I [Jeremiah] chose to pursue this project in hopes to learn more about a field within my major, robotics. Programming a robot to perform specific tasks and learning how to problem solve, real and physical problems, have always been an interest of mine that I wish to turn into a skill. This project, I believe, was a great choice for me in the sense that I am going to be able to apply my skills in programming and code to make something move in the physical world, which I find very exciting. I have also decided to take this opportunity to treat my learning environment as a work environment, so that by the end of this project I will have an idea of what it’s like to work with others in the same field, as well as other disciplinaries i.e., mechanical engineers.

**Goals/Objectives**

The purpose of this project is to assist in the inspection of University of Central Florida’s storm drains. To iterate, the goal is to build a functioning robot which can accomplish a set of objectives, such as inspection, evaluation, and integrity check of the storm drains. Being that the conditions of the storm drains are wet, made of concrete and metal, and are 20 feet below the ground, there are restrictions that need to be worked around and solved. As for must haves, the robot will be tethered, most likely by a steel cable for recovery if needed. Also, since the robot will be operating underground, a wireless connection is not possible and will instead be connected via ethernet cable. Due to the conditions that the robot will be operating in, good lighting is needed which in return will allow for good visibility for the cameras.

**Equipment**

The robot will require several types of hardware such as, cameras, controls, circuit boards, lights, motors, tether, power supply and a cooling system. These will be designed and provided by the mechanical engineers who are working alongside us during the manufacturing of the robot. As for the computer scientists, several pieces of hardware will be needed in order to successfully program the robot to perform its set tasks. One of these required pieces of hardware will be the NVIDIA Jetson Nano Developer Kit, which is already equipped with computing power to run AI workloads, which can be useful in developing the final version of the robot. With the NVIDIA Jetson Nano alongside with other sensors, the robot may be able to perform its tasks more efficiently, such as detecting cracks, cave-ins, and hazard conditions, allowing users to effectively complete their tasks within the storm drain. For the mentioned sensors, laser mapping, ultrasound sensors, and light sensors may be used in order to create a more efficient robot that can detect issues that the user may not see or realize.

**Broader Impact**

With the completion of this project, its applications can help not only the university, but also cities who are prone to being rained on or flooded. The robot can be used as a replacement for a person, as conditions in storm drains can get risky and dangerous from gas leaks, cave-ins and wildlife. This robot can increase the efficiency of many inspections done by cities or construction companies, saving them time and money as well as lowering the risk of injury for laborers. The application of this project doesn’t stop with the inspection of storm drains though, the idea of completing a risky task using a controlled robot can help in other fields in the workforce i.e., construction.

The success of this project can bring to light the significance that computer scientists and engineers can be beneficial to society in a way that makes life easier and safer for everyone. People will see how the innovation of science and engineering can make a brighter future for the world, and advance society to a new level of efficiency and safety. As this innovation ripples into the future, inspired people will want to partake in the pursuit of this brighter future, creating more and intuitive engineers and scientists.

**Legal, Ethical, and Privacy Issues**

The misuse of this robot can lead to legal issues, as it is probable that this robot will be equipped with a weapon in order to fend off any wildlife it encounters, and it will be equipped with cameras, lights and sensors. The misuse of the weapon can lead to serious injury or fatality. Also, if this robot were to be inserted into a storm drain in which it is not allowed to be in, trespassing will occur, and as the robot is equipped with cameras and sensors, a breach of privacy will occur as well. The issues listed from misuse can lead to legal action and should be avoided.

Geographical Tracking

One of the major objectives in this project is for the robot to track its position inside the storm drain, so that the surface can be marked and indicate where the said obstruction is located from the surface (Figure x.xx). There are a handful of possible ways of doing this, but most exceed the allocated budget, or are too complex.

A picture containing iPod

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GPS

An idea that was brought up, but immediately rejected, was the use of a Global Positioning System (GPS). GPSs are found in many appliances and applications, such as cellular devices, computers, satellite phones, and more. Originally, the use of a GPS was for military use, but has then been extend to commercial and public use. The way a GPS works, is by taking advantage of the many satellites that orbit the Earth and use triangulation to pinpoint the location of the device using GPS (Figure x.x1). As to why this idea was rejected, it’s because for a GPS to work, it has to be within the sight of multiple satellites. Since the environment in which the robot will operating in is underground, there is no line of sight for the satellites, making this idea unsound.

A picture containing object, first-aid kit

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Ultimately, this idea would have been the most efficient and practical method of tracking the robot’s position while in the storm drain. Unlike the other ideas, the complexity and implementation of this idea would have been practical, easy and useful, but because GPS requires a direct line of sight between the robot and satellites, this idea can’t be used.

It is possible to create a makeshift GPS for the robot, but that would require additional components that would have to be separate from the robot, as well as requiring financing from the budget.

Radar

The use of radar is within the scope of the project, it would allow for tracking distance traveled in an accurate fashion, as well as be used to detect any obstructions inside the storm drain. The way a radar functions is by transmitting signals with an antenna and receiving the bounced signal to determine the distance, size, and location of an object (Figure x.x2). By using radar, another object may have to be lowered in alongside the robot, to act as a starting marker for the robot, but detecting cave-ins and obstructions would be easy, and efficient on time.

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Radar would a good option for tracking distance traveled, but it would require more financing, and advanced code in order to properly use the radar. Additionally, more components would be needed in order to construct the radar, increasing the complexity and maintenance of the robot. In addition, there are several conditions in which the radar would not function properly, or to its full potential. The first condition would be that the storm drains aren’t always leveled, meaning that if the robot was traversing the pipe with deviations in terrain, there is a chance that the marker that was placed as a starting point, may not be detected by the radar due to difference in elevation, thus ruining the point of the starting marker. Secondly, there are slight turns within the storm drain pipes, meaning that the starting marker may be out of sight, and thus ruining the point of the starting marker again. Thirdly, any obstacles that are inside the drain can possibly prevent the sonar from functioning.

Another use of radar is Ground Penetrating Radar (GPR). This allows for finding objects located underground, from the surface. Using radar in this fashion would be practical in finding cave-ins and obstructions inside the storm drain, but it doesn’t allow for the user to evaluate the conditions inside the storm drain, along with the fact that pipes may run under buildings in which the user won’t be able to properly follow the layout of the storm drain pipes. To further reason as to why GPR isn’t a good idea is the fact that obtaining a GPR is expensive and would require funding over the designated budget.

Overall, radar is a good idea as a concept, but it adds onto complexity as well as financing. There are also many things that can inhibit the radar from functioning, meaning that the radar would need specific or perfect conditions for it to operate as expected. Furthermore, with the conditions inside the storm drains, using radar would not be the most optimal or practical option to track the robot’s traveled distance.

Sonar

A similar idea that was considered, was the use of Sonar, which is very similar to radar (Figure x.x2). Instead of radio waves, sonar uses and manipulates sound waves at a high frequency in order to locate any objects. This concept is similar to how bats use echolocation, in which a pulse of sound is released, and a receiver then calculates the position and distance of an object based on the time it takes for the echoed sound to return. Just as the radar had its specific conditions in which it would function properly, sonar has conditions that mirror the problems of radar, such as using a starting marker. Furthermore, sonar would be more complicated and complex due to the fact that sound waves will bounce off the surrounding walls more inside the storm drains, and overwhelm the receiver, thus inhibiting the sonar from operating properly.

In this case, using sonar would be inconvenient to implement, especially in the conditions that the robot would be working in; it would require additional funding and advanced math techniques to properly map out and understand the incoming data. Overall, sonar seems to be one of the less likely ideas, due to its inconvenience and complications.

Tether Length

A rudimentary idea that is taken into consideration is to just measure out the length of the tether once the robot discovers any cave-ins or obstructions inside the storm drain. In order to do this a few concepts were brought up that could help with measuring.

One concept discussed was to place the tether on a reel and calculate the length of tether used based on how many rotations the reel has gone through. One reason as to why this concept was rejected was because of its inaccuracy. By pulling the tether off the reel, the radius would constantly get smaller, thus requiring a remeasurement of the radius in order to calculate how much tether has been used.

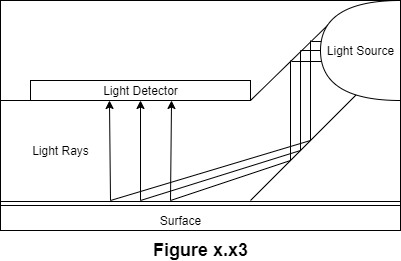
Another concept, involving the reel, would be to mark up the tether to indicate a unit of length, feet, yards, meters, etc. and then have the tether run through a sensor that would count each mark, resulting in a total distance traveled. This idea proved to be practical in the sense that it is easy to implement, cost efficient and practical. By having a marked tether run through a sensor, there is no room for error and would also be easy to program. The complexity of this concept is also very low, allowing for quick use and measurement.

A few concerns that arose for both concepts are the fact that the tether can get tangled or misaligned when reeling in said tether. Although the robot and tether system will be handled by professionals, there is still a possibility that the tether will get tangled in the reel, in which it would add more time to the operation to untangle. Another concern is the fact that the robot would need extra torque and power in order to pull the tether off the reel. Realistically, the robot should only have enough torque and power to pull itself, and not have to unwind the tether from a reel.

Overall, the second concept is effective and has a high chance of being the main method of measuring distance traveled. The pros, in this case, outweigh the cons and allow for simplicity to take place when implementing this system. It contains practicality, simplicity and efficiency when achieving the goal of measuring distance traveled, by the robot.

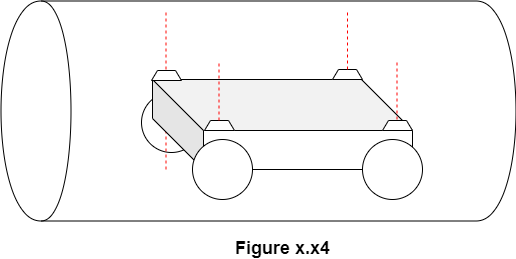
Optical Mouse Sensor

One such solution to tracking the distance traveled by the robot is the use of an optical mouse sensor. An optical mouse sensor uses a light source and a light detector in order to calculate movement in relation to the surface it’s on (Figure x.x3). Like the sensor underneath a computer mouse, the robot can use this sensor to achieve the same functionality. By using this sensor, the robot can track what direction it’s going, as well as how far it’s gone.



In order to successfully implement this idea, several optical sensors will have to be used, since just having one sensor will not be enough. These sensors will have to be placed all over the robot, locations that track the robot’s actual movement in three-dimensional space. The level of complexity to program this would be moderate since it would only involve vectors and matrices in three-dimensional space.

To properly execute this system of optical sensors, there will have to be at least eight different optical sensors (Figure x.x4), four on top of the robot, and four underneath the robot. This implementation would be effective because some sensors may be blinded by mud, or anything that can be found in the storm drains, and by having more than one sensor, there will be other optical sensors to take its place along with the fact that by having more sensors, the more accurate the calculation of distance travelled will be.



In total, using optical mouse sensors is a good idea, but there are some inconveniences that make it difficult use this idea. One such problem is the wide range of optical sensors, ranging from low quality and basic sensors to high quality and advanced sensors. Each of these tiers will of course have a different price range, making these sensors either very cheap or extremely expensive. Another problem is that most optical mouse sensors require a flat surface in order to properly function. Inside the storm drain, the surface will not be smooth, instead it will be wet, rough and made of concrete. What this means is, the light being used by the optical mouse sensor will be diffused or refracted, resulting in the sensor not being able to receive the bounced light. Depending on the quality of the sensor and its source of light, this problem can be overcome, but may be impractical and inefficient with the budget.

Wheel Rotation

An obvious idea that is highly leaned towards, is the calculation of distance travelled based on how many times the wheels on the robot have rotated. This concept is basic, practical, and not complex at all. Even though it may be the most basic idea, it redeems itself though its effectiveness and efficiency. By adding a sensor to count how many wheel rotations have occurred, a program will have to just use an equation, with wheel diameter taken into consideration, to find the total distance travelled by the robot.

Though this method has a high chance of being used, there is one major concern that is taken into consideration, the problem of wheel slippage. Wheel slippage will most likely occur within the storm drain, especially with the conditions the robot will be operating in. Slippage occurs when the wheels on the robot can’t get enough traction on the surface it’s operating on, and so rotation of the wheel occurs but no directional movement is achieved. This can be detrimental for the goal of tracking distance because, based on this method of tracking, any excess wheel rotation will contribute to the totality of wheel rotations.

By having extra wheel rotations that do not contribute to actual distance traveled, the distance traveled may be misrepresented and misinform the user. Being that this robot is being used and operated to find any cave-ins, and or obstructions in a storm drain underground, its severely important that tracking the robot’s location must be accurate so that operations above ground can take place in an efficient manner.

Methods of how to prevent slippage have been narrowed down to the type of wheel to be used. Several wheels have been discussed, and only a select few characteristics have been chosen to be mandatory.

One such characteristic is the fact that the wheel should be heavy in order to allow the robot to stay stable on the surface of the storm drain. Also, in order to make the wheels heavy, the wheels will most likely be made of a solid material, with minimal air. This is beneficial, such that by having solid wheels, they will sink in water and not float. Furthermore, by having solid and heavy wheels, the robot can remain stable when maneuvering.

Another characteristic is treading on the wheel. Treads are useful because they allow for the wheel to stay in contact with whatever surface they are operating on top of (Figure x.x5). In addition, treads are designed to repel water from the contact surface, which in this case is very beneficial for the robot and for the environment the robot will be operating in.

A close up of a logo

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Overall, using wheel rotations as the method of tracking distance traveled is the most appropriate approach for this project. This method contains minimal problems, in which can easily be corrected, if errors were to occur. In addition, this method proves to be most practical, intuitive and budget efficient way of tracking distance traveled by the robot.

Communication Methods

An important component for the robot to operate properly is its method of communicating with the computer and user. There are a handful of ways that communication can be achieved, such as ethernet cable, and wireless connections. There are various types of wireless connections that can be used in order to establish a connection between the robot and computer. Some examples of these wireless connections include radar, Bluetooth, and Wi-Fi, which are all essentially radio waves, just being manipulated in various ways.

Communication: Radio

For the first method mentioned, radio waves operate by transmitting electromagnetic signals from one location to another, without the use of a direct connection, such as wires. There are two important pieces of hardware that allow radio to work, the transmitter and the receiver. The transmitter sends out the radio waves, while the receiver receives these signals (Figure x.x2).

Since radio waves fail at penetrating rock and reaching underground, a transmitter and receiver will have to be made and lowered into the storm drain along with the robot. This transmitter would then be tethered to the computer in order send and receive data from the robot. Radio waves also travel at the speed of light, meaning that the transmission of data would be fast and in real time. This would allow for real time video feedback and let the user control the robot a lot easier, without a latency in video feedback. In addition, radio waves can reach long distances, so long as the transmitter and receiver are strong enough, and therefore allow for the user to potentially drive the robot from one end of the storm drain, to the other. Overall, using radio signals to control the robot is a possibility, but implementing the hardware and programming it may be tedious.

There are some negative sides to using a wireless connection though. As previously stated, an extra piece of hardware will be required in order to properly transmit and receive data to and from the robot, which in turn may take more resources from the allocated budget. Secondly, wireless connections always have the chance of being intersected or negated, by other signals and noise. What’s meant by noise is, the irregular fluctuations that can accompany a signal and obscure it. Another negative aspect is the fact that the wireless connection can be blocked off by objects that are thick and dense enough, such as concrete. If the robot were to get behind rubble, or go through a narrow passageway, driving out of sight of the transmitter, it’s possible that the robot will not be able to send or receive any signals, thus leaving it stuck with no way of controlling the robot and immobilized. If this were to occur, a person would have to be sent into the storm drain to either retrieve the robot, or put the robot back in range of the transmitter, defeating the purpose of the robot, to inspect the storm drain in the place of a person.

Communication: Ethernet Cable

The other form of communication comes through the use of an ethernet cable to transmit data and signals, to and from the robot. There are several benefits by using an ethernet connection over a radio connection, while at the same time several deficiencies that can make the wired connection seem like a second choice.

Even though the wired connection may not be as fast as radio waves, the speed at which ethernet cables work, is enough to transmit data in a timely manner. By using a Local Area Network (LAN) connection, transmitting data can reach speeds up to 100 Megabits, or 10 Megabytes per second, which is a fast connection; one that is enough to transmit video in what can seem to be real time. LAN is a computer network that connects several computers within an area (Figure LAN), which in our case is just the robot and computer.

A screenshot of a cell phone

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To list the few advantages of using an ethernet cable over a wireless connection, the physical cable should be taken into consideration. By having a wired connection, it’s less likely that noise will interrupt the video feed and cause discrepancies. This will allow for a higher quality video feed and make it easier for the user to assess the conditions inside of the storm drain. Furthermore, by having an ethernet cable, it would be difficult to lose connection to the robot in the storm drain. The only way to lose connection would be if the ethernet cable was severed or became unplugged from the robot.

On the negative side, having an ethernet cable run between the robot and computer can add some complications. One obvious example, is the fact that the cable can get tangled by debris inside the storm drain, making the operation done by the robot more difficult. Another inconvenience is the limited distance the robot will be able to travel, because of the finite length the ethernet cable has. Unlike a wireless connection, the robot will be required to drag the extra weight of the ethernet cable. This means that the robot will require extra power and will vary depending on how long the cable is. As for another problem of using a wired connection, the robot may end up being submerged in water. This would require the cable port on the robot to be waterproofed because the said port could be a breeching point for water. This is a problem that has been discussed in which several solutions have been conceived. One such solution is to add a sleeve over the ethernet cable to keep the water out and another solution would be to use rubber stoppers on the ports. These two solutions are the best proposals, based on practicality.

Overall, between wired and wireless, wired maybe the best option. Reasons to support this is the want for quality over quantity. Even though a wired connection may not be as fast as a wireless one, the quality of video will be far better than that of a wireless one. In addition, by using a wired connection, extra hardware such as a transmitter and receiver will not be required for the robot, thus saving resources in the budget.

Controller Method

In order to operate the robot, two methods have been brought up, computer keyboard and console controller. These two methods of operating the robot have been discussed and agreed that both will most likely be used interchangeably. By having two methods of controls, the user can choose how they would like to control the robot while also having a second method as a failsafe, just in case one method becomes unusable.

Controller Method: Keyboard

In comparison, the keyboard will have more buttons than that of a console controller. This difference in button count could be beneficial for the robot in respect to functionality. By having more buttons, more things can be programmed onto the robot, making it easier for the user to execute desired tasks. On the other hand, by having more buttons, the user may get overwhelmed or confused and mistake one button for another, resulting in an undesired action. Realistically, the robot won’t be programmed with many automated actions based on the requirements. Also, if using a console controller is to be included, the number of buttons being used on a keyboard should match the number of buttons on the console controller. By doing this, the functionality between keyboard and controller will be one to one and will allow for the user to swap between both methods without having to worry about extra actions and buttons.

Controller Method: Console Controller

As for using the console controller, the user may feel more comfortable operating the robot this way because it can give control over how much power is being outputted by the robot, such as movement speed. Also, console controllers are very intuitive and are widely used by many people, meaning that it could be easier for the user to operate the robot with the controller. A console controller usually comes with two joy sticks, one for directional steering, and another for camera angle. By allowing the camera on the robot to be controlled by one of the joy sticks, typically the right one, inspection of specific areas inside the storm drain can be made with ease.

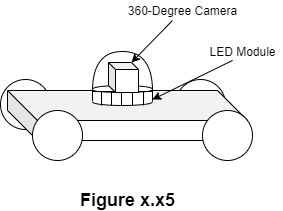
Between keyboard and controller, keyboard can will be more practical if different autonomous actions were to be programmed into the robot. By having more buttons, more actions can be programmed and thus allowing for more functionality on the robot. In respect to console controllers, controlling the robot would be a lot easier because of the intuitive design. The controller comes equipped with pressure sensors, meaning that more control is granted to the user. The user would be able to control how fast the robot is moving, and control where the camera is facing, independent from the rest of the robot. This means that only the camera would have to move, instead of moving the entire robot in order to change what the camera sees. Both methods have their pros and cons, but by having both implemented as methods of operating the robot, users can choose which approach they find more comfortable.

Lighting Method

For lighting, several ways to illuminate the dark conditions inside the storm drain have been thought of. Multiple methods and designs have been discussed, such as a 360-degree light around the robot, or having a light attached to the camera so that whatever the camera is pointing at is illuminated. The type of lights that are most likely to be used are Light Emitting Diodes (LED) because of how powerful they can be without the need for much power. Compared to other light sources, LEDs are not only the most efficient, but they also emit small amounts of heat, which is optimal for the robot in a heat output aspect. As for the downside of using LEDs, the price range of these lights are a lot higher than other lighting options. The reason for this is that LEDs get more expensive depending on their power, or how many lumens they can output. A lumen is a unit of measure for how much light is emitted per second. This means that depending on the requirements of this project, if the user is to be able to see far, through the video feed, the price of lighting can get expensive. In addition, there is a possibility for multiple light sources on board the robot, meaning that in order to have acceptable lighting, more resources may have to be allocated for lights in the budget.

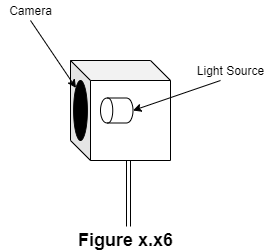
Lighting Method: 360-Degree Light

As previously mentioned, there are two approaches for equipping the robot with lights. The first idea is to put lights all around the robot, encompassing it in a 360-degree ring of lights (Figure x.x5). By doing this, the area around the robot will always be lit up, allowing for a uniform distribution of light. In addition to this idea, if the project advances with the use of a 360-degree camera, this lighting method will be useful and practical. Overall, this lighting system seems to be the most efficient method for lighting up the storm drain but may become expensive depending on how many lights are required to achieve the 360-degree area around the robot. Secondly, depending on the power of the lights, the price range will rise alongside the light’s lumen output.



Lighting Method: Light Attached to Camera

The other approach for lighting is to attach a light onto the camera. By doing this, a light will always be shining wherever the camera is looking. Taken into consideration, this can be the most cost-efficient option since only one light would be required. In addition to cost-efficiency, it may be much cheaper to get a powerful single light rather than multiple lights. There are some downsides to this approach though, such as having a singular light source. If this light source were to go out, the user would not be able to operate the robot properly because they will not be able to see what they’re doing. This occurrence would practically immobilize the robot. Secondly, by having a single powerful light, more heat may come from it, resulting in the need for heat dissipation methods.



Both methods are useful in their own respect, each having their pros and cons, but depending on what is desired on the final product, one of these methods will have to be chosen. Between both approaches, having a 360-degree light that can cover all angles of the robot would only be useful for a 360-degree camera. In addition, if one of the light modules were to go out, there would be other light sources on the robot that can illuminate the storm drain for the user. The downside to this method would be the price of all the lights, cumulatively. On the contrary, having a light source be attached to the camera would efficient in the sense of simplicity, but since it’s the only source of light it should have a high lumen output.

Cameras

On the topic of cameras, there are several types of cameras that can be used in order to capture video and stream it to the user. There are only several cameras that can operate in the conditions the robot will be going into. Some examples are Go Pros, Canon IVY, Olympus Tough TG, Nikon Coolpix and Kaiser Baas. These are a handful of cameras the robot can operate with, but depending on the minimal requirements, some options will be more practical than others.

One brand of cameras that are being looked at are Go Pros. These cameras are well known for their durability and quality. They are waterproof, meaning that submerging this camera won’t be a problem. In addition, Go Pros are also shock proof, which means that they can be dropped from high heights or absorb a large amount of impact and not get damaged. These two qualities are great for the conditions in which the robot will be operating in and are practical.

Along with Canon, there are other previously named brands that have developed their own waterproof cameras. Although this is the case, the go to for effective waterproof cameras would have to be Go Pros, because they are known to be taken into water along with other extreme conditions. In the market, Go Pro seems to take control because of their quality and durability.

There is one setback to using Go Pro as the camera, it costs much more than the other options. As of right now the GoPro Hero7 is at $200, whereas its competitors such as Canon, range from $80 to $100. This means that if multiple cameras are desired for the robot, more resources will have to be allocated for the cameras within the budget, especially if the option of Go Pro is selected.

Implementation: Single Camera

As for implementing cameras, there are a several approaches on how these cameras will be used. One such method is the use of one camera, which can be swiveled and turned by motors on the robot (Figure x.x8). By having this option for the camera, the user can easily look around and inspect anything they want within the storm drain by controlling the swivel and or axle.

A picture containing text

Description automatically generated

There are several negative sides to using a singular camera though. One being that the user would have to manually turn the camera and adjust the axle and swivel individually in order to look at what is desired. This could be time consuming for the user and slow down the operation, or even be frustrating for the user. Overall, this concept is rudimentary and works, it’s simple and practical, but there are other approaches that can fix these small problems for the user.

Implementation: Multiple Cameras

One other implementation of cameras is the use of more than one camera. This concept requires at least two cameras where one camera would be facing the front and the other facing the rear. This allows the user to easily control and know what is around the robot. To increase this effect, more cameras would be required in order to see in all cardinal directions. By having more cameras facing in multiple directions, the user won’t have to adjust the robot in order to face anything in the storm drain, instead the user would have to just adjust that specific camera.

This concept has its pros, such as seeing more and having multiple backup cameras, but also has its cons. One such con would be the implementation of these cameras, having the processor communicate with all of them at the same time. In addition, programming all the cameras would be a hassle and could lead to complications. Furthermore, depending on the type of camera that will be used, the price of all multiple cameras can severely raise the cost of the robot, meaning more money would have to be allocated to the cameras.

Implementation: 360 Degree Camera

One big solution to the problems made by two previous ideas would be the use of a 360-degree camera. This camera would allow for the use of only one camera module, while also encompassing a 360-degree field of view for the user. This takes both previous methods into one because the user wouldn’t have to turn the robot or camera in order to view something, and the camera would already provide a 360-degree view, meaning that there would be no necessity for more than one camera.