Semi-Autonomous Inspection Robot

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Abstract

An inspection robot can be used to overcome the challenges associated with the inspection of objects in confined spaces. The robot can also be used in disaster areas to recover objects and rescue human life that are beyond the reach of individual rescue operators. The current project involves the design and development of a semi-autonomous, remote controlled, inspection robot. The robot will use a camera with Wi-Fi protocols to perform its functions. The design uses a four-wheel drivetrain for traversing steep ascents and descents while reducing the risk of overturn.

Four active infrared sensors are used to find the distance to an obstacle located around the robot. Information from the infrared sensors will be used to determine the direction of travel allowing the robot to navigate efficiently. The robot is capable of recording images using forward and backward-facing video cameras to aid in navigation.

Introduction

According to the U.S. Occupational Safety and Health Administration (OHSA), on average, there are a total of 20 deaths per year inside confined spaces.[1] This leads to fines issued by OHSA.[2] In most cases, these deaths were primarily related to the inhalation of air that was depleted of oxygen or actually toxic due to the tasks being performed inside of these spaces. Normally, entering these confined spaces requires special permits and training that is certified by OSHA for all workers that will be on site.

Tasks are being completed by robotics systems more often than ever in numerous industries across the globe. These robotic systems are allowing workers to avoid many of the hazards that have plagued the working world since the industrial revolution. Confined spaces have been a major concern ever since sanitary sewers were first introduced in cities and required workers to keep them maintained. Within the last 30 years, the risks of working in these environments have only been slightly decreased. Fortunately, with the introduction of robotics and electronics, these risks have decreased even further. Due to decreasing safety concerns, more and more telecommunications infrastructure is being located underground or inside cramped cabinets. This provides a need for a robot with extraordinary capability.

The solution developed to minimize these risks is known as an inspection robot. The primary design goal of this device is to act as an inspector that can find a problem. Robots have the advantage of being very good at finding problems not seen in visual human inspection.[3] They are ideal for finding cracks that are just beginning to develop.[4] It has not been designed to solve any discovered problems due to limitations on expertise, time and budget. This robot has been centered around the goal of creating a semi-autonomous vehicle that will operate on its own without human control in situations where communication is lost, so that it will not become stuck at a certain point on its inspection route.

Two major differences exist between this robot and other inspection tools. First, it is designed around a Raspberry Pi architecture. This makes the apparatus very adaptable to the many different circumstances that different users may encounter. This kind of construction also makes it easy to replace the control circuitry as a Raspberry Pi microcontroller can be purchased by anyone with little difficulty.

The other area that sets this unit apart is its ability to be controlled over a Wi-Fi signal. Most inspection robots make use of tethered cables.[5] It is possible to create inspection units using Wi-Fi, as discussed.[6] Being able to transmit commands over Wi-Fi can be useful in certain situations. For example, if the area it is traveling through does not have thick walls between it and the Wi-Fi Source, there is no cable for user to worry about getting caught and stuck somewhere in things like conduit or piping. In order to defend against the situation of an environment with poor signal, there is an option to tether the robot through the already mounted Ethernet port.

Methods

This project is subjected to a few constraints. A space constraint requires the robot to fit within certain dimensions that the team decided would be a sizing box of 12 in x 12 in x 12 in. The design size allows the robot to fit in ducts that supply 680 cubic feet per minute of air or greater. Thus, this implies it will be able to check any area that is supplied with conditioned air that has a square footage of over 680 square feet; assuming the building design follows the guideline of one cubic foot of air per minute for every square foot as discussed in the table from Oregon's building code.[7] The next major constraint was that it had to be powered by an electric battery, preferably a rechargeable NI-MH or LI-POLY. This required that battery placement and accessibility be considered in the build design. A final major constraint that had to be considered was the operating environment. This necessitated the design to be built with the electric motor vertically offset at a minimum of 1.5 inches from the axles. This accounted for the potential risk of going through puddles up to one inch deep.

The powertrain design uses two electric motors to provide the power to the axles, one for each side of the device. This two-motor design is used in order to allow for steering without mounting the wheels on a pivot. Wheels were chosen for energy efficiency.[8] As a result, this required that each wheel is on a separate axle. The motor torque is transferred from the motor shaft to axle shafts using standard #25 chains. This chain is run between two sprockets: one on the motor shaft and the other on the axle shaft. The speed to torque reduction is performed by the differing sizes of the axels to step down the speed while increasing the torque.

The design was created in Creo Parametric that allowed analysis of a virtual model for potential interference in the design of the device. The model also allowed the design team to test different commercial off-the-shelf parts in the designed model with ease in order to find the correct parts that would perform the specified functions.

For reinforcement purposes, the structure of the robot is primarily aluminum 6061 “L Channel” extrusions. This material was chosen due to its high strength per weight ratio, its machinability, and the ease of purchasing. Plastic framing was considered early in the design process, but it was determined to be more difficult to source the required plastic in very small quantities than to simply go with the aluminum. Thus, in order to match the engineering requirements to the team’s

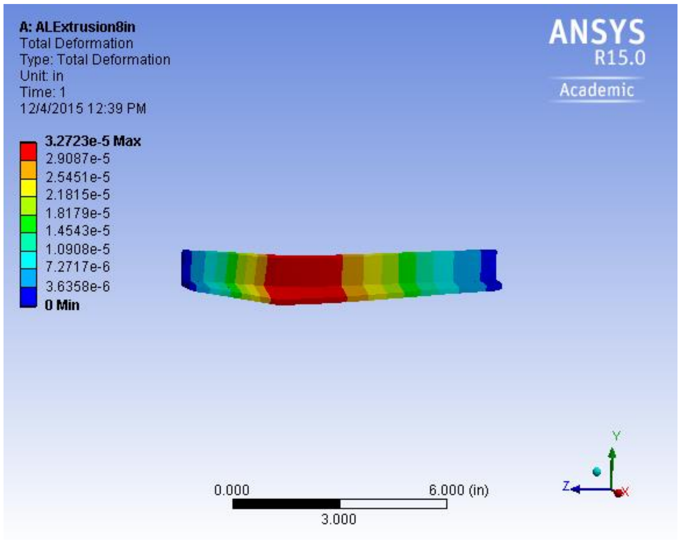

Figure 1: Finite Element Analysis of the Frame

assigned budget, aluminum was selected. The structure of the robot was checked for deflection using Von Mises stress theories. Due to the robot weighing little and having a low loading, the deflection that was calculated was below 0.001 inch. This can be seen in Figure 1.

When the design process began, the team had previously determined the robot would need to use steel or aluminum for all shafts on the robot. Calculations were used in order to determine the best shaft material for use, including shear moment calculations, to test for the amount of deformation expected out of the shaft. Additionally, the DE Goodman and Gerber criteria were utilized to test the risk of failure and determine if the safety factor on the shaft was greater than one.

Running these calculations determined either aluminum or steel would work as the shaft material. The primary goal then became to match the wheel mounting point to the shaft via a commercially available shaft. A matching shaft and wheel were found, by utilizing a hexagonal shaft made of steel. Some concern was indicated regarding the sharp points potentially causing stress concentration issues, but the loads on the shaft were very low so it was considered to be unnecessary. Lastly, this final shaft was checked for fatigue failure and it was found that, due to the low load, the risk of failure was extremely minimal.

A unique methodology for the robot's operation is designed around the use of integrated cameras and sensors. The cameras are used to record images for post-inspection review by the operator, while the sensors are used for navigation. The design makes use of infrared distance sensors and ultrasonic range finders. These have both been successfully used in the past for other kinds of robots.[9 10] By integrating these into the programing, the robot has the ability to transmit these variables to the user and also semi-autonomously decide how it should proceed. The signals from the sensors are sent as pulse width modulation (PWM). This is a standard industry communication protocol that relies on high and low voltages to send data packages.

Results

The design results are shown in Figure 2. Construction based on the design is currently proceeding. As the project was constructed, minor design change considerations were required. These changes were made to address how to most efficiently fasten different parts of the robot together. Especially in the drivetrain, where the both sides of the axle has all of the components locked on using a screw and washer. Another consideration that has been considered was how well the design would keep in a straight line. In order to improve this a larger mounting bearing surface was used.

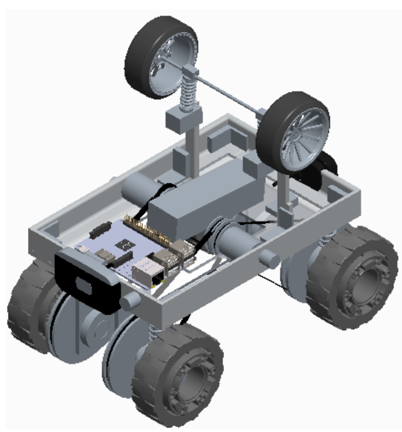

Figure 2: Model of the Inspection Robot

Discussion

Constructing and planning the development of a semi-autonomous robot was no easy feat, but it proved to be extremely successful. Numerous examples of this success come from the results obtained through testing, which back up the analytical data obtained during the design phase. The robot can clearly withstand the rigorous tests it has been put through. The robot was able to successfully navigate the obstacle course and held up without even a distant sign of problems. Utilizing FEA and engineering calculations proved helpful to ensure the design would be able to hold up to the testing. As a result of taking the time to perform the calculations and simulate the

FEA, the robot performs exactly as expected. The results obtained from the data early on correspond with the observed analysis of the project. There is virtually no deformation that occurs on the frame. In addition, the gearing of the motors worked out even better than anticipated. The shafts are more than sturdy and clearly demonstrate the calculations from the design process are accurate.

Conclusion

The project used several advanced engineering tools and techniques. With the number of deaths increasing yearly due to navigation into risky tunnels and dangerous environments, it is essential to embrace this type of device. There are many incidents where it becomes difficult to detect a life in potential harm. The project will help in improving safety and reliability of equipment and workplace conditions.

The semi-autonomous inspection robot was made successful through intensive research in the engineering field. All the decisions made throughout the project have aspects of engineering and accurate calculations. The design process gave the group a great first experience in design and construction of an engineering project. It demonstrated where shortcomings are likely to occur when working in the industry and provided useful experiences on how to correct them. Great teamwork was fundamental in ensuring the success of this task. It is evident that all students involved were determined to come up with special equipment while using engineering as a tool to conquer all the constraints that arose. For instance, this robot emerges as unique from others due to the use of the Raspberry Pi architecture. Choosing a Raspberry Pi architecture enabled the longevity and usefulness of the product, while also enabling a wide array of functions at a low cost. Furthermore, the decision to use Aluminum Al-6061 as its body structure reflects on the bright ideas behind this project. The use of other engineering tools such as cameras and the internet enabling equipment propels this project to a top level status in the field of student engineering. With this in mind, it is evident that any company will be ready to grasp the knowledge from this project for their use and satisfaction. Therefore, people in the world should be ready to accept positive changes and innovations coming from great minds to make the world a better place.

Acknowledgements

There were challenges associated with the design, build, and testing activities in the project. The team would like to recognize everyone who contributed to building the inspection robot and making it such a success. This includes, first and foremost, thanking all of our team, who through their hard work made this project come to fruition. Secondly, we would like to acknowledge Dr. Mazumder for his assistance, guidance, and teaching on product design. In addition, John O’Brien reviewed all designs for their manufacturability, and assisted in the actual manufacture of the design. Lastly, a large and extended thanks to the friends and family of the team, as they have been a great resource for support since the beginning of the project.

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