SUMMARY REPORT

Development of Inspection Tools for DST Primary Tanks

Pneumatic Pipe Crawler

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Introduction

In August of 2012, traces of waste were found in the annulus of the AY-102 double-shell tank storing radioactive waste at the DOE Hanford Site (Washenfelder, 2014), prompting the need for developing inspection tools that can identify the cause and location of the leak. To assist in this effort, Florida International University (FIU) is investigating the development of inspection tools that are capable of accessing the bottom of the tank floors. This effort has led to the development of a pneumatic pipe crawler.

Project Description

The pneumatic pipe crawler is an inspection tool designed to travel through the air supply line, leading to the central plenum of AY-102, and to provide live video feedback. The proposed inspection path is about 100 feet from grade, down through one of the drop legs, and then lateral to the center bottom of the tank secondary containment, as shown in Figure 1 below. The route consists of all welded schedule 40 pipes which are 3 and 4 inches in diameter, reducers and several elbows. The four drop legs branch from the “header ring” with a diameter of 3 inches, transitioning then to 4 inches.

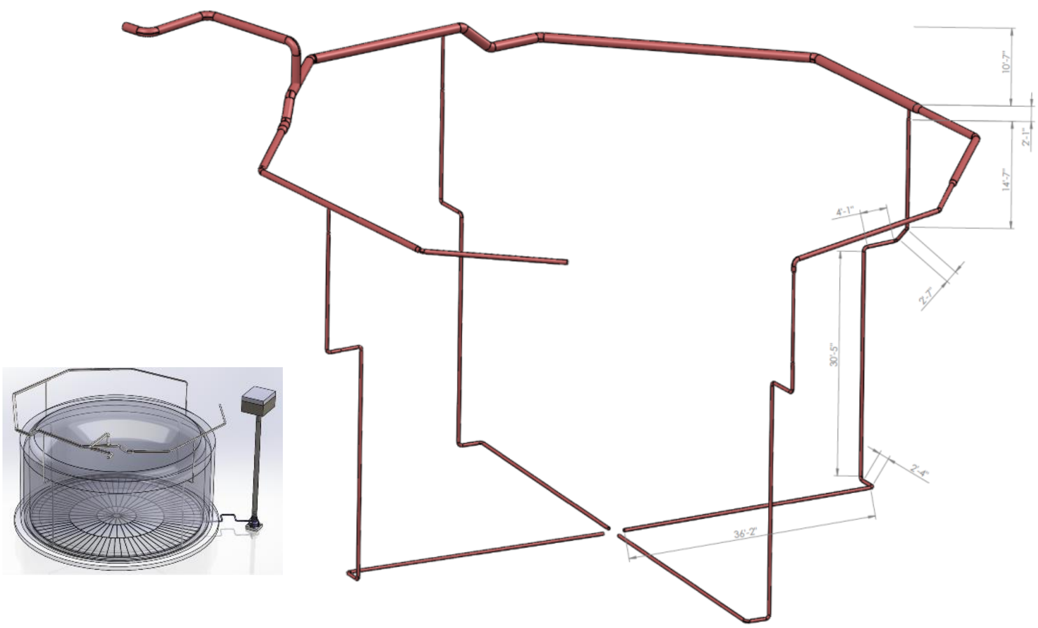

Figure 1. AY-102 air supply lines.

The inspection route to the central plenum through the air supply lines has the following requirements:

1. navigate through pipes and fittings (3" and 4" diameter)
2. climb vertical runs

3. tolerate elevated temperatures (170 ^{o}f)
4. tolerate moderate radiation levels (85 rad/hr)
5. provide a means for removal in the event of a malfunction

Additionally, the crawler will need to provide live video feedback; however, plans for carrying additional instrumentation are been considered.

The successfully designed pipe crawler is a worm type robot with a modular design, composed of interchangeable cylindrical modules connected with flexible links. Figure 2 shows a rendering of the updated crawler designed at FIU.

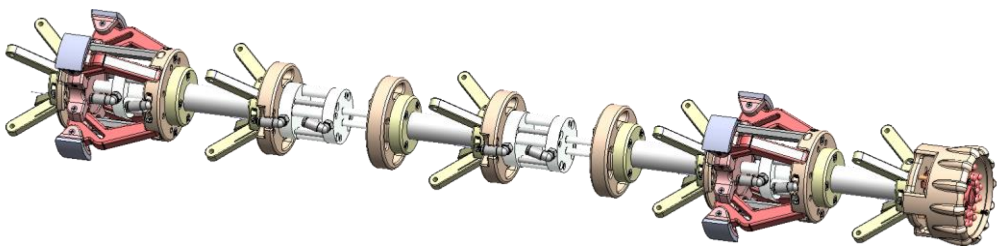

Figure 2. FIU's pneumatic pipe crawler.

Design Concept

The design is an evolution of previous pipe crawlers developed at FIU (Pribanic, et al., 2013). The tool builds on the concept of using a peristaltic propulsion motion powered by pneumatics from the previous crawlers, and modifies the design with a modular approach combined with off-the-shelf pneumatic actuators to produce the contractions of the peristaltic motion.

A pneumatic powered crawler is suitable for highly radioactive environments with potential exposure to flammable gases. The locomotion system does not require embedded radiation hardened electronics and electric actuators. The design is also inherently ignition-proof, since pneumatic actuators are not likely to produce electric sparks common in some electric motors and actuators.

In addition, a peristaltic propelled crawler offers an appropriate design for decontamination. As illustrated in Figure 3 below, the device can navigate inside a pipeline without using any external moving parts, such as wheels and continuous tracks, and can be designed to be fully encapsulated in a disposable elastic skin. In extreme cases, the crawler itself can be considered disposable due to its affordable design.

Another advantage to the crawler is associated with its modular design, which has the potential to be customizable. Other specific tasks could be accomplished with the addition of extra modules, such as instrumentation, material sampling, and pipe repair.

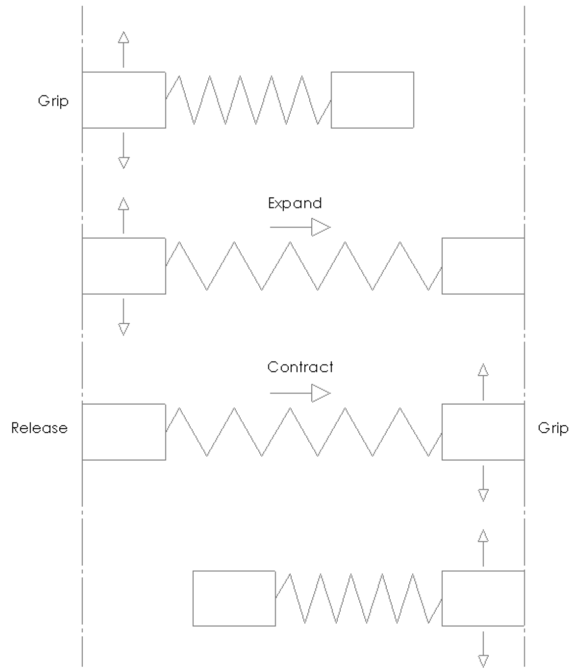

Figure 3. Peristaltic locomotion.

The crawler's basic design is composed of five modules linked by flexible connections (Figure 4):

- the front camera,
- the front and back grippers, and
- the two middle expansion modules.

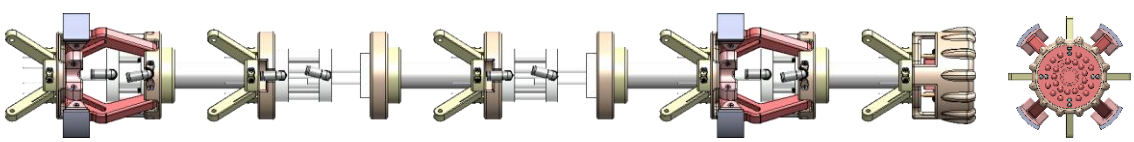

Figure 4. Pneumatic pipe crawler.

Figure 5 shows an overall schematic of the crawler, which also includes two additional primary components: the control box and the tether. The major components are described in the sections below.

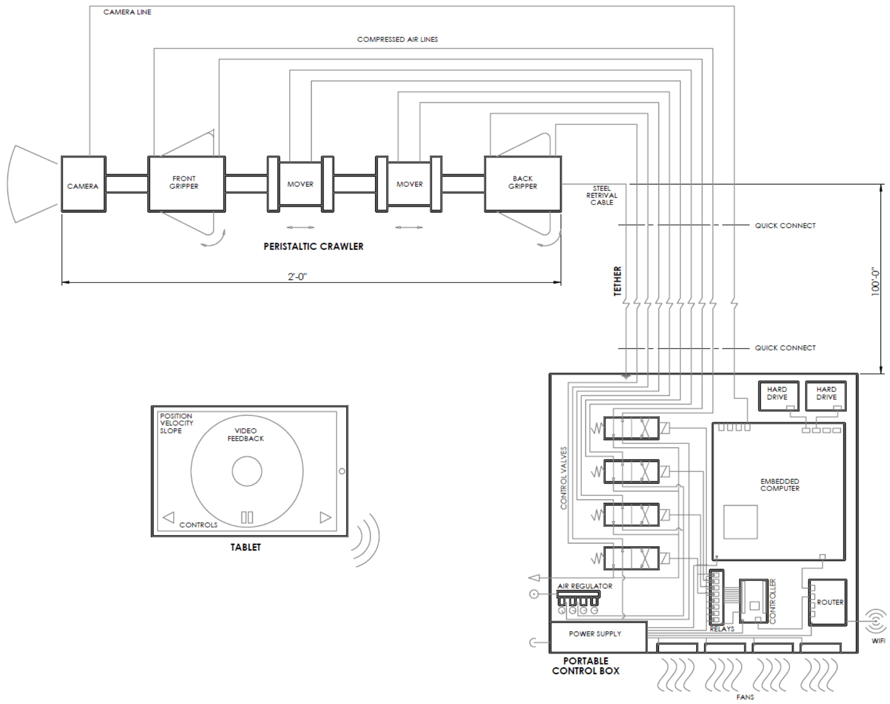

Figure 5. Overall schematic of pneumatic pipe crawler.

Expansion Module

Shown in Figure 6, the expansion modules use compact nonrotating tie rod air cylinders to propel the crawler forward during the coordinated peristaltic movements of contraction and expansion. The cylinders have two parallel piston rods that prevent the rotation of the front camera. The actuators have 3/4" stroke, 3/4" bore diameter and are capable of producing 40 lbs force at 100 psi.

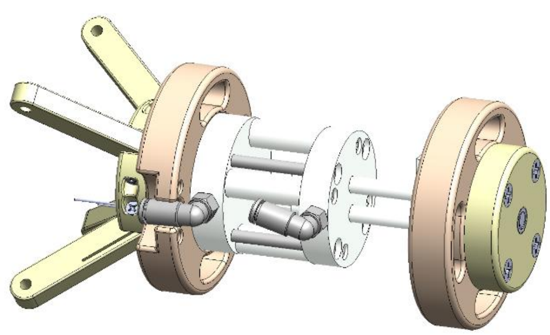

Figure 6. Expansion module.

Gripper Module

The gripper modules, shown in Figure 7, are designed to grip pipes and fittings with internal diameters varying from 3" to 4".

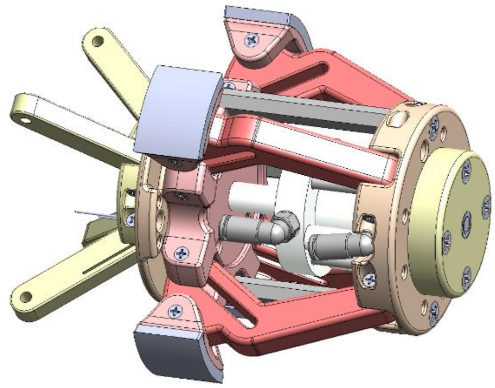

Figure 7. Gripper module.

Maximizing the grip strength of the module was a major factor in the development of the peristaltic crawler. Increased grip strength will allow the device to carry additional instrumentation, and to inspect longer pipelines, which will be critical for other potential inspections. Figure 8 shows the evolution of the gripping mechanism during the primary phases of the module design.

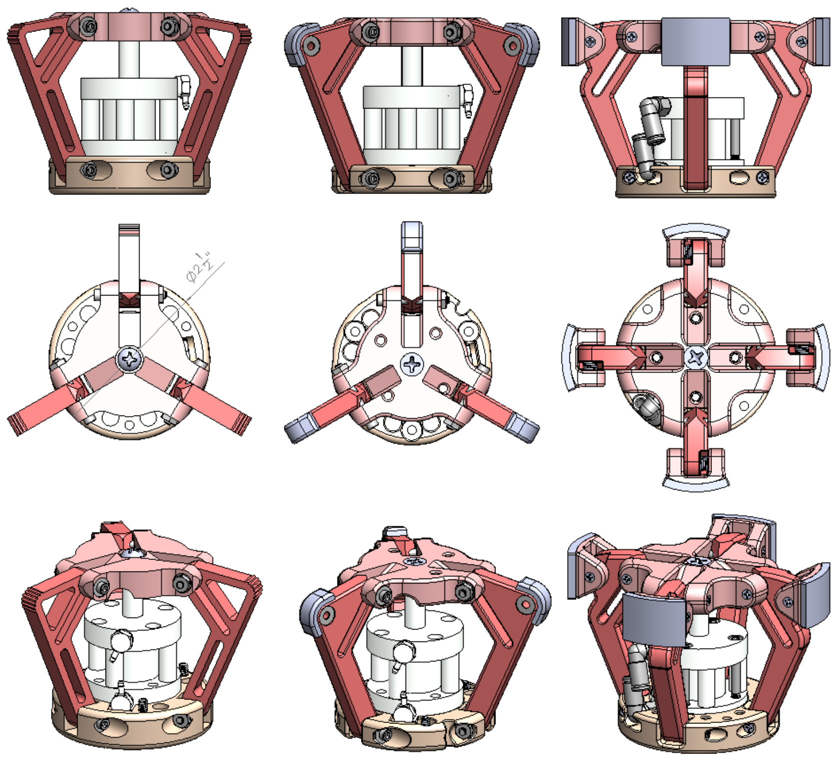

Figure 8. Design evolution of the gripper modules.

Stronger grips were obtained by increasing the number of claws per gripper, and by redesigning the claws using hinged tips with cylindrical pads. As shown in Figure 9, the redesigned claws also use extension springs to retrieve the pads when the mechanism closes, keeping a tight fit during crawling.

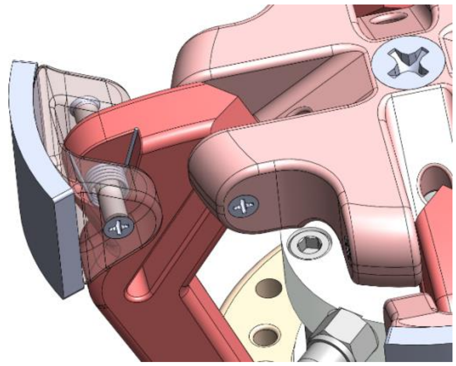

Figure 9. Gripper claws with hinged pads.

To open the claws, the grippers use compact tie rod air cylinders. The initial design provided a gripping force of 18 lb which was increased to 40 lbs with the implemented design modifications. The achieved grip of 40 lbs is equivalent to the maximum force in which the expansion modules can propel the crawler. However, that value might change with the existing conditions of the pipe surface. This potential issue will be evaluated during the next phase using engineering scale test beds.

Camera Module

The front camera module, shown in Figure 10, carries a day-night 1.0 megapixel (720p) digital camera, with infrared cut-off filters and LEDs. The camera is an independent module, and can be easily replaced depending on the specific application.

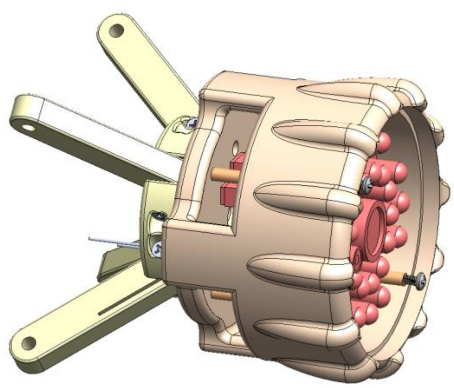

Figure 10. Camera module.

One of the recent enhancements in the design of the front camera casing is the addition of external ribs, shown in Figure 11. As illustrated in Figure 12, the ribs help the camera overcome fitting misalignments in the pipeline during turning maneuvers.

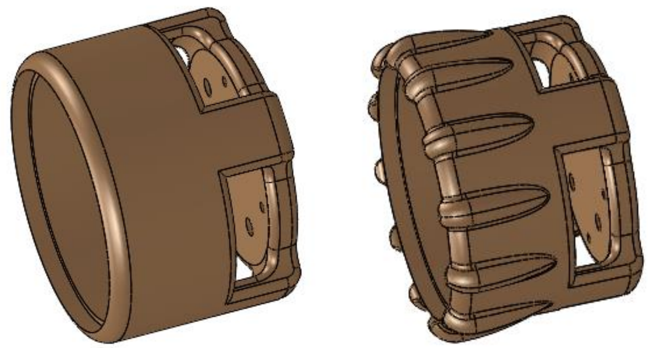

Figure 11. Original front camera case and redesign.

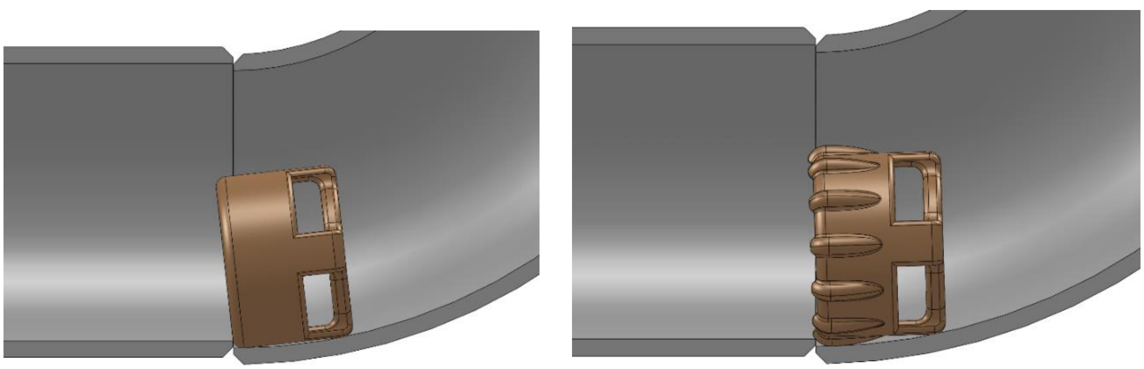

Figure 12. Piping misalignment and front camera overcoming.

Module Flexible Connection

All modules are linked by flexible connections shown in Figure 13. The flexible connections allow the unit to bend and keep the modules centered during navigation thru the pipes and fittings.

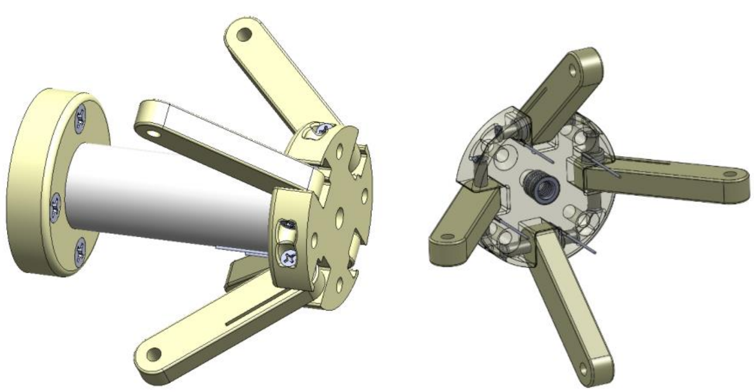

Figure 13. Module flexible connection (left), guide mechanism (right).

Guide mechanisms are installed at each module. As illustrated in Figure 13 and Figure 14, the mechanism uses small arms and torsion springs to keep the modules at center of the pipes and fittings, which minimizes bouncing and dragging of the unit. The guides also prevent the bulldozer effect (collection of debris) in the front camera.

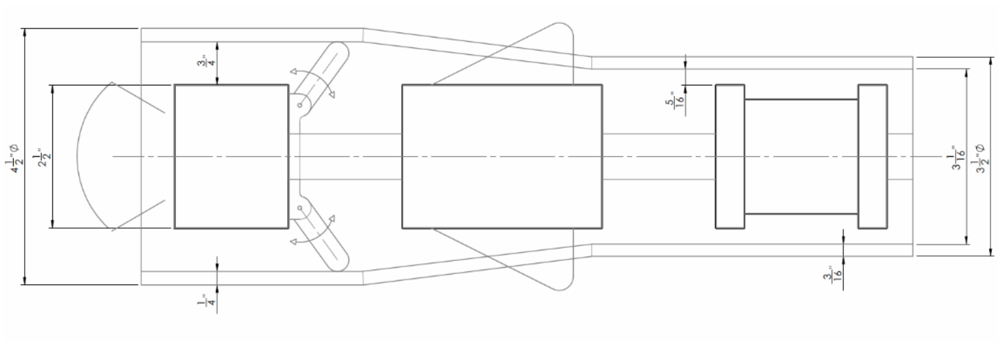

Figure 14. Guide mechanism illustration.

Control Box

The crawler control box is portable and suitable for field deployments. A diagram illustrating each of the key components is provided in Figure 15.

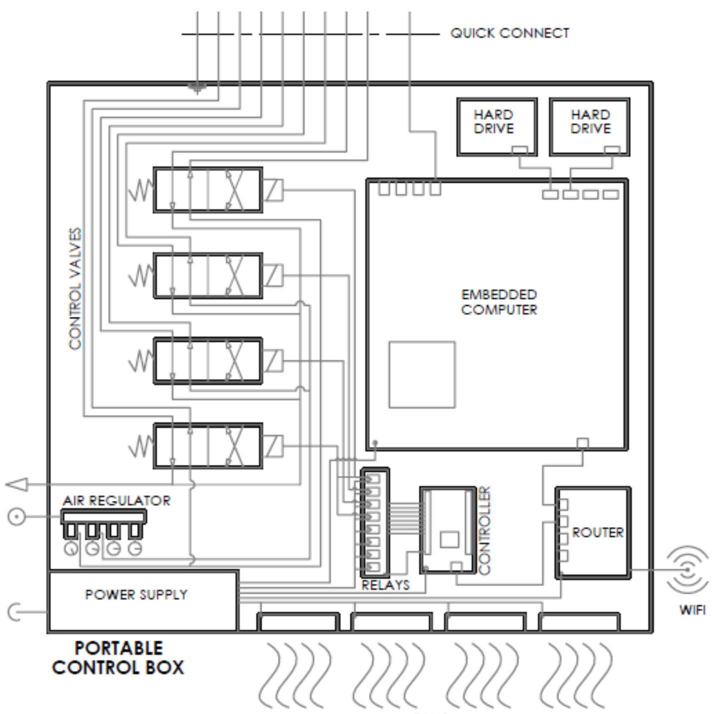

Figure 15. Control box sketch.

Using the control box, the crawler movement is fully automated and can be controlled remotely using any handheld device connected to the private wireless network of the box. The controlling software can be custom-designed, which increases the versatility of the tool.

The speed of the crawler is determined by the peristaltic cycle. The cycle distance is defined by the displacement of the expansion modules. For this configuration, the cycle distance is 2 inches. The cycle time is programmable; however, the working frequency is influenced by the pressurization of the pneumatic lines and the tether length.

Tether

The tether required for the proposed inspection will be approximately 100 feet in length and consists of the following lines:

- 8 pneumatic lines,
- 1 digital video feedback cable, and
- 1 retrieval steel cable.

The retrieval cable will be responsible for carrying out the pulling load, and relieving tension in the other lines of the tether. The bundle is also enclosed by an abrasion-resistant sleeve, which will protect the cables from wear and tear.

Bench–Scale Tests

To validate the design concept and demonstrate the potential of the crawler, two testbeds were manufactured to evaluate various parameters of the crawler. Tests were primarily focused on evaluating the unit's maximum pull force, maneuverability, and navigational ability.

Figure 16 shows the testbed where pulling tests were conducted. These tests were crucial in evaluate the gripping performance of several designs and consisted of unistrut structure that held various pipes and included a pulley system for aligning the load on the crawler within the pipe. The crawler grippers were extended to keep the position locked and loading was increased until the crawler moved. As previously noted, the maximum pulling force obtained was 40 lbs.

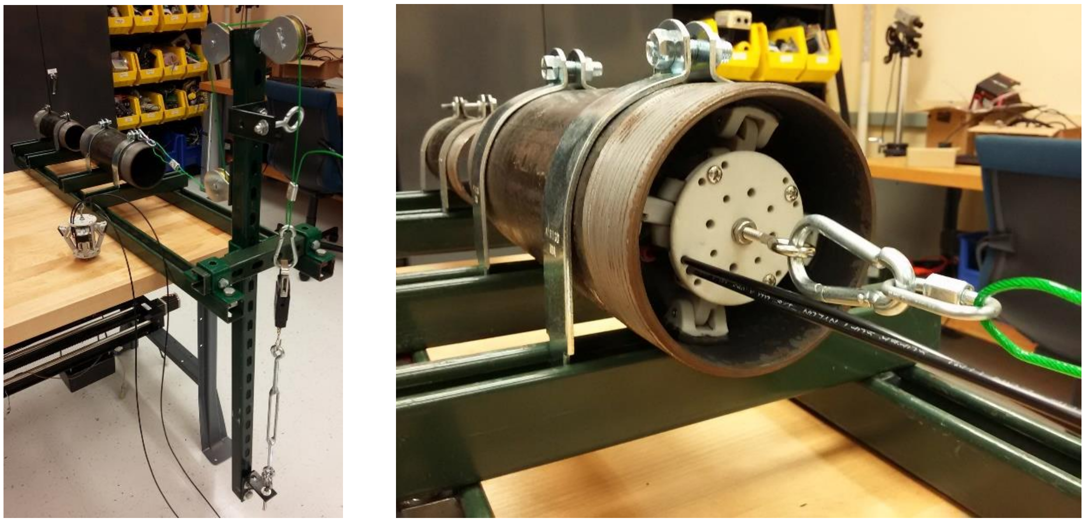

Figure 16. Bench-scale pulling tests.

Figure 17 shows the other bench scale testbed used in the maneuverability tests during the crawler design process. The test loop consists of 3" and 4" diameter clear PVC pipes and carbon steel fittings. The testbed provides 3 elbows, 2 reducers, vertical risers, for the crawler to navigate through.

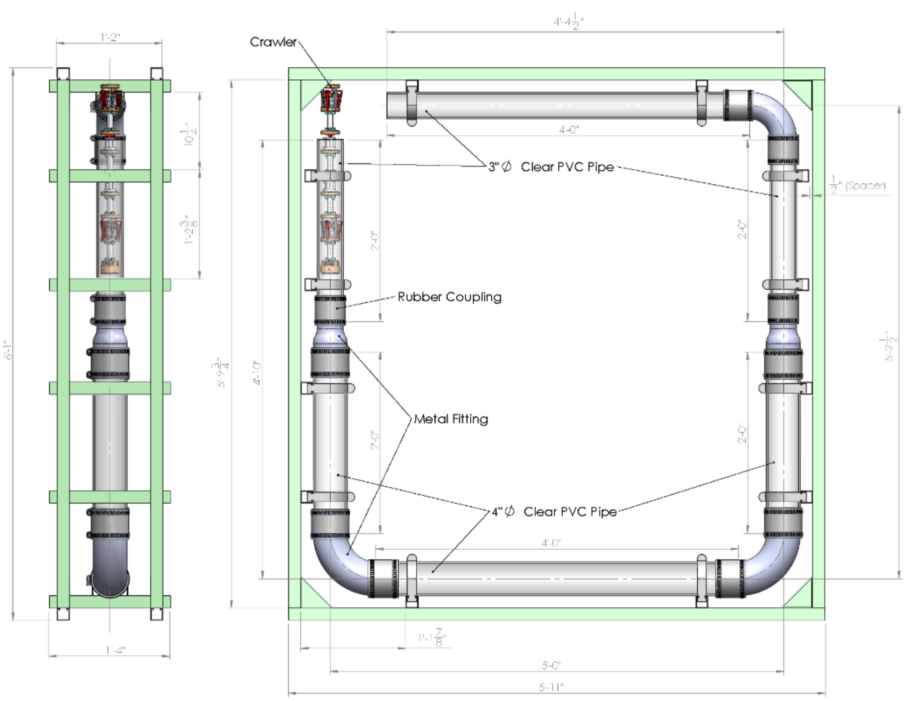

Figure 17. Bench-scale test loop.

Figure 18 shows the crawler successfully navigating through a 3" elbow in the pipe loop, where several levels of misalignments were tested. Based on the results of the bench-scale tests, the crawler has great potential to accomplish the proposed inspection and provide visual feedback of the air supply lines and of the tank central plenum.

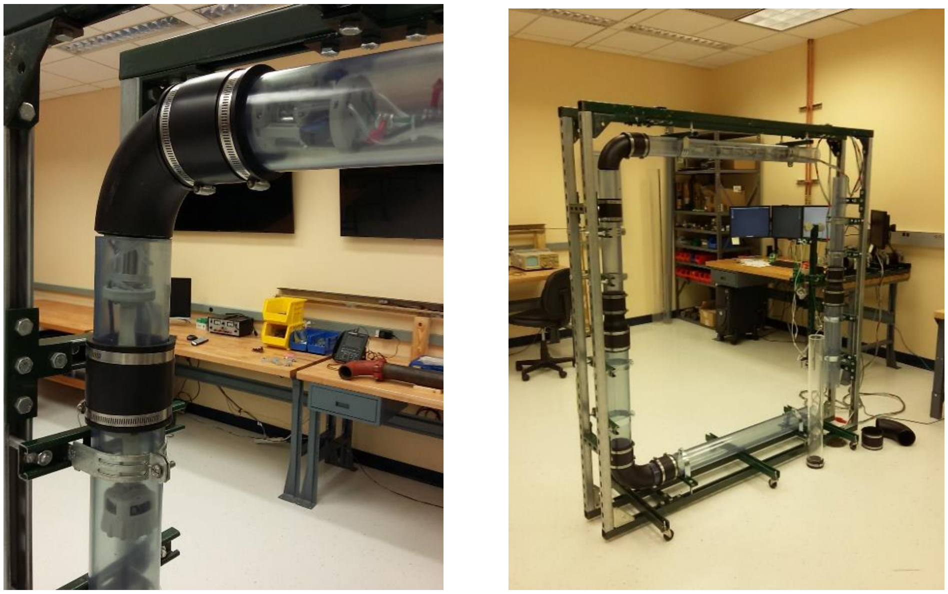

Figure 18. Bench-scale maneuverability tests.

Prototypes

Figure 19 shows the most updated prototypes of the pneumatic pipe crawler. A majority of the parts for the prototype were 3D printed and assembled. The use of in-house 3D printed thermoplastic parts has significantly expedited the designing and testing process of the inspection tool.

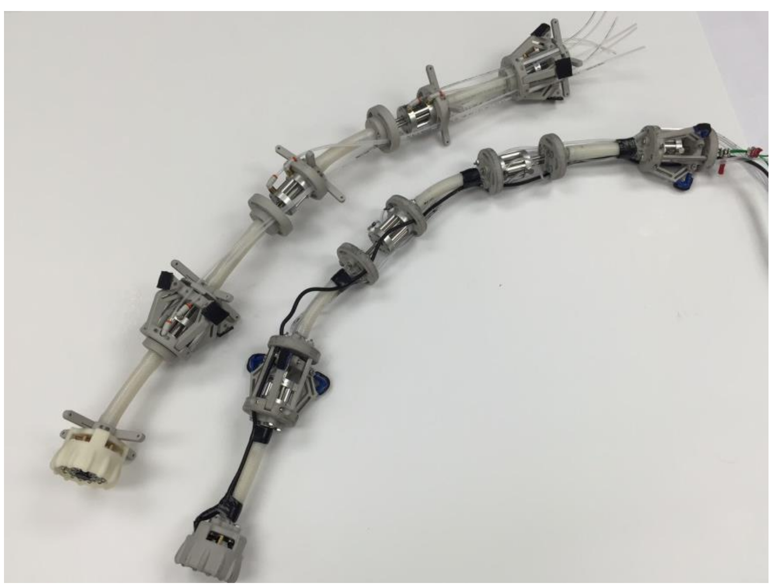

Figure 19. Updated prototypes of the pneumatic pipe crawler.

Path Forward

Future plans for the crawler include:

a) designing and constructing a full scale mockup testbed,
b) developing a delivery mechanism for deployment,
c) integrating various sensors,
d) designing additional instrumentation modules for non-destructive inspection,
e) designing an full electric version, and
f) scaling the design for inspection in pipes with smaller diameters.

References

1. D. J. Washenfelder, "Forensic Investigation of Hanford Double-Shell Tank AY-102 Radioactive Waste Leak," Waste Management Conference, Phoenix, Arizona (2014).

2. T. Pribanic, D. McDaniel, A. Awwad, “Design Optimization of Innovative High-Level Waste Pipeline Unplugging Technologies,” Waste Management Conference, Phoenix, Arizona (2013).