STUDENT SUMMER INTERNSHIP TECHNICAL REPORT

Deployment of the Pipe Crawling Activity Measurement System (PCAMS)

DOE-FIU SCIENCE & TECHNOLOGY WORKFORCE DEVELOPMENT PROGRAM

Date submitted:

September 14, 2018

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Submitted to:

U.S. Department of Energy
Office of Environmental Management
Under Cooperative Agreement # DE-EM0000598

FIU | Applied Research Center
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ABSTRACT

The Portsmouth Gaseous Diffusion Plant was built during the Cold War Era, in an effort to better arm the United States during this tumultuous time. It was used to enrich uranium which would be used in the development of nuclear weapons. Measurement of deposits of leftover uranium within the pipes of the facility is both time consuming and expensive. The deactivation and decommissioning of them is a lengthy process filled with many obstacles, ranging from manual deployment challenges to long counting times. The internship was focused on the completion and deployment of the Pipe Crawling Activity Measurement System (PCAMS), which is a robot in development by Carnegie Mellon University's (CMU) Robotics Institute to address this problem. It included supporting the team during both a cold and hot deployment, in addition to multiple weeks of preparation leading up to that point. Another portion of the internship was dedicated to the policy side of the Department of Energy (DOE) at the headquarters building located in Washington D.C.

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1. INTRODUCTION

This paper provides insight to the operation of the Pipe Crawling Activity Measurement System (PCAMS), along with various design choices and functionality. The system measures grams of uranium 235 (U-235) per foot within deposits in the process piping. It provides a safe and efficient alternative to gathering information from pipes of varying diameters (30” and 42”). The system is more than just a robot, taking advantage of a network comprised of different components. These components include:

- RadPiper robot
- Launch rig
- Tablet interface
- Calibration pipes (30” and 42” diameters)
- Post processing software
- PCAMS database
- PCAMS server

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). Additional support for internship costs were provided by Carnegie Mellon University. During the summer of 2018, a DOE Fellow intern Michael DiBono spent 10 weeks doing a summer internship divided between Carnegie Mellon University's Robotics Institute, the Department of Energy Headquarters in Washington DC, and the Portsmouth Gaseous Diffusion Plant, under the supervision and guidance of Dr. William Whittaker (CMU) and Rodrigo Rimando (Office of Technology Development, DOE EM). The intern's project was initiated on June 4, 2018, and continued through August 10, 2018 with the objective of supplementing CMU's efforts with the development and deployment of an alternative method to survey radioactive deposits in process pipelines. This research was also supported by two additional DOE Fellows from FIU, Christopher Excellent and Joshua Nunez.

3. RESEARCH DESCRIPTION

The PCAMS Network

While under the operation and supervision of a non-destructive assay (NDA) technician, the RadPiper robot travels at a constant speed when traveling through pipes of varying diameters (30” and 42”). A detector, positioned parallel to the pipe’s centerline, logs the spectra of gamma radiation detected from the U-235 deposits within the pipe. Acquired as counts per second, it is transformed to a moving average of counts per foot based off of the robot’s velocity. The grams of U-235 per foot of pipe are proportional to the integration of counts under the 186 keV peak corresponding to the isotope of uranium. The calculations and corrections necessary for self-attenuation are made automatically within the PCAMS’s post-processing software.

PCAMS is capable of providing the locations of the loadings within the pipe it is inspecting. Encoder counts are logged from the movement of the tracks that support the robot. The absolute distance is acquired from a laser range sensor at the rear of the robot. The encoding and laser data are fused together within the post-processing, in order to achieve an accurate and precise history of the robot’s journey through the pipe (both forward and backward).

The physical deployment of the robot is not performed manually by the NDA technician. First the launch rig is placed onto a scissor lift with the use of a hand-pump crane. The launch rig is secured using two keys on the front legs. The robot is then lifted from the robot stand onto the launch rig, where it sits until sent into the actual pipe. Pipes are located at varying heights, and therefore require the launch rig to be properly aligned with the end of the pipe using the scissor lift. Before going into the pipe, the RadPiper performs a quality control (QC) check to confirm the background radiation. After returning from its travel (whether completing a full run or initiating a safeguard procedure), the RadPiper performs a post-run QC check in order to assure there was no change in ambient radiation. PCAMS is used to log data, process gram loadings, and auto generate reports in regards to deposits of U-235 within pipes.

Sensor Suite of RadPiper

The RadPiper robot contains a series of various sensors that work together in order to collect the required data. The sensors are divided between the front and rear of the robot. At the rear, the planar laser scanner (also referred to as a LiDAR) produces a surface model of the pipeline deposit geometry. The rear-pointing laser range finder is used in conjunction with the rotary track encoders in order to measure the distance driven.

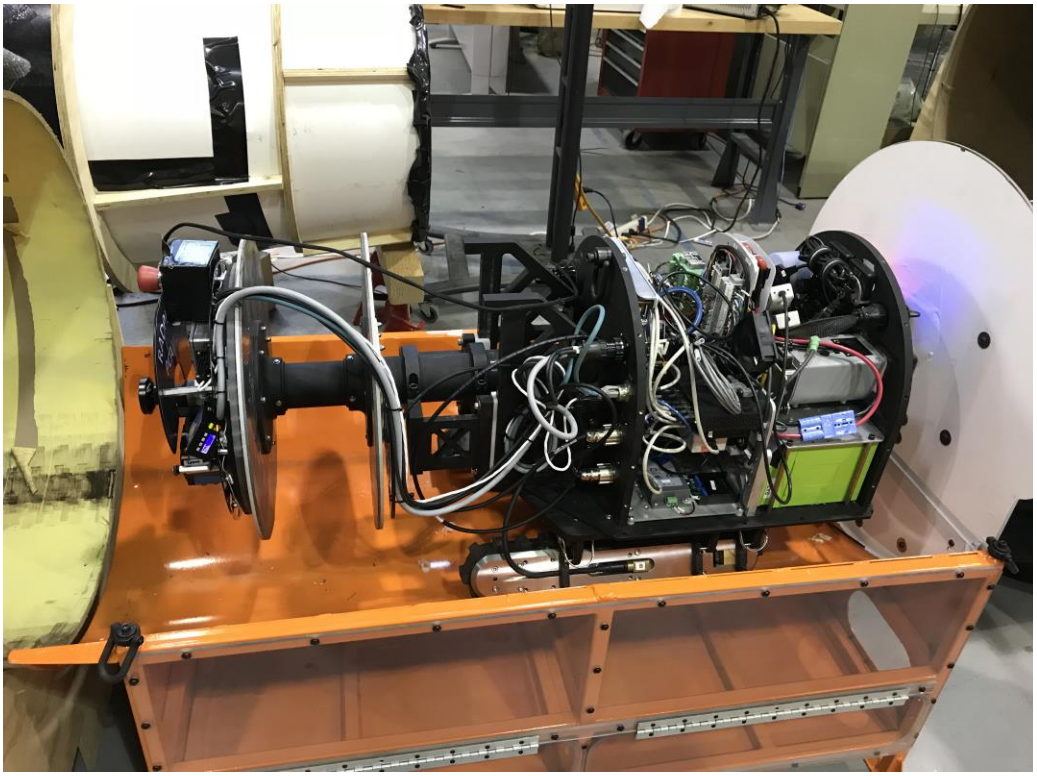

Figure 1. RadPiper robot in launch rig.

At the front, a camera provides video feedback of the robot's journey through the pipe. A three dimensional mapper measures the approaching geometry, which is used to trigger the robot's safeguard procedures. The safeguard initiates when an obstruction over a certain size is detected, and forces the robot to reverse direction and return to the launch rig. Two single-point distance sensors also support the safeguarding of the robot.

The most important part of the RadPiper lies in the collimating discs at the front of the robot. This is the section that acquires the data regarding the gamma radiation counts. The measured quantity of U-235 is proportional to the counts that occur under the 186 keV peak. A pair of discs bracket a NaI(Th) detector. The distance between the discs is set so that the detector can only view a foot of pipe wall at a time. This is achieved through a lead plate backing an aluminum one, which limits the field of view of the detector. This is positioned parallel and coaxial to the centerline of the pipe. An americium-241 source is embedded in the detector assembly, which allows for a comparative quality control check. This entire setup is referred to as the collimator of the robot.

The height of the collimator along with the track angles can both be adjusted to allow the robot to run through either a 30" or 42" diameter pipe. These are both adjusted when the robot is in the robot stand, and should not be attempted while the robot is in the launch rig. The movement is achieved with the same hand-pump crane that is used to place the robot onto the launch rig.

Figure 2. Robot stand that allows for the transformation of RadPiper to either 30” or 42” configuration.

Preparation for Deployment

The primary task of the internship was to assist the CMU team in preparing the PCAMS system for deployment in both a cold and hot test at the Portsmouth Gaseous Diffusion Plant, located in Piketon, OH. The CMU team divided the task across multiple disciplines in order to effectively work on the project. Originally working with the mechanical team, Mr. DiBono also worked with the software team in order to help troubleshoot the robot for the actual deployment.

While working with the mechanical team, Mr. DiBono assisted in the machining of various parts for the RadPiper robot. One such part was an integral part of the collimator, which detected locations of radiation radially. In order to minimize the interference of wires that needed to stretch past the collimator, a mechanism needed to be constructed to distribute the wires diagonally across the discs. This was achieved by utilizing a variety of machines, including a computer numerical control (CNC) router, a bandsaw, and several hand tools.

Another major part of the assigned task was to assemble various test conditions to better prepare PCAMS for deployment. The pipes at the Portsmouth site have a variety of openings that needed to be detected to allow for proper safeguarding of the technology. One type was designed as a swept-t, which was used in order to maximize the velocity of fluids traveling through the pipe. The testing apparatus to simulate the swept-t opening was constructed out of metal flashing and cardboard, and was then used to calibrate the safeguard features of the RadPiper robot.

Figure 3. Swept-t pipe section under construction.

The CMU team also wanted to prepare the system for varying geometries within the pipes. Mr. DiBono and Mr. Excellent designed a series of geometry tests in order to meet this need, ranging from a series of block tests to circumferential rings that lined the insides of pipes. The blocks, made from wood, were evenly spaced across a test pipe with the original intent of simulating deposit buildup. The block tests exposed a major flaw in PCAMS, which was not accurately logging the location of the flagged geometries. The circumferential rings were used to simulate possible buildup around the weld seams that line the interior of the pipes. They were each made with varying thicknesses, in order to simulate various levels of buildup. The rings were especially important, as they showed that the rotating LIDAR on the back of the system was able to properly detect them.

A test involving blocks of varying thicknesses was also implemented, in order to confirm that the logging of geometries of varying heights was correct. Five test articles were prepared with a constant length (10”) and width (2”), but with varying thicknesses. They were first placed horizontally in the pipe and then vertically, in order to allow for a total of 10 different tests for thickness. The locations of these blocks also inspired a more precise system of localization for the robot, as it was unable to accurately show their locations in the post-processing report.

When working with the software team, Mr. DiBono was able to learn how to operate the robot. Assigned the role of “Test Master” for the cold test, he was required to assist the NDA technicians with the testing of the robot in various configurations divided between two configuration pipes.

After the completion of both the cold and hot tests, Mr. DiBono traveled to Savannah River National Laboratory in order to learn about the current activities at the site. The site visit included a presentation of an intumescent foam being evaluated by Mr. Nunez at Florida International University. A tour of the facilities was provided, and included hands-on interaction with several technologies being developed by the lab. Presentations by the lab's interns were also provided, to showcase their summer research efforts.

After touring the Savannah River Site, Mr. DiBono returned to the DOE Headquarters in Washington, DC. After seeing the hands-on aspect of the EM mission, Mr. DiBono was exposed to the policy side at headquarters. He was able to observe multiple meetings from top management within the Office of Environmental Management, and was tasked with writing a white paper on the effects of robotic systems on work environments. The white paper concluded that robots were supplements to the workforce rather than replacements, and provided various statistical accounts on how robots benefited the workforce rather than taking opportunities away from employees.

4. RESULTS AND ANALYSIS

The results from the geometric tests are depicted in the following images. The images are 2-D representations of the pipes. They slice the pipe into multiple one-foot sections. Each section is split from the top and then unrolled, in order to provide the image below. With this design, the bottom of the pipe is represented in the center of each image while the top is evenly divided between both the leftmost and rightmost edges. The test articles are depicted in different colors indicative of the height of the objects.

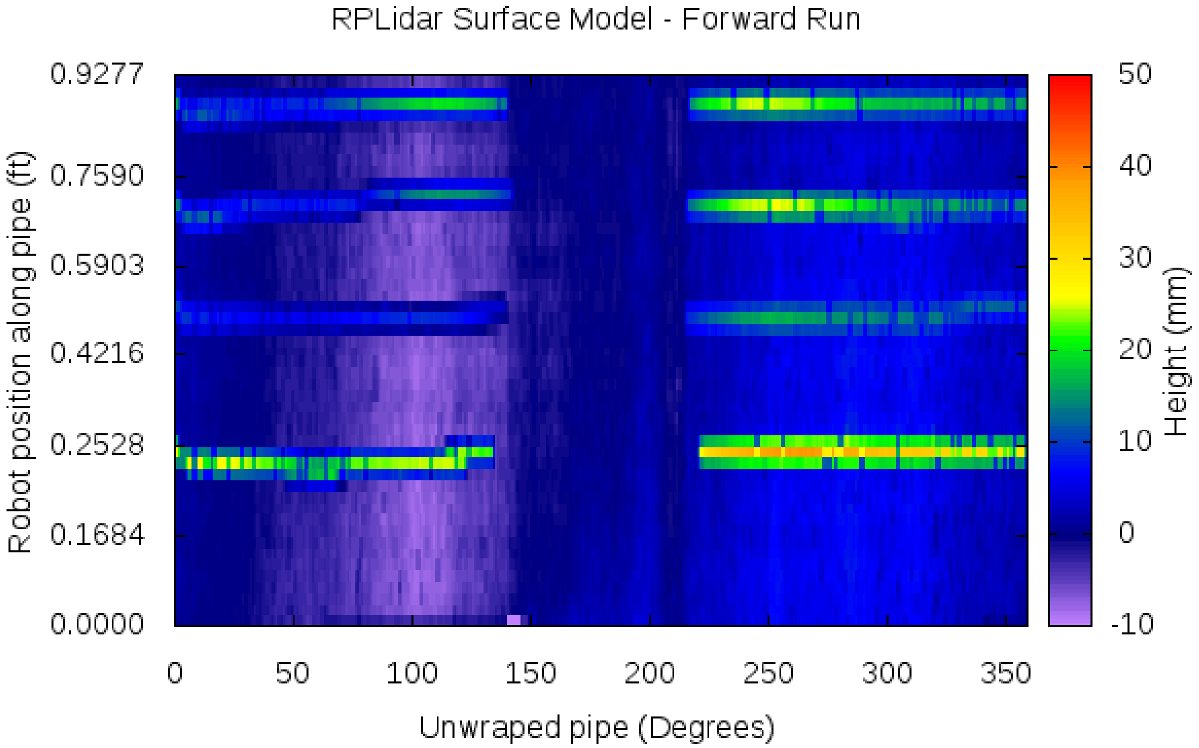

Figure 4. Forward image mapping of the wooden ring obstacles detected by the rear mounted LiDAR,

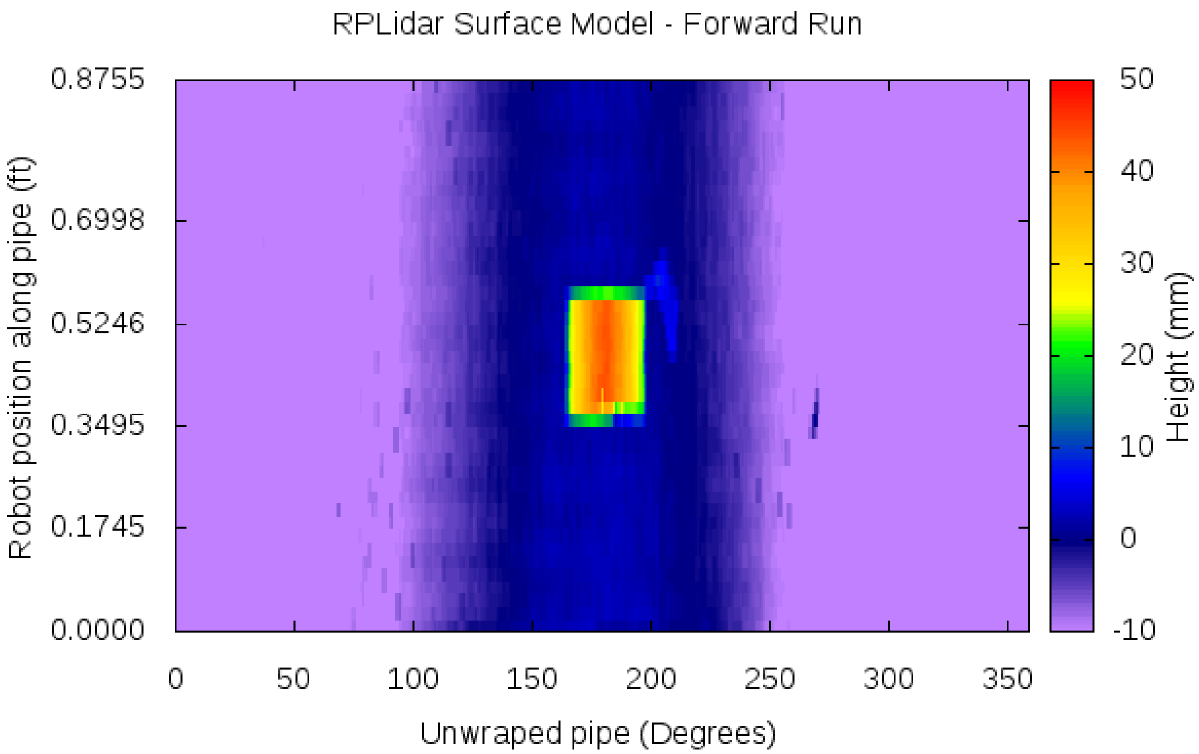

Figure 5. Forward image mapping of the rectangular blocks detected by the rear mounted LiDAR.

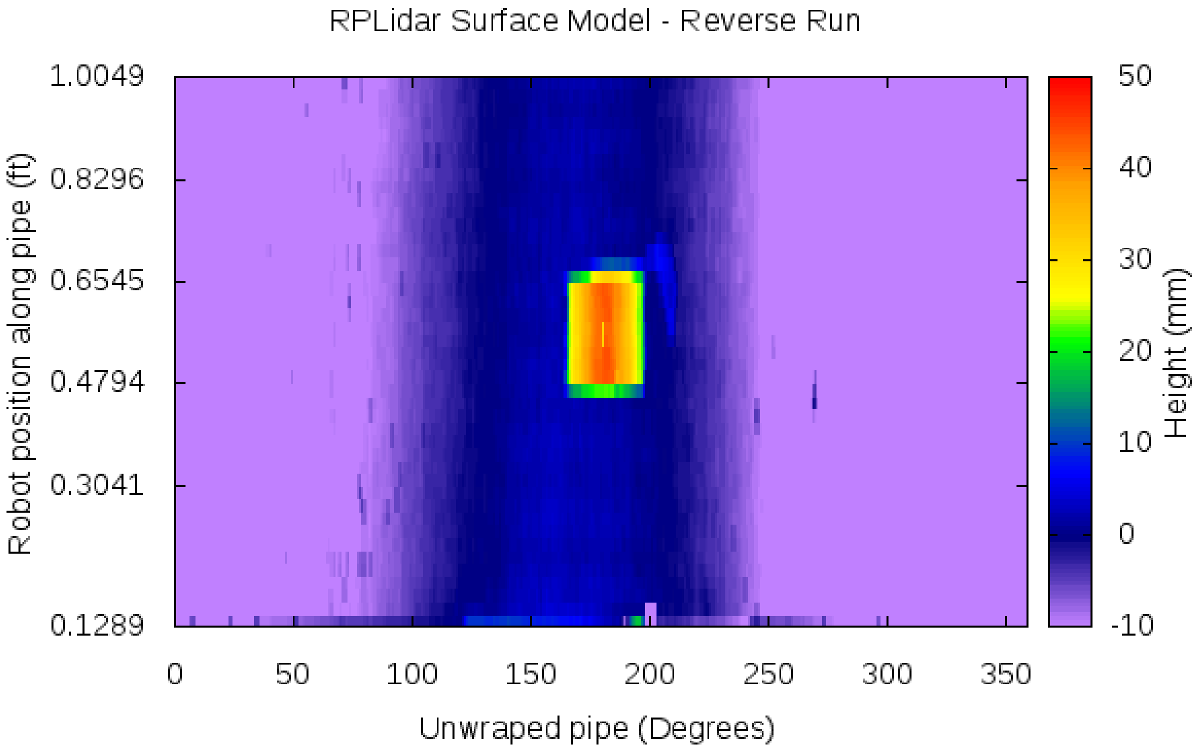

Figure 6. Reverse image mapping of the rectangular block pictured in the previous figure.

As observed in the figures above, the geometry tests revealed that the robot was unable to successfully map the locations of the test articles in the pipe. Not only was this a major problem for the robot to be unable to properly determine the locations of these articles, but a major problem to the overall localization of the robot within the pipe itself. This was crucial to the deployment of the robot, and was promptly fixed by the software team.

While at the cold test, Mr. DiBono was able to successfully complete over 80 tests of the robot between calibration pipes of varying diameters (30” and 42”). The tests were necessary to confirm that the robot was able to successfully detect and localize uranium deposits in the pipes. Calibration pipes were designed to have removable lids along their surface, allowing different uranium sources to be placed in known locations. Tests ranged from varying geometries to varying sources. Mr. DiBono was responsible for directing the NDA team to place sources in certain areas, and monitoring the team as they operated the robot. With the success of the cold test, PCAMS was able to advance to the hot test.

Figure 7. Calibration pipes with sections cut out, to be used for the cold test.

At the hot test, PCAMS was able to move from a controlled cold environment to an actual hot application within the pipes of the Portsmouth plant. The robot was able to successfully travel through both the 30” and 42” diameter pipes, showing that the system works. Safeguarding procedures triggered correctly, and the robot was able to successfully traverse the pipes.

The results of the white paper reflected that robots are not harmful to the workplace, instead greatly benefiting safety and productivity. While some employees were directly swapped for robots, the robots created new jobs, as they still needed operators and managers in most applications. The white paper was presented to Rodrigo Rimando, Director of Technology Development for the Office of Environmental Management.

5. CONCLUSION

A clear understanding of how the PCAMS system benefits the Portsmouth Gaseous Diffusion Plant was obtained, along with an idea for other applications of the system. Due to the success of the system, a request for units to go into other sized pipes was received by various observers at the hot test. PCAMS is a system set to benefit worker safety and improve the efficiency at which they are able to complete inspections of pipes. The robot was able to achieve within 10 minutes what it would otherwise take a team of operators multiple hours.

6. REFERENCES

Carnegie Mellon University's Robotics Institute, & PCAMS Team. (2018). Technical basis for pipe crawling activity measurement system (pcams01).