## STUDENT SUMMER INTERNSHIP TECHNICAL REPORT

# Pipe Crawling Activity Measurement System (PCAMS)

## DOE-FIU SCIENCE & TECHNOLOGY WORKFORCE DEVELOPMENT PROGRAM

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# ABSTRACT

Measurement of uranium-235 (U-235) in holdup deposits within old uranium enrichment facilities is time consuming and very costly. Radiometric assay from outside the pipes suffers from manual deployment challenges, attenuation of detection through pipe walls, long counting times, approximately modeling, and shortfalls associated with transcription and human interpretation. The deactivation and decommissioning (D&D) process of cutting into these pipes creates a unique opportunity for robotic in-pipe assay to address these problems. This project introduces the Pipe Crawling Activity Measurement System (PCAMS) as an automated solution. An in-pipe robot logs radiometric, geometric and odometric data while the PCAMS post-processes the data to compute accurate, certain, paperless assays of U-235 in hold up deposits within the process piping. The robot's enabling capability is an innovative radiometric collimation method that views only a one-foot moving annulus of pipe wall. This exploits the internal axisymmetry of the pipes to provide a direct measurement of industry-standard grams per foot of U-235.

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# 1. INTRODUCTION

This paper profiles the Pipe Crawling Activity Measurement System (PCAMS) with its purpose, components and functionalities. PCAMS robotically measures grams of uranium 235 (U-235) per foot within holdup deposits in process piping. The system provides a safe and efficient way of gathering information from within the process pipes without putting workers in harm's way. Multiple components comprising the PCAMS system work together to gather and process the reported information, including:

- the RadPiper robot
- Launch rig
- Tablet interface
- Two calibration pipes (30 and 42 inch diameters)
- Post processing software
- PCAMS database
- PCAMS server

These are more fully discussed in the following sections.

# 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, Christopher Excellent, spent 10 weeks doing a summer internship at both Carnegie Mellon University's Robotics Institute and the Department of Energy's Headquarters in Washington, DC 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 10th, 2018 with the objective of investigating the PCAMS method at CMU. This research was also supported by two additional DOE Fellows from FIU, Michael DiBono and Joshua Nuñez.

# 3. RESEARCH DESCRIPTION

### The PCAMS Method

The RadPiper robot acquires PCAMS data while driving at constant, deliberate speed in a pipe. A detector positioned on the pipe's centerline logs the spectra of gamma radiation emanating from U-235 deposits on the pipe walls. Spectra acquired as counts per second are transformed to a moving average of counts per foot using knowledge of the robot's velocity. The grams of U-235 per foot are proportional to integration of counts under the 186 keV peak corresponding to the uranium isotope. That calculation with corrections for self-attenuation and uncertainty (along with many other calculations) is made automatically in the PCAMS post-processing software.

Beyond knowing what the U-235 loadings are per foot, PCAMS answers the equally important questions of exactly where those loadings are located in a pipe. The robot logs encoder counts from its track motion along with absolute distance along a pipe from its point laser range sensor. The encoding and laser data are then fused during post-processing into a precise time-history of the robot's outbound and return traverse of a pipe.

An NDA technician deploys RadPiper into pipes without any manual lifting. RadPiper is stored, moved and lifted in a launch rig that nestles the robot. The lifting rig is moved, raised and docked to pipes via a remote-controlled scissor lift. Once aligned with a pipe, a tablet interface launches, commands and monitors the robot. The robot traverses until it autonomously detects an end-of-pipe condition like a closed valve, then it reverses, returns and parks in its launch rig. Data from the run is then transferred to the PCAMS server and stored in the PCAMS database. The NDA analyst or Program Manager then analyzes the data using the post processing software. The resulting processed information is used to generate NDA and nuclear criticality safety (NCS) reports. Hence, PCAMS is used to log data, process calculations of gram loadings, and auto-generate reports.

### The RadPiper Robot

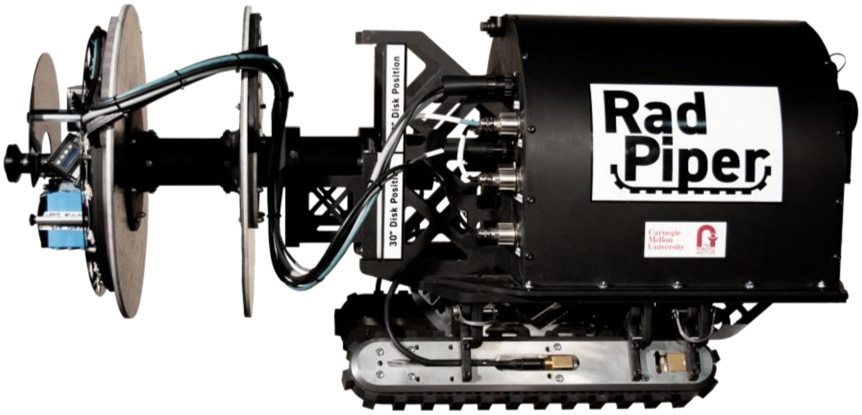

**Figure 1. The RadPiper robot.**

The planar laser scanner on the RadPiper robot produces a surface model of the pipeline deposit geometry. It also registers the robot to the pipe's entrance. The rear-pointing laser range finder was mentioned earlier as an odometry sensor. There are two rotary track encoders that measure the driven distance. A camera acquires visual imagery as the robot travels through the pipe. RadPiper also contains a forward three-dimensional mapper that measures geometry ahead of the robot and triggers the robot's safeguarding and reversing protocol. Two single-point distance sensors augment forward safeguarding.

Using these sensors, RadPiper launches and recovers from the same open end of a pipe. It logs readings from the above sensors during its forward and reverse traversal. This redundancy of forward and reverse readings provides checks and certainties on the information calculated from the data. Another key factor of RadPiper is its ability to assay two different pipe sizes: a 30-inch and 42-inch pipe diameter. RadPiper transforms between these two configurations by adjusting its collimator assembly for height and its track angles for normal contact to pipe walls.Together, these sensors provide key information to ensure the robot's safety and performance.

The disc-collimated gamma detector is the heart of PCAMS. This is the part of the robot that acquires spectra of the gamma radiation counts. The measured quantity of U-235 is proportional to the counts that occur under the 186 keV peak. This energy corresponds to the U-235 isotope. A pair of discs bracket a NaI(Th) detector. The disc separation distance is set so that the detector views a foot of pipe wall at a time and precludes all else. The discs preclude any gamma measurements from forward or rearward of the one-foot field-of-view. The robot positions the discs and detector on the centerline of the pipe and coaxial with the pipe. A small source of americium-241 is embedded in the detector assembly so that the resulting known americium peak in the spectrum can augment quality checking.

## Deployment Preparations

The primary internship task involved preparing the robot for its deployment at one of the Department of Energy's gaseous diffusion plants in Portsmouth, OH. Multiple (and multidisciplinary) tasks had to be completed to achieve this goal. Most of the work was centered around the mechanical components of the project. Working with the project team, Mr. Excellent was able to successfully aid in the design of testing modules that would be used to determine how effective the robot was at collecting geometric data. More specifically, the team wanted to determine if RadPiper would effectively detect and log the location of weld seams inside the pipes. A 270 degree wooden ring was designed to have a thickness of 1 inch and a width of ½ inch. The ring was also designed to be self-holstering while inside both the 30- and 42-inch pipes. The successful design of this ring allowed the programming team to improve the robot's code to ensure that the robot can detect the ring as well as log its location. The team then furthered these tests by making more rings with varying thicknesses for both pipe configurations. Rings with thicknesses varying from ¼ inch all the way up to the 1 inch were designed. These modules can be seen in Figure 2.

**Figure 2. Wooden rings being installed inside the pipes for testing.**

By developing a surface model from the radial range data, the robot scanned and detected these obstacles. The team developed a range of rectangular test articles that were 10 inches long and 2 inches wide, but with varied thicknesses. This was done to ensure that while those rectangular articles were placed inside the pipe, the robot will be able to detect all of them and properly log their location inside the pipe. For the first test, the test articles were oriented in a longitudinal sense and the test run. Then the modules were oriented 90 degrees from that original orientation and the distance from the bottom of the module to the bottom of the pipe was measured; this calculation was essential in being able to analyze if the robot was properly logging the thicknesses. An image of these rectangular modules can be seen in Figure 3. After this test was conducted, the programming team evaluated the data collected by the robot and realized that the robot was detecting and logging the locations of the modules. However, the locations logged between the forward and backward traversals differed. Being able to observe this problem was crucial to having a successful project.

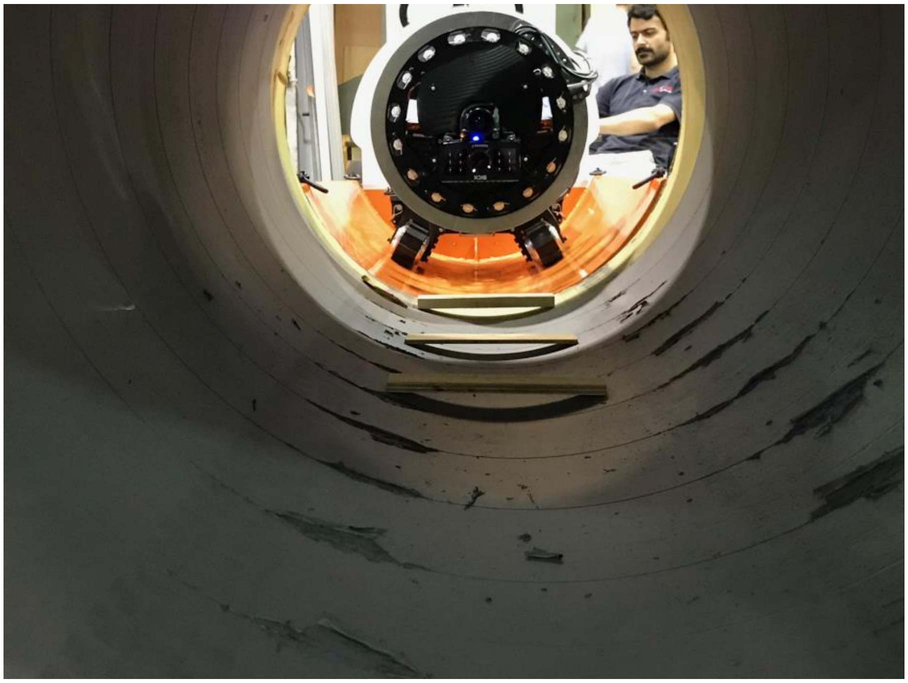

**Figure 3. Rectangular modules, located at the bottom of the pipes, being testing.**

While the programming team was resolving the issue mentioned above, the mechanical team and Mr. Excellent began working on a swept-T. This mock-up was essential to the project because it allows for testing of the robot's safeguarding protocol since the robot is only designed for a straight inspection, and is unable to turn through the elbows of the pipes. Building this mock-up required the mechanical team to first design it on SolidWorks, which is a type of computer aided design software. Then the team proceeded to manufacture the swept-T and attach it to the other pipes before running the test. The robot safely triggered its safeguarding protocol and stopped before reaching the swept-T. The mechanical team and Mr. Excellent were also responsible for completing the launch rigs. The launch rigs are the home base or the hub from which the robots are launched into the pipes. They contain all of the electronics that allow the robot to communicate with the NDA tech as well as the charger which re-charges the robot as needed. To complete the launch rigs, the antennas and doors were mounted in front of the slots that host the electronics.

# 4. RESULTS AND ANALYSIS

In this section, the results from the geometric tests are depicted in the following images. The images are a 2-D representation of the pipes. These graphics slice a one-foot length of cylindrical pipe along its top, then unroll the cylinder into a rectangular view. The top of the pipe appears on both right and left edges. The bottom of the pipes appear in the center of each image. The test articles are depicted in a different colors indicative of the height of the objects as the images clearly demonstrate.

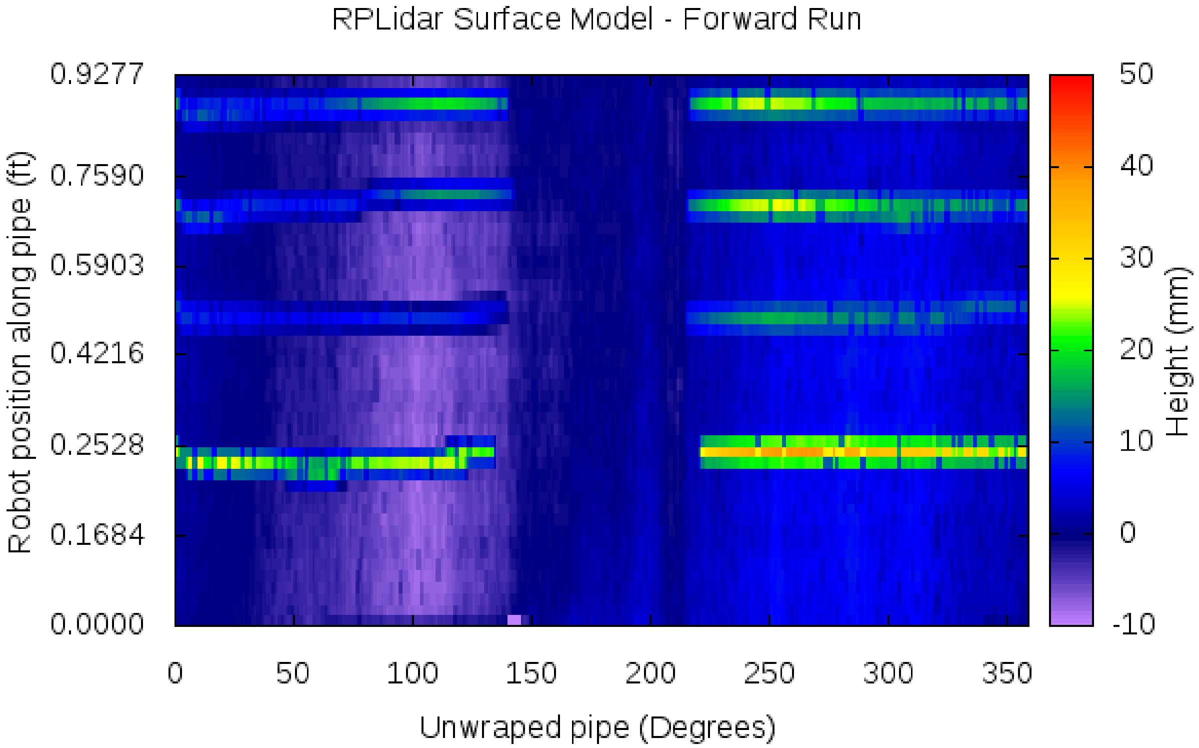

**Figure 4. Forward image mapping of the wooden ring obstacles being detected by the robot's RPLidar.**

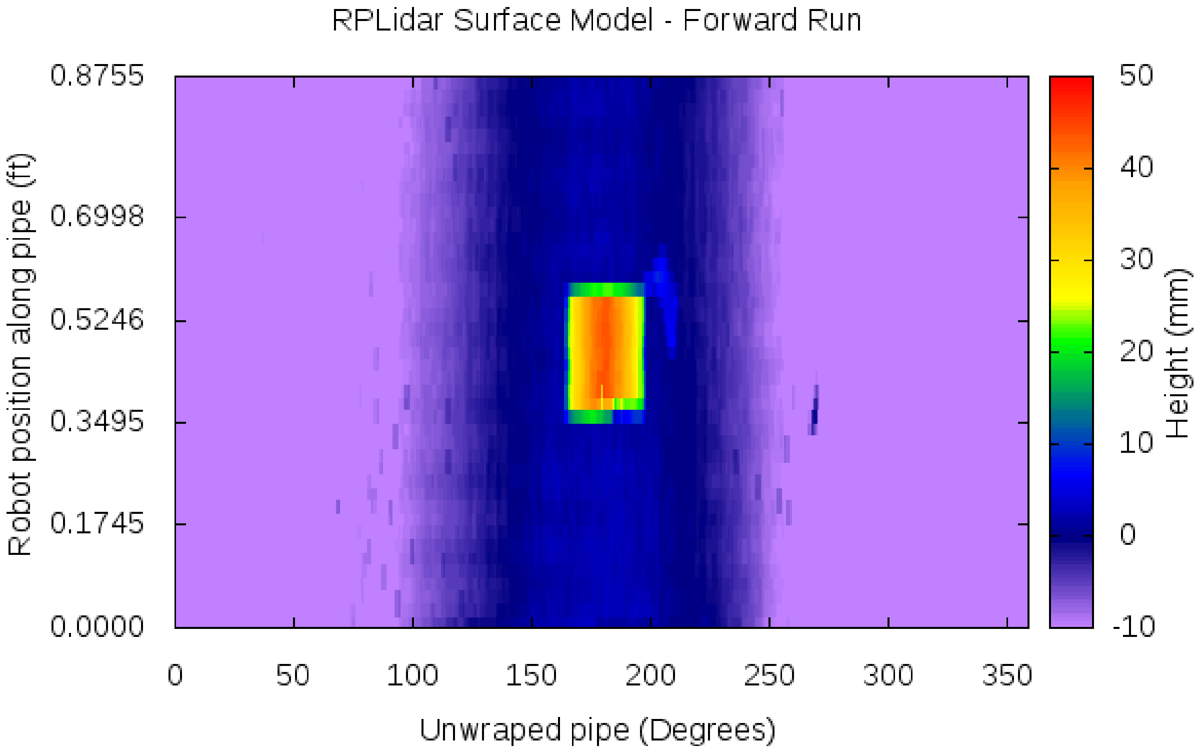

**Figure 5. Forward image mapping of the rectangular blocks being detected by the robot's RPLidar.**

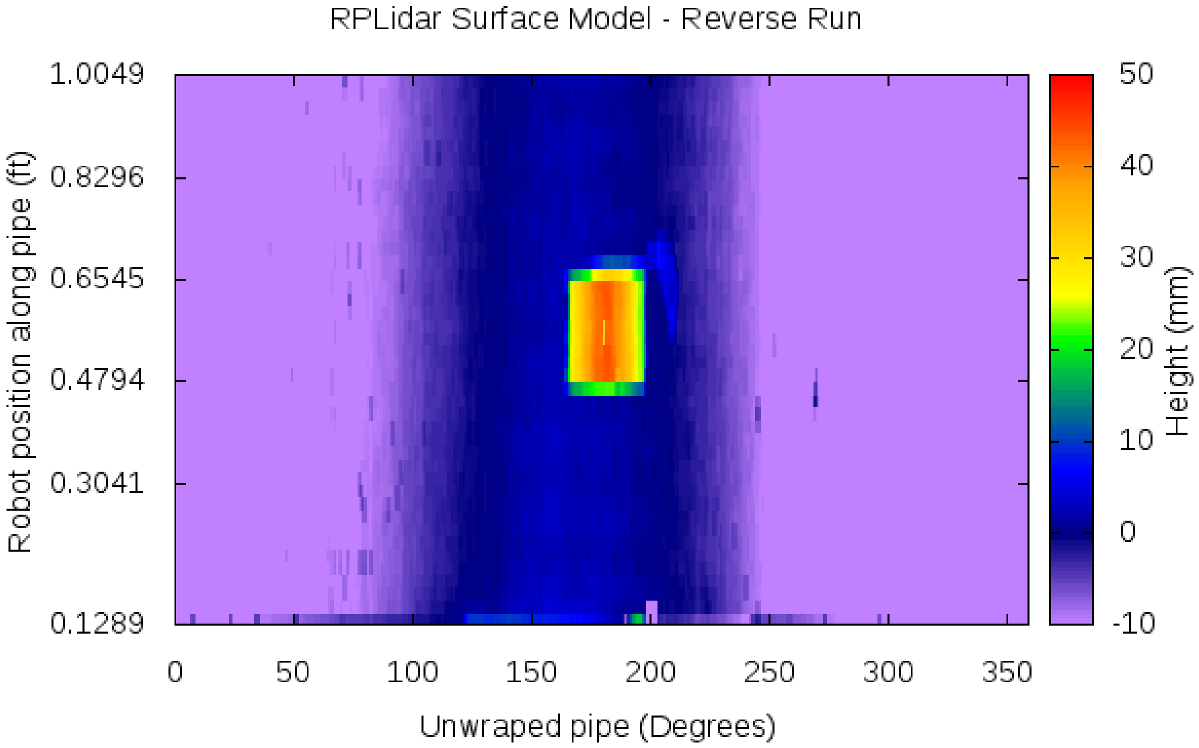

**Figure 6. Reverse image mapping of the same rectangular block from Figure 5 being detected by the robot's RPLidar.**

One of the issues that resulted during preparation for the deployment of the robot was that the RPLidar of the robot had difficulty in mapping the exact location of the rectangular blocks, (Figure 3 depicts this test being conducted.) The forward traversal and the reverse one mapped the blocks differently; this can be seen in Figure 5 and Figure 6. Although the differences in mapped locations were not dramatically large, it is still an issue because precise mapping of the deposits is crucial to the success of the whole project. Failure to accurately map the deposit locations can result in hazardous situations while the deactivation and decommissioning of the plant is in process. In any case, the issue of mapping the blocks correctly was mainly a software issue, and thanks to the efforts of the programming team, this issue was resolved.

# 5. CONCLUSION

Upon the completion of Mr. Excellent’s investigation of the PCAMS method, a clear understanding of why the PCAMS method would be beneficial to the Portsmouth Gaseous Diffusion plant was obtained. PCAMS is a method that is set in place to improve worker safety at the site while providing a safer and more efficient way of inspecting the pipelines for gamma radiation. Using its various components: the RadPiper robot, the disc-collimator, and all the other components that make this system work, the PCAMS method allowed for a successful deployment of the RadPiper robot within the gaseous diffusion pipes while successfully collecting crucial data during the hot demonstration that occurred onsite in the month of July 2018. Moreover, the hot demonstration provided operational evidence for how the PCAMS method would improve worker conditions by eliminating direct contact between the workers and the pipes during inspections.

# 6. REFERENCES

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