STUDENT SUMMER INTERNSHIP TECHNICAL REPORT

Simulation of a Mobile Robotic Platform in Gazebo and RViz using ROS

DOE-FIU SCIENCE & TECHNOLOGY
WORKFORCE DEVELOPMENT PROGRAM

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Principal Investigators:

Michael DiBono, DOE Fellow Student
Florida International University

Dr. Mitch Pryor, Mentor
Nuclear and Applied Robotics Group – University of Texas at Austin

Florida International University Program Director:

Leonel Lagos Ph.D., PMP®

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ABSTRACT

The purpose of this internship was to simulate a mobile platform designed for the inspection of the H-Canyon Air Exhaust (CAEX) tunnel at the Savannah River Site. The platform, named VaultBot, consists of a Husky base, two Universal Robots UR5 manipulator arms, and a single SICK LMS291 light detection and ranging (LIDAR) sensor, although in simulation a second LIDAR was added. The VaultBot was simulated in Gazebo (an open source robotics simulator) in tandem with RViz (a 3D visualization tool), using the Robot Operating System (ROS). While in the simulation environment (modeled after the CAEX tunnel), the VaultBot is able to provide vertically-aligned 2D laser data from the second LIDAR, which can be used to create a pointcloud of the tunnel's walls. The miniature inspection tool in development at Florida International University was also simulated in order to demonstrate its capabilities in a similar environment. Finally, a full-scale mockup of a section of the CAEX tunnel was constructed in order to test the VaultBot in a real environment. For future work, the knowledge and practice gained from this work at the University of Texas at Austin will be taken to Florida International University to incorporate with their robotics systems as needed.

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1. INTRODUCTION

The H-Canyon is the only hardened nuclear chemical separations plant that is still in operation in the United States. Located at the Department of Energy's (DOE) Savannah River Site (SRS), its operations included using a chemical separations process to recover uranium-235 and neptunium-237 from enriched-uranium fuel tubes which were provided by nuclear reactors (both domestic and foreign). While originally constructed in order to produce nuclear materials in support of defense weapons systems, it now plays a role in the elimination of nuclear materials. The H-Canyon exhaust air is routed through a tunnel, traveling through a sand filter, fans, and out of the stack. This tunnel, named the Canyon Air Exhaust (CAEX), is made from reinforced concrete. The conditions within the tunnel create a major challenge for its inspection, which is required to evaluate the tunnel's structural integrity. These conditions include:

- Acid vapors
- Air ducts with varying diameters (1 meter and 0.5 meters) that require inspection
- Alpha contamination
- Beta-gamma dose rates (10-1,000 mRem/hr)
- Debris and other physical obstacles
- Pools of water as deep as 13"
- Uneven floor surfaces

There have been multiple partial inspections with various inspection tools. The first three inspections were performed by lightweight and small tethered systems. These systems were low cost and were used to deploy a teleoperated pan-tilt-zoom camera. They were only deployed in areas close to the H-Canyon building, and all three eventually became stuck and irretrievable. This added to the list of obstacles that tools already had to overcome to do a proper inspection of the tunnel. A new system was developed in 2014 in order to perform further inspection. The Inspection Crawler (IC) was still low-cost and teleoperated, featuring a scissor lift with an extendable mechanical slide and two pan-tilt-zoom cameras. This tool inspected approximately 100 meters of the tunnel before falling debris prevented the retraction of the mechanical slide, resulting in the system tipping over when operators attempted to drive the platform.

In order to recover the IC, a new system was created that was capable of up-righting it. The Recover Crawler (RC) was designed to perform minimal inspection with its main task being to help clear the IC from the inspection path. It was able to upright the IC; however the IC was unable to perform any additional inspections. The RC inspected approximately 200 meters of the tunnel after lifting the IC, and was successfully retrieved and decontaminated. It was unable to perform the necessary inspections behind the air ducts, but it did collect images from areas that were never before inspected.

There is still a need for a system that can provide better methods to view behind the hanging ducts and pipes, while also being able to overcome all of the harsh conditions of the tunnel. SRS also expressed a desire to develop more sensors past video imaging, collect simultaneous localization and mapping (SLAM) data from LIDAR, and perform everything in real time. In order to create a system that meets these requirements, the University of Texas at Austin's Nuclear and Applied Robotics Group (UT NRG) created a team with unique expertise and backgrounds, made up of Florida International University (FIU), the University of Florida (UF), AREVA, and Savannah River National Laboratory (SRNL). Each section of the team is responsible for a different portion of the project, with the focus of this paper being on the efforts of UT NRG and FIU.

2. EXECUTIVE SUMMARY

This research work has been supported by the DOE-FIU Science & Technology Workforce Initiative, an innovative program developed by the US Department of Energy's Environmental Management (DOE-EM) and Florida International University's Applied Research Center (FIU-ARC). During the summer of 2017, a DOE Fellow intern Michael DiBono spent 10 weeks doing a summer internship at the Nuclear and Applied Robotics Group in the University of Texas (Austin, Texas) under the supervision and guidance of Dr. Mitch Pryor. The intern's project was initiated on June 3, 2017, and continued through August 12, 2017 with the objective of learning ROS to create a full simulation of the VaultBot mobile platform in Gazebo.

3. RESEARCH DESCRIPTION

3.1 VaultBot

UT Austin has developed a dual-arm mobile manipulator for inspection and radiation surveying. While meeting many of the requirements necessary for the inspection of the CAEX tunnel, the VaultBot does not meet all of them. It consists of a Clearpath Husky base with a FitPC and inertial measurement unit (IMU) mounted inside the user bay. Mounted to the front is a SICK LMS511 2D light detection and ranging (LIDAR) sensor, used for mapping and navigation. The VaultBot utilizes two Universal Robots UR5 industrial manipulators mounted to a steel bulkhead on the top of the Husky.

3.2 Husky Base

The Husky is a medium sized robotic development platform. Weighing about 50 kg and capable of supporting a maximum payload of 75 kg, it has a maximum speed of approximately 1.0 m/s. This platform was chosen due to the unit's ability to withstand harsh environments.

3.3 SICK LMS511 LIDAR

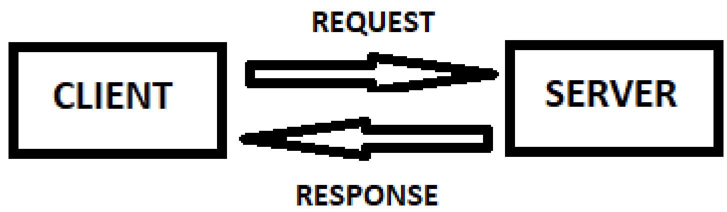
Light detection and ranging (LIDAR) sensors use ultraviolet, visible, or near infrared light to image objects. Light is reflected through backscattering. The SICK LMS511 uses infrared light (905 nm) to create these images, with a maximum scanning range of 80 m. The LIDAR is pivotal to the mapping of the CAEX tunnel. The data collected from the LIDAR can be used for the creation of a map of the CAEX tunnel.

3.4 Universal Robots UR5 Industrial Manipulator

The UR5 is an industrial manipulator with a maximum range of 850 mm. It has six rotating joints, all with a working range of ± 360º and a maximum speed of 180º/sec. Each arm can support a maximum payload of 5 kg, and weighs a total of 18.4 kg. The arms have a variety of settings, one of the most useful being the "teach" mode. While in this mode, the joints of the arm can be positioned in any way while still in torque. The arm also has controller level monitoring of joint position, speed, and torque during operation, and will perform an emergency stop if values are detected outside of the specified thresholds. This is important, as it can reduce the concern of manipulator collisions with the environment due to localization errors.

3.5 Robotic Operating System

The systems developed at UT NRG utilize the Robotic Operating System. Robotic Operating System (ROS) is an open-source collection of software frameworks for robot software development. The systems are comprised of independent *nodes* which communicate with each other over *topics*. Nodes are not aware of what they are communicating with. Instead, they either *subscribe* or *publish* to the relevant topic, depending on if they are interested in the data provided (subscribe) or would like to generate data (publish). Due to the structure of this system, if a node publishes a message, there is no guarantee that another node is subscribing to that message. The alternative method of communication to this is called a *service call*. In a service call, one node (*client*) sends information (*request*) to another node (*server*), and waits for a reply. The reply from the server node is called a *response*.



Packages are the modules of ROS, organizing software and containing things such as ROS nodes, configuration files, etc. Packages are meant to make developed items in ROS easily reusable. ROS does not redefine the traditional vocabulary of programming, instead adding features to the programs themselves. It allows communication between them, and provides a collection of various code libraries as extensions. The framework that ROS creates is extremely useful for robotics, as programs used for simulation can also be used interchangeably with the actual robot.

3.6 Gazebo

Simulation is important to the design of a robotic system. Should a system fail in a simulation, it will fail in a real environment. Simulations provide further insight to design flaws and allow researchers to “practice” with a system before committing to building a physical one. It is better to catch a failure in a simulation then in a real environment due to the extra cost, building times, etc. that come along with a physical build.

Gazebo is a dynamic physics simulation software. It provides realistic rendering of environments in a 3D world. Robot models can be custom built and simulated using Simulation Description Format (SDF). These models can be interchanged within custom world files, allowing for robots to be tested in the exact same environment and conditions as others. Sensors can be implemented in simulation, ranging from contact sensors to laser range finders.

The CAEX tunnel was modeled in Gazebo as a custom world. The Vaultbot was then simulated in this environment.

3.7 RViz

RViz is a 3D visualizer that is used for the display of sensor data and state information from ROS. It is a package in ROS that visualizes robots, laser data, etc. Data obtained from a simulation or from a real environment can be visualized, and multiple vision processes can be displayed at the same time (pointclouds, cameras, etc.). RViz can also be used to control robotic arms, which was useful for the simulation of the Vaultbot.

3.8 Simulation of the Vaultbot

The simulation of the Vaultbot was performed in Gazebo, with sensors being visualized in RViz. The Vaultbot within the simulation is capable of lateral movement with its four simulated wheels. It was given two speeds, a slow and fast setting. This movement was controlled with a dual joystick game controller. The two UR5 arms mounted to the left and right side of the Vaultbot can be manipulated into various poses within RViz. A variety of predefined poses were created for the arms, ranging from a compact mode with the arms as close to the sides of the Vaultbot as possible, to an inspection mode involving the arms positioned to place a camera behind the larger diameter pipe.

While the physical Vaultbot only has one 2D LIDAR (mounted to the front of the robot), the simulated Vaultbot has a second 2D LIDAR mounted on top of its main body. The second LIDAR was positioned so that the laser was facing vertically towards the sky. The front facing LIDAR was used for the purpose of creating a map of the world, while the vertically facing LIDAR was used to create a model of the tunnel. The model of the tunnel was achieved by stitching the 2D laser scan data together scan-by-scan, creating a 3D model (Figure 1).

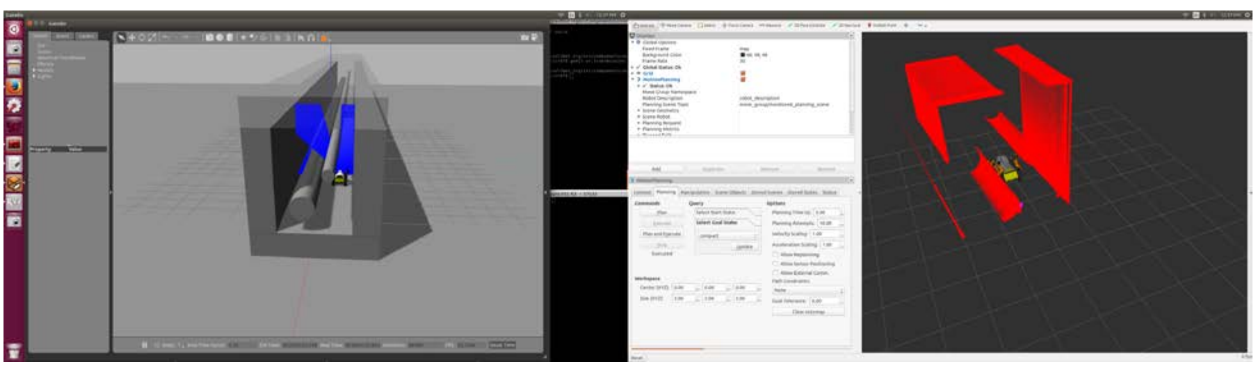


Figure 1. While the Vaultbot is within the Gazebo simulation of the CAEX tunnel (left), it can stitch together the laser scan data from the vertically mounted 2D LIDAR to form a 3D model (right).

A ROS package was created to contain all of the components needed. The CAEX tunnel world, the Vaultbot, and all of the sensors were programmed to launch from a simple file.

3.9 Simulation of the Miniature Rover

There was motivation for the team at UT to utilize a technology developed at Florida International University (FIU) for better inspection of the tunnel. The magnetic miniature rover developed at FIU would be able to reach around the pipe into places unreachable by the arms of the Vaultbot. Due to this, there was motivation to support the simulation of the miniature rover in tandem with the Vaultbot. While not the primary focus of the internship, the miniature rover was simulated in Gazebo. With a camera mounted to the front, the miniature rover can travel across the tops of the pipes within the simulated CAEX tunnel world. The data from the camera is visualized within RViz.

3.10 Construction of Physical Mockup of CAEX Tunnel

Another goal of the internship was to construct a physical mockup of the CAEX tunnel in order to test the Vaultbot and other developed technologies within a more realistic setting. While the mockup constructed can't emulate a majority of the harsh conditions the platform would experience (ranging from acid vapors to extreme temperatures), the purpose of it is to demonstrate the constraints on size needed to fit and maneuver within the tunnel. The section of the constructed tunnel was made out of wood, with metal tubes of diameters close to that of the actual tunnel suspended from the top beams. The Vaultbot was able to successfully travel throughout the tunnel, although the internship ended close to the actual testing of the robot in the tunnel.

Figure 2. Construction of the section of the CAEX tunnel.

5. CONCLUSION

All of the primary goals of the internship at the University of Texas at Austin were met. Through the use of ROS, the Vaultbot and all of its sensors was successfully simulated within the Gazebo world of the CAEX tunnel. A physical mockup was constructed in which to test the actual Vaultbot. In addition to the requested work for the internship, the miniature rover developed by Florida International University was partially simulated within the Gazebo world of the CAEX tunnel as well. For future work, the knowledge gained from this internship will be applied to fully implement a simulation of the miniature rover into a Gazebo world of the annulus of the HLW tank AY-102 at the Hanford Site.

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