Project Number: MQP TP1-IPG1

Experimental Validation of a Scalable Mobile Robot for Traversing Ferrous Pipelines

A Major Qualifying Project (MQP)

Submitted to the Faculty of

WORCESTER POYTECHNIC INSTITUTE

In partial fulfillment of the requirement for the

Degree of Bachelor of Science

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Robotics Engineering

This report represents the work of four Worcester Polytechnic Institute (WPI) students, submitted to the faculty as evidence of completion of a degree requirement. WPI routinely publishes these reports on it's website without editorial or peer review.

ABSTRACT

This project involved the design, construction, and testing of magnetic wheels for use on a mobile robotic platform developed for the laser welding of oil and gas pipelines. The current process is a dull, dirty, and dangerous job that can easily be delegated to an enhanced process with the use of a mobile robot. The goal of the project was to experimentally validate a scalable magnetic wheel design for use on a mobile robot platform. This involved researching and testing various types and configurations of magnets for use in magnetic wheels, constructing test fixtures, modifying a test chassis, as well as developing a control algorithm to accurately track the weld seam and traverse the pipe.

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EXECUTIVE SUMMARY

There are numerous industrial applications for a mobile robotic platform. This Major Qualifying Project (MQP) focuses on two in particular: pipeline and shipbuilding industries. With the gas and oil industry growing around the world and ships used for global transportation these are valuable markets that have large opportunities for profit. The most common pipelines being constructed are natural gas lines, with approximately 75% of all construction between the years of 2011-2015. With the many construction jobs and future projects planned within the United States, as well as through partnerships with neighboring countries, the pipeline industry will continue to move forward. This is an industry that has many applications for a robotic platform. Welding is the most obvious use, although companies could use a mobile platform to inspect the current pipeline for problems and weaknesses. These construction jobs are currently very tedious and physically demanding for workers. A robotic platform operated by workers would be a safer option and would consistently achieve the desired weld quality.

Examining the areas of improvement for the laser welding of oil and gas pipelines revealed the motivation behind this MQP. The project sponsor, IPG Photonics, is seeking to develop a mobile robotic platform for laser welding that can traverse completely around an oil and gas pipeline. The sponsor is interested in eventually entering the market with a commercial robot starting with a design from zero approach. This project lays down the groundwork for our sponsor's endeavor, focusing around experimental validation to ensure decision-making for initial designs.

Once the inspiration for the project was realized, we determined exactly what we wanted this robotic platform to do. We compiled an extensive list of functional requirements to ensure that the robot would be capable of performing up to the sponsor's initial expectations. We constructed this list through industry research, literature reviews, and recommendations from our sponsor. The most important functional requirements revolved around the geometrical constraints of the chassis, the payload capacity of the platform, and the speed at which the robot should travel. Research in the industry of oil and gas pipeline welding revealed that the approximate minimum diameter of pipe being welded was 0.5 meters. Based on this information, we set a functional requirement that our robotic platform should have the capability of traversing around a 0.5 meter pipe. In terms of payload, the team calculated the payload of all fixtures involved with laser welding and determined that the platform should be able to support a payload of 15 kilograms. This calculation includes a laser head, cable bundles, and necessary equipment. And on the subject of speed, the sponsor had a strict requirement that the robot should maintain a constant speed of 80 inches/minute to ensure a quality weld.

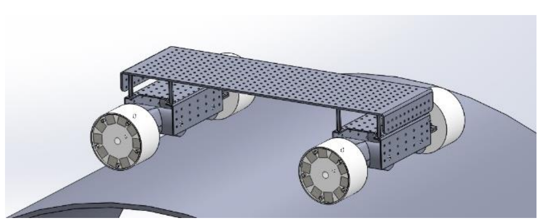

Figure 1: CAD Rendering of Prototype

A novel wheel was designed to facilitate adhering a robot platform to a ferrous surface of varying geometry. 3D printing was used to create physical models of early stage designs. Featuring embedded permanent magnets spaced around the periphery of the wheel, the novel design was successful in adapting to varying circular and flat geometries. The wheel is an example of scalable design in that increasing the number of wheels and magnets will increase the payload capability of the robot chassis.

The first two experiments we performed were the Magnet Engagement Test and the Magnet Force Test. The objective of these experiments was to identify which magnets would perform best in four specific areas: engagement distances, vertical force, shear force and force applied at 45 degrees. The magnets tested were chosen to offer as much diversity within testing as possible, varying in length, width, height and shape. The full analysis showed clear stand out magnets, which included two block magnets and one cylinder. One of each geometry was chosen for further testing with the wheel design.

A commercial off the shelf robot chassis was used as a test platform for the novel magnetic wheel design. The chosen platform featured a universal bolt-hole pattern on the top surface, simplifying the task of laying out robot electronics. Two of the six wheels were removed such that the geometry functional requirement could be met. 3D printing technology was used to prototype wheel designs, allowing intermediate analysis of wheel effectiveness.

In order to perform experiments in a dynamic environment, we needed to add simple controls to our prototype. In order to control the chassis, we initially started with the Orangutan X2 for motor control. This controller provided enough current to run both sets of motors. The X2 was used to control the motors, take input from the control board, and send a start byte to the Arduino Uno. As the project progressed and we added more advanced sensors, we picked up an Arduino Uno. This allowed us to read all of the sensor data and preform all calculations off-board the X2. The Uno read the raw accelerometer and gyroscope values from the Inertial Measurement Unit (IMU), then it sent those values to the X2. The sensor that we focused on was the Triple-Axis IMU with 3 accelerometers and 3 gyroscopes allowing us to measure linear acceleration and angular velocity along three axes.

After the robotic platform was manufactured and wired with controls and sensors, the team tested the prototype with two experiments that analyzed the performance of the model. These tests were designed to ensure that the functional requirements were met with the current design.

The first experiment was to test the payload capacity of the platform. The robot was equipped with the magnetic wheels and attached to the bottom of a pipe fixture. Weights were then added to the robot to test how much the robot could hold without breaking magnetization from the pipe. With the optimal geometry of magnets in the wheels, the robot resulted in an average payload capacity of 17.48 kilograms, which indeed exceeded our functional requirement of a payload capacity of 15 kilograms.

The second experiment was designed to validate out functional requirement of smooth and constant speed traversal of a ferrous surface by measuring the effect of magnet spacing on robot mobility. With the accelerometer logging data, the robot was run for a set amount of time across a steel surface. This data was compared to the baseline where the wheels were propped up off of the ground. Looking at the data, clear spikes in acceleration are visible at evenly spaced intervals that correspond to the spacing of the magnets. From this we can conclude that decreasing the spacing between magnets will decrease the jerk of the wheels, allowing for a smoother traversal of a ferrous surface.

Throughout the process of designing a mobile robotic platform for traversing ferrous pipelines, the team was able to come to a number of conclusions, as well as many recommendations for future work to be done on this project. It can be stated that the torque requirements of the motors are a function of the magnet shear strength. The robot must break the shear strength of the magnet with the surface in order for the wheels to turn and remain on the surface. With the payload testing validation, it can be stated that with an increase of the number of wheels and number of magnets, there is an increase in the payload capacity. In terms of the cogging effect, it can be stated that decreasing the spacing of the magnets in the wheels will reduce the cogging effect.

We believe that the focus of future work should be improved design and reiterations of the testing we performed. Additional testing should investigate the payload effects of adding wheels, reducing magnet size, multiple wheel designs, magnet orientation, and wheel size. With these tests, further design of a more robust chassis will be needed. This chassis should include high torque motors in order to better meet the needs of our applications. The consolidation of electronics down to one microcontroller as well as the integration of more sensors allowing for autonomous pipe traversal with advanced software functionality is also an area of future work. The team feels that the deductions that we have made in terms of design and testing have laid out a solid groundwork for a possible revolution in the oil and gas pipeline welding industry.

Figure 2: Final Manufactured Mobile Robotic Platform