allow traversing hills and pits effectively. In addition, the thin lobes had too much curvature and too little surface area to allow attaching sensory dog balls to assist with traction. This wheel design also had a smaller diameter than other designs, resulting in lower ground clearance, which presented high centering problems.

Figure 1.5 2020 wheel design

The 2023 wheel design (Figure 1.6) consisted of a wheel that had a larger circumference then the 2020 wheel design and large straight lobes. The straight lobes allowed these wheels to have an immense amount of traction allowing the robot to climb over rocks, pits and hills very effectively. Also, the larger diameter of the wheel provided greater ground clearance which helped with high centering. Due to the flippable design of the robot, this larger diameter was crucial to allow for clearance on both the top and bottom of the robot. However, the large flat lobes would push through the sand while turning, making turning more difficult. They also did not assist with turning. Although this wheel design is great, it could not be used because of the unique nature of the central twist. Since it would not assist with turning all the stress would be too great for the central pivot hinge and it would start pivoting every time the robot would try to turn.

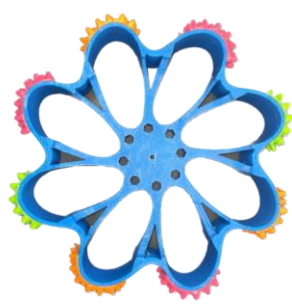

Figure 1.6 2023 wheel design

After reviewing these two previous designs, this year's team decided to combine both designs to create a wheel with excellent traction and better turning capabilities (Figure 1.7). To start, the diameter of the new wheel design was increased to 24 cm, which is larger than any wheel on previous robots. Then the size of the lobes was increased to accommodate sensory dog balls for traction. Finally, the lobes were slightly twisted to gain an advantage in turning while only minimally affecting traction. Lessening the twist allowed for most of the traction provided by the untwisted wheel design to be retained while still allowing easier turning. Overall, the traction of the 2025 wheel design is slightly lower than the 2023 wheel design, but the advantage of easier turning was found to outweigh the decrease in traction.

Figure 1.7 2025 Wheel Design

Two-part Body design

The central twist (Figure 1.8) provided a challenge regarding the actual design of the body itself. The pivot would have to take up the entire center section of the robot. This provided a unique opportunity to incorporate a modularity that no previous robot had. The rover has two separate compartments for the body that are connected by the central twist.

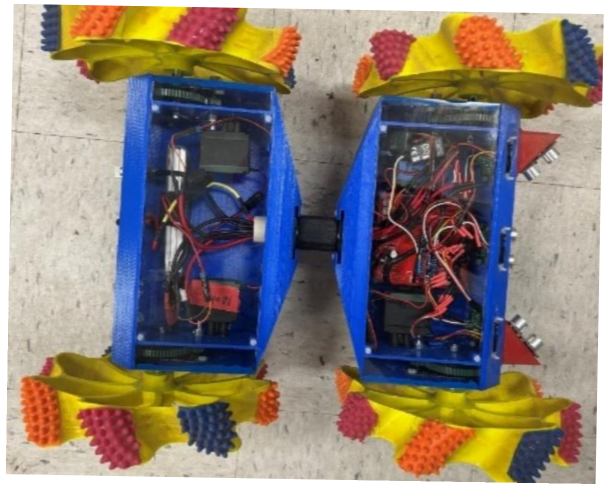

Figure 1.8

The first module holds the circuit board, the motor controllers, the gyroscope and LCD screen. It also contains the sensory array and two gearboxes and motors for the front wheels. This holds all the essential components required for the robot to operate and function. This feature enables versatile modularity, accommodating various attachments on the back of the initial module. The attachment enables the robot to connect with other modules with this featured slot designed to accommodate a circular ABS plastic ring, allowing for a seamless and secure fit. It would then be secured by four support screws that increased the overall structural integrity. Then over the top there was a clip that was shaped like crescent that secured the top of the attachment. The lid of module one is made from clear acrylic. Acrylic was used because it is tough and does not easily break or shatter. As previously mentioned, the acrylic is also clear so any blatant issues with the electrical wiring or the gear systems that is contained within the rover can be identified easily.

Module two was the attachment that was used for A.X.O.L.O.T.O.L. It contained the battery, two motors and two gearboxes, and the back wheels. It would allow the robot to have a full body and ample support for the central pivot hinge. Module 2 also utilized a clear acrylic lid so there was visual access to the battery and the gear systems. The back also had the USB connector that was used for programming the robot without removing the lid.

A.X.O.L.:

To prove that A.X.O.L.O.T.L. could be utilized as a module for future improvements a way was fabricated to keep the front part and make it a fully self-functioning entity. During planning for this new project, it was suggested to keep this new robot under the 1.5 kg weight category that is required for it to be considered a small robot. From this idea sprang A.X.O.L. (Figure 1.9), TSC's entry into the 1.5 kg weight category. A.X.O.L. utilizes the front half of A.X.O.L.O.T.L. as the central system that controls all the main components. The goal was to keep all the features that were present in the larger robot, while accommodating modularity. To do this a new method of locomotion was designed that didn't require a lot of weight and space.

Figure 1.9 AXOL

The Tailfin:

The first attempt at providing stabilization was the tailfin design. Essentially, the tailfin would act like a trail behind ski and provide rear support with the ground. The tailfin was curved upwards on the front like a ski to enable it to slide off any rocks that it encountered. Unfortunately, the amount of drag this tailfin produced was underestimated. Also, the tailfin did not have enough surface area and ended up sinking into the sand, preventing A.X.O.L from moving forward. It also did not allow for smooth and consistent turning. Due to these factors the tailfin idea was replaced with a trailing wheel design.

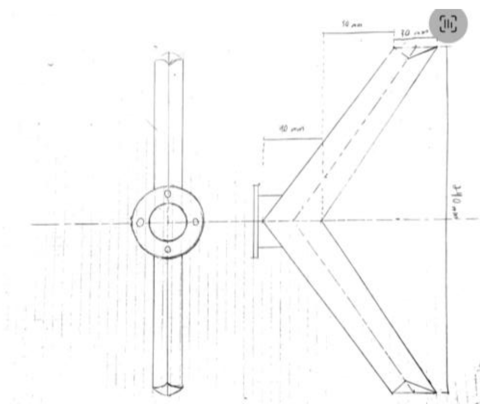

Figure 2.0 The Tailfin

The trailing wheel was created to solve the drag and turning problems of the tail fin design. Due to weight constraints, the trailing wheel had to be designed as lightweight as possible. The apparatus is mounted by a U-bracket (Figure 2.1) to the mounting system on the back of the robot. This bracket holds the trailing wheel, which has the same diameter as the powered wheels of. It was made from specially cut out foam board that allowed it to remain extremely lightweight while maintaining structural integrity when turning. During the first sand tests for A.X.O.L. the trailing wheel performed admirably. The wide diameter of the wheel allowed it to easily climb over smaller rocks. This trailing wheel was also light enough to allow A.X.O.L. to flip over when sent from forward to reverse. This unique feature was found to be incredibly useful for getting out of corners and getting away from pits.

A.X.O.L. had to be slightly changed to incorporate the same functionalities in A.X.O.L.O.T.L. while staying under the 1.5 kg weight limit. First, the battery used in the larger robot had to be swapped for a smaller on that provided the robot with the same amount of voltage but a lower amp hour rating. Another major weight reduction was from removing material from the chassis; this was accomplished by cutting out inner dividing walls which did not affect the structural integrity. (Figure 2.2).

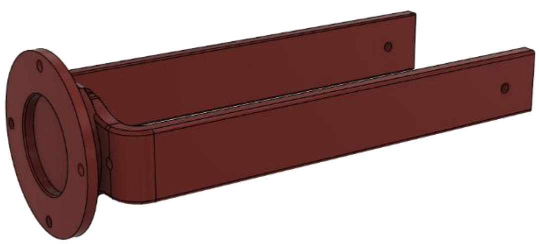

Figure 2.1 U-bracket

Figure 2.2 Trailing Wheel

Circuit Board:

The redesigned circuit board (Figure 2.3) is another major improvement to the overall workings of the electronics. The redesigned circuit board (Figure 2.3) is another major improvement to the overall workings of the electronics. The board utilizes a copper pour ground plane. This technology has become the standard for most industrial circuit boards but, until now, has never been utilized by the Trinidad State Robotics team. It decreases resistance in the ground plane, which increases conductivity and helps to prevent brown outs. The board is custom fitted to house a Propeller Flip microcontroller which is the central processing unit of the robot. Another addition was the Schottky diode, this important unit was added to the board to prevent damage to components from reverse polarity. The reason a Schottky diode was implemented was because in comparison conventional diodes have a very high voltage drop which dissipates heat and lowers the voltage going into the board.

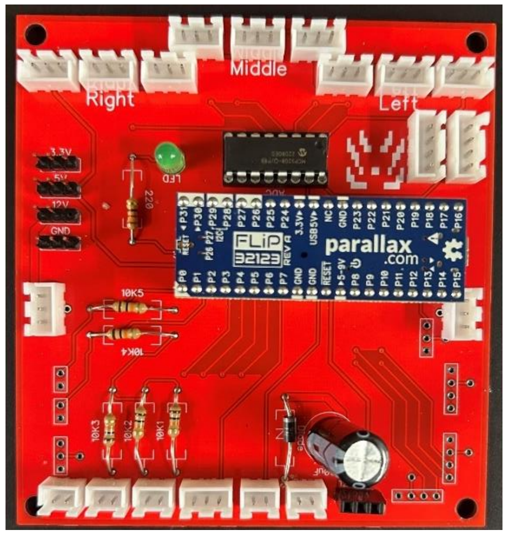

Figure 2.3 Circuit Board:

One advancement that was made to the connections on this year's circuit board is the implementation of JST (Japanese Solderless Terminals) Connecters (Figure 2.4). JST connectors only connect when properly lined up, which prevents accidentally connecting devices with reversed polarity. This solves a major issue of burning out sensors because of accidental reverse plug ins. These have been implemented across the board to prevent any such issues from reappearing.

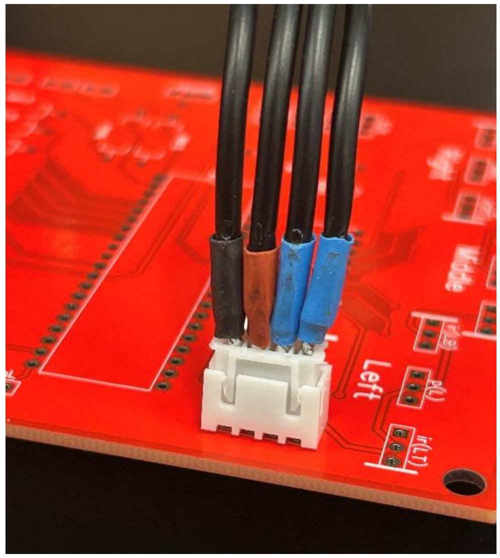

Figure 2.4 JST Connecters:

One massive challenge was figuring out a method of wiring two different body sections together and make them run flawlessly together. The design for A.X.O.L.O.T.L. required two motors powering the front set of wheels and two in the back section. Also, wires for a power switch and programming connection had to be run from the rear into the front of the robot. All of these individual wires had to be run through the narrow central pivot section. To solve these issues the front wires were made detachable from the wires running through the pivot section. This was accomplished by utilizing a detachable wiring harness. By undoing a few screws, it can smoothly detach the front from the back.

Custom wires were fabricated to divide power to the left and right side of the robot and attach to VEX motor controllers. 12awg OFC (oxygen free copper) wires were chosen to handle the high current draw of the motors. The wires for the other systems such as the ultrasonics, IRs, and the gyroscope all had to be custom fitted with JST connecters.

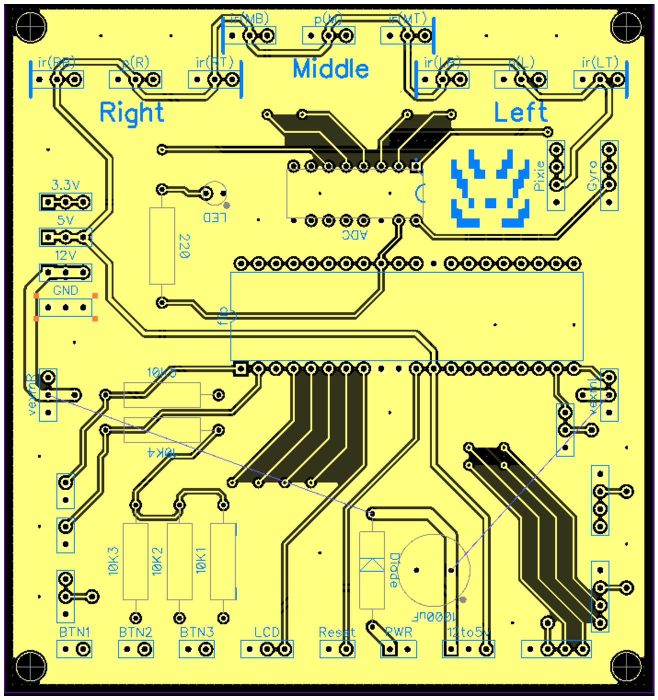

Figure 2.5

Programming:

The programming team's objective was to create a program that operated on both A.X.O.L.O.T.L. and A.X.O.L, allowing them to head in the correct direction while navigating around obstacles including rocks, pits, and walls. In addition, the program needed to allow the robots to continue navigation and obstacle avoidance even when flipped over. An LCD screen and buttons were installed on A.X.O.L.O.T.L. to allow adjustments to be made to the robot's operation without the need to reload the program from a laptop (Figure 2.6).

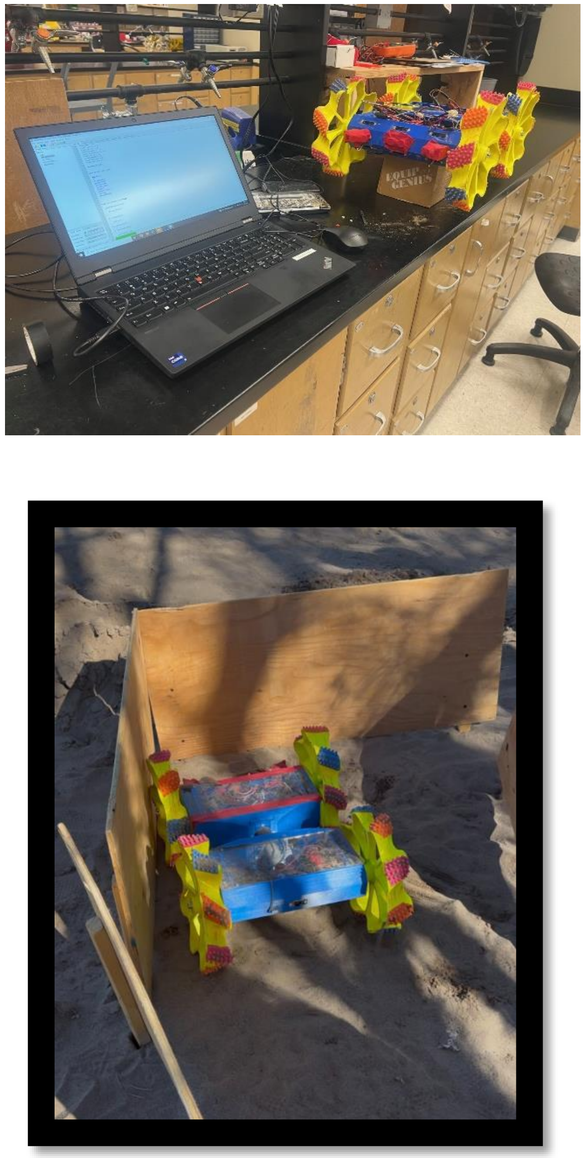

Figure 2.6 Standard Navigation and Laptop

The standard navigation program was written in Propeller C, which is a language designed for Parallax's Propeller chip. This chip was chosen because it contains 8 cogs, or cores, which allows the robot to multitask. Although each core runs independently, data can be shared between the cores. Due to this design, one core contains the main navigation logic, and the other cores collect sensor data, control the motors, and run a timer.

When the robot is powered on, the LCD screen prompts the user to choose which aspects of the program need to be enabled and allows for a target heading to be set for navigation. Buttons on the side of the robot allow these parameters to be set. To set the target heading, the robot is pointed in the desired direction, and then one of the side buttons is pressed. Once set, the target heading is stored in a variable while the robot is navigating. Ultrasonic sensors allow A.X.O.L.O.T.L. to avoid large obstacles that might be encountered while navigating at the Great Sand Dunes Challenge. These include rocks, walls, and logs. The ultrasonic sensors detect obstacles that come within a certain distance in front or on the side of the robot. An obstacle avoidance function is triggered when the robot comes within 15cm of an object. This function analyzes the sensor data and proceeds accordingly to avoid the obstacle. Infrared sensors provide A.X.O.L.O.T.L. with the ability to avoid pits and locate smaller rocks. There are 6 infrared sensors; three on the top and three on the bottom. This layout was designed so that A.X.O.L.O.T.L can detect pits when it is flipped over. With the three sensors on each side, this allows the robot to have maximum coverage when detecting pits. The function for the infrared sensors operates very similar to the ultrasonic function. The robot will analyze the sensor data and navigate accordingly to avoid the pit. This year, the infrared sensor avoidance function was improved. When the robot analyzes the infrared sensor data, it checks how many infrared sensors are simultaneously detecting a pit or an obstacle. If two or more infrared sensors detect the obstacle, it will execute a full stop, move backward, and perform a larger turn to fully avoid the obstacle. However, if only one infrared sensor is triggered, it will execute a full stop, move backward, and perform a smaller turn. This minimizes how far the robot moves to get around a pit while still allowing for effective pit avoidance. Although the ultrasonic and infrared sensors are vital components of the robot, the MPU9DOF gyroscope sensor is what allows the robot to reach its destination. The MPU9DOF module contains an integrated gyroscope, compass, and accelerometer. A cog continuously gathers data from this sensor and uses it to direct A.X.O.L.O.T.L towards its destination. First, the robot will check if it is heading towards the correct destination. If so, the robot will continue to move forward. If not, it will calculate how far it is from the target heading. If it is within 20 degrees of the target heading, then it will continue moving forward. If it is not, then it will find the most efficient way to rotate towards the correct destination. However, if an obstacle is detected, the robot will wait for three seconds before correcting its heading, giving it time to fully avoid the obstacle. Through testing, three seconds was found to be the optimal time that would allow the robot to completely avoid the obstacle before heading towards its destination. This feature is made possible by the timer cog, which keeps track of the time elapsed during different operations.

Figure 2.6 Inverted Sensor Array:

One of the most unique improvements implemented this year was the inverted ultrasonic sensor array design. In previous years, the sensor array involved three ultrasonic sensors placed at different positions across the front of the robot (Figure 2.6). This sensor placement required each ultrasonic to individually cover its side of the robot to prevented us from hitting larger objects. One major disadvantage found in testing was that this design had many blind spots between each sensor. These blind spots meant the robot could encounter a small object in one of the blind spots which could cause it to get stuck or damage a sensor. The team set out to solve this issue by redesigning the sensor array. Initially, the team discussed the option of LIDAR because of its ability to receive a large amount of distance readings all at once. However, the size, weight, and cost of a quality LIDAR sensor were prohibitive. A large LIDAR sensor would make it difficult for the robot to operate both upright and flipped. Also, LIDAR sensors can be heavy, and the team wanted to keep the robot as light as possible. Overall, LIDAR had too many downsides to be a viable option for the robot. Inspiration for a new design was taken from the sensor array on TSC's 2023 robot F.R.O.G., because that robot had the unique ability to have detachable ultrasonic mounts. This sparked the idea of flipping the orientation of the ultrasonic sensors inward so the left ultrasonic would look across the robot to the right side and the right ultrasonic would look across the robot to the left side. Meanwhile, the central ultrasonic maintained its position. This unique design eliminated the blind spots that caused an issue with previous robots. After some rigorous testing, it was found that this new design not only worked for eliminating blind spots but also improved accuracy at obstacle detection. This new sensor array allowed the robot to see obstacles directly in front of it and obstacles directly in front of the wheels. Testing found the optimal angle for the right and left ultrasonic sensors was 45 degrees in order to maximize detection accuracy. If the left ultrasonic detected an obstacle, it would avoid the obstacle on the right and move left. If the right ultrasonic detected an obstacle, it would avoid the obstacle on the left and move right.

Specialized Coding Functions:

One major goal of programming was to incorporate specialized coding features. Not only would the robot have a standard navigation program but also have features that would improve the navigation capabilities of the robot. One of the major specialized coding features was the ability to flip. To accomplish this, the robot needs to detect when it is flipped and recalculate the compass heading. Although this can be determined mathematically, it is more accurate to flip the robot when setting the target heading at the beginning of navigation. This is because there is iron content in the sand which distorts the magnetometer values. The compass direction is predetermined at the beginning of the course, but an additional step is required if the robot was to flip. To correctly determine both compass directions, A.X.O.L.O.T.L. is flipped to collect the target direction. The robot will know it is flipped by reading the values of the Z-axis. Positive values indicate an upright robot, and negative values indicate a flipped robot. Other than the gyroscope, the sensors also change. The top infrared sensors become activated when flipped and the right and left ultrasonic switch when flipped. As it navigates the course, the headings will alternate as needed to keep A.X.O.L.O.T.L. on track whether flipped or not.

Another specialized coding feature is the stuck function. The stuck function allows the robot to escape obstacles that were not detected with its sensors. Some reasons for this failure of detection were because the obstacle was too low to detect, or an obstacle would get stuck near the central pivot. As a result, the robot needed a way to get unstuck. This year the stuck function relies on the gyroscope. As previously mentioned, the robot will attempt to navigate towards its destination throughout the course. However, when it is stuck, it will have trouble in moving towards the destination. This is one of the best indicators that it is stuck. If the robot is trying to move towards the destination, but is having trouble for more than 15 seconds, the robot will begin a series of motor functions to help it escape. The robot will enter a loop of moving backward, forward, left, and right. This loop is conditioned until the robot is finally able to head towards its destination. So, once the robot is unstuck, it should be able to go back towards its destination.

This year, a new feature was implemented that allows the robot to change its target heading during navigation. In previous years, the courses would sometimes have an unconventional route where the robot must navigate an L-shaped course. In the past, the robots would be set at a specific angle to get past this, but this year, the robot can change directions within a course. Using the timer cog, if activated, the robot can switch directions after a time set by the user. This feature was only used on A.X.O.L.O.T.L because it contained an LCD screen which allowed for easier configuration.