Development of a Pipe Crawler Inspection Tool for Fossil Energy Power Plants

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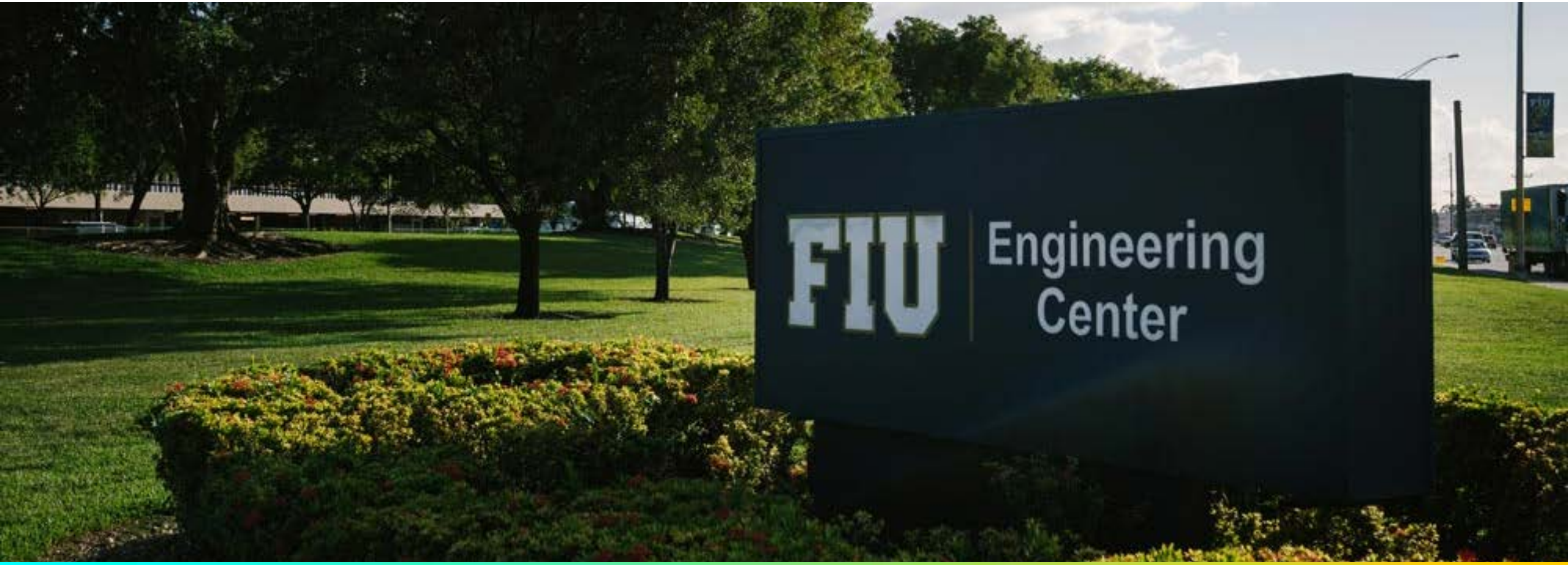

Development of a Pipe Crawler Inspection Tool for Fossil Energy Power Plants

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Project Description and Objectives

Typical Power Plant Inspections

- Challenging and time consuming
- Manual and external
- Conditions sometimes unsafe for humans
- Difficult/impossible to access areas

Present Research Work

- Robotic inspection as an alternative to monitor the structural health of plant components
- Improves capabilities of the fossil energy community to better understand the health of critical components in their infrastructure
- Reduces plant down time, increasing efficiency and cost savings

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Project Description and Objectives

- The objective of the proposed project is to develop a robotic inspection tool that can provide information regarding the structural integrity of key pipeline components in fossil fuel power plants that are not easily accessible.

- The proposed system consists of a tethered pipe crawler that can navigate through 2-inch diameter pipes typically found in the boilers of fossil power plants.
- The primary system will also house sensors that can be used to determine the state of the health of the pipes. The sensor suite includes an optical camera, LiDAR (light detection and ranging) and ultrasonic transducer (UT) sensors that can be used to obtain thickness measurements of the pipes.

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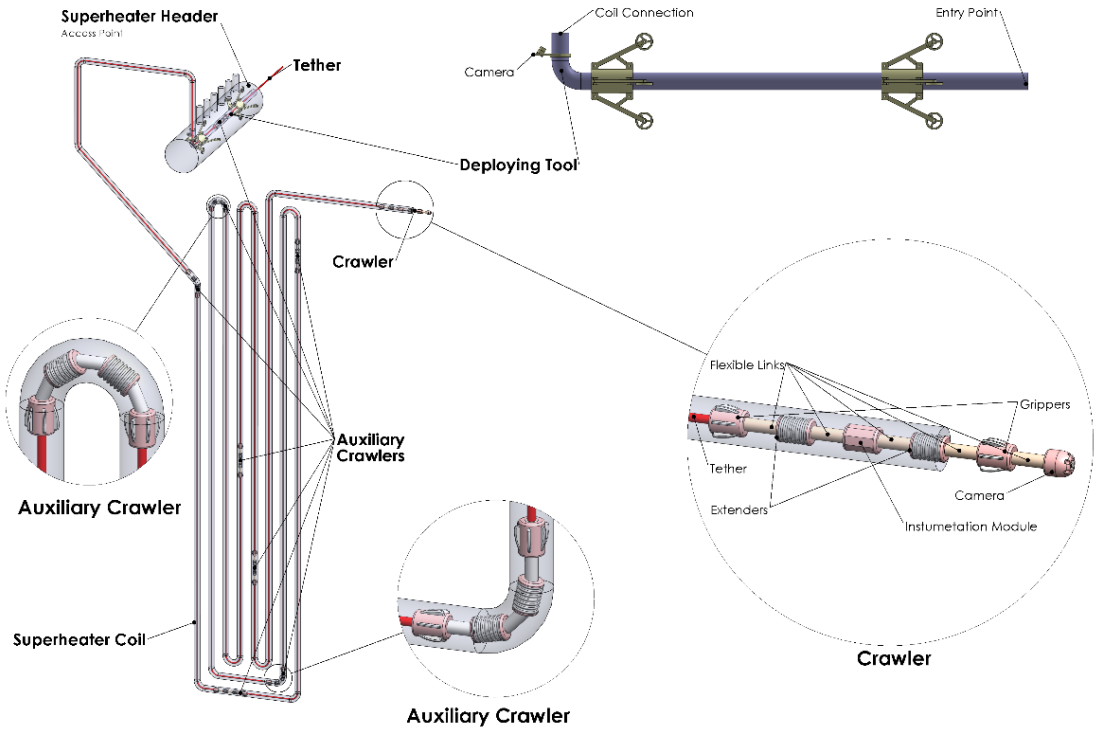
Project Description and Objectives

- Utilize lessons learned from previous pipe crawler and inspection tools
- System will navigate through 180-degree bends
- Multiple systems will be coupled together to distribute tether load
- Deploying mechanism through the header

Superheater Header & Tubes



Inspection Tool Operation

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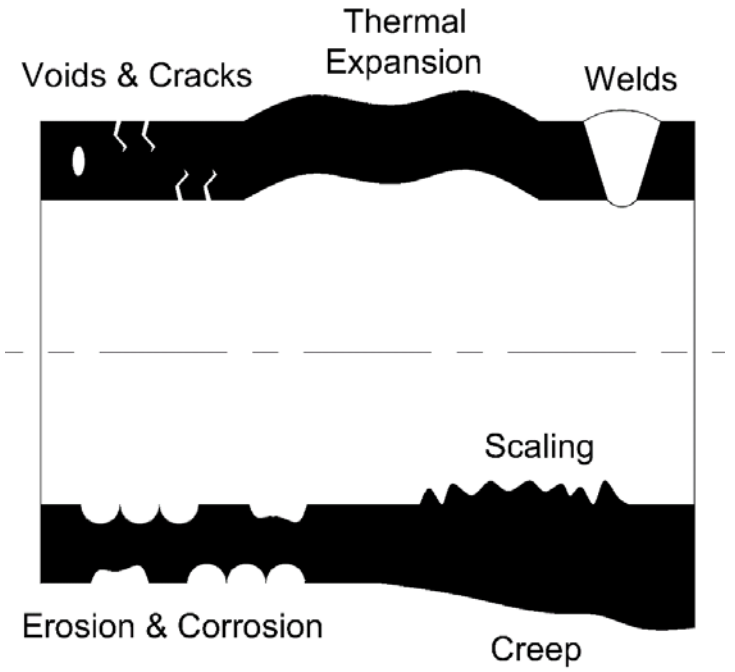
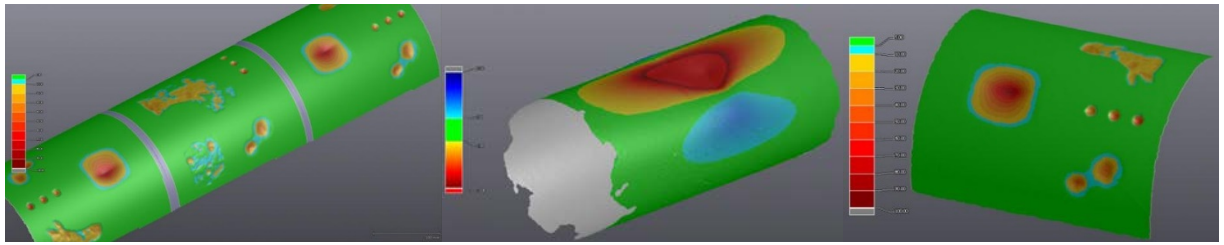
Project Description and Objectives

Inspection Tool Concept

- Sensors will be incorporated into a sensor module to detect pipe irregularities
- The module is customizable and will include an optical camera, IMU, range finder (LiDAR)
- Visual inspection of interior surface – anomalies in pipe, scaling, wear, weld seams
- An additional module will include a UT sensor for surface preparation and thickness measurements.





Surface mapping

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Project Description and Objectives

Tasks to be Performed

Task 1.0 - Project Management and Planning
Task 2.0 - Robotic Crawler Development
- Subtask 2.1 – Conceptual design of modules
- Subtask 2.2 – Manufacturing and testing of modules
- Subtask 2.3 – Assembly and initial testing

Task 3.0 – UT Sensor Analysis
- Subtask 3.1 – UT Sensor Evaluation
- Subtask 3.2 – UT Sensor Requirements

Task 4.0 – Sensor Module Development
- Subtask 4.1 – UT sensor module
- Subtask 4.2 – LiDAR sensor module

→ Task 5.0 – System Integration
- Subtask 5.1 – Multiple crawler design and integration
- Subtask 5.2 – Power and instrumentation control/communication

Task 6.0 – Full Scale Testing

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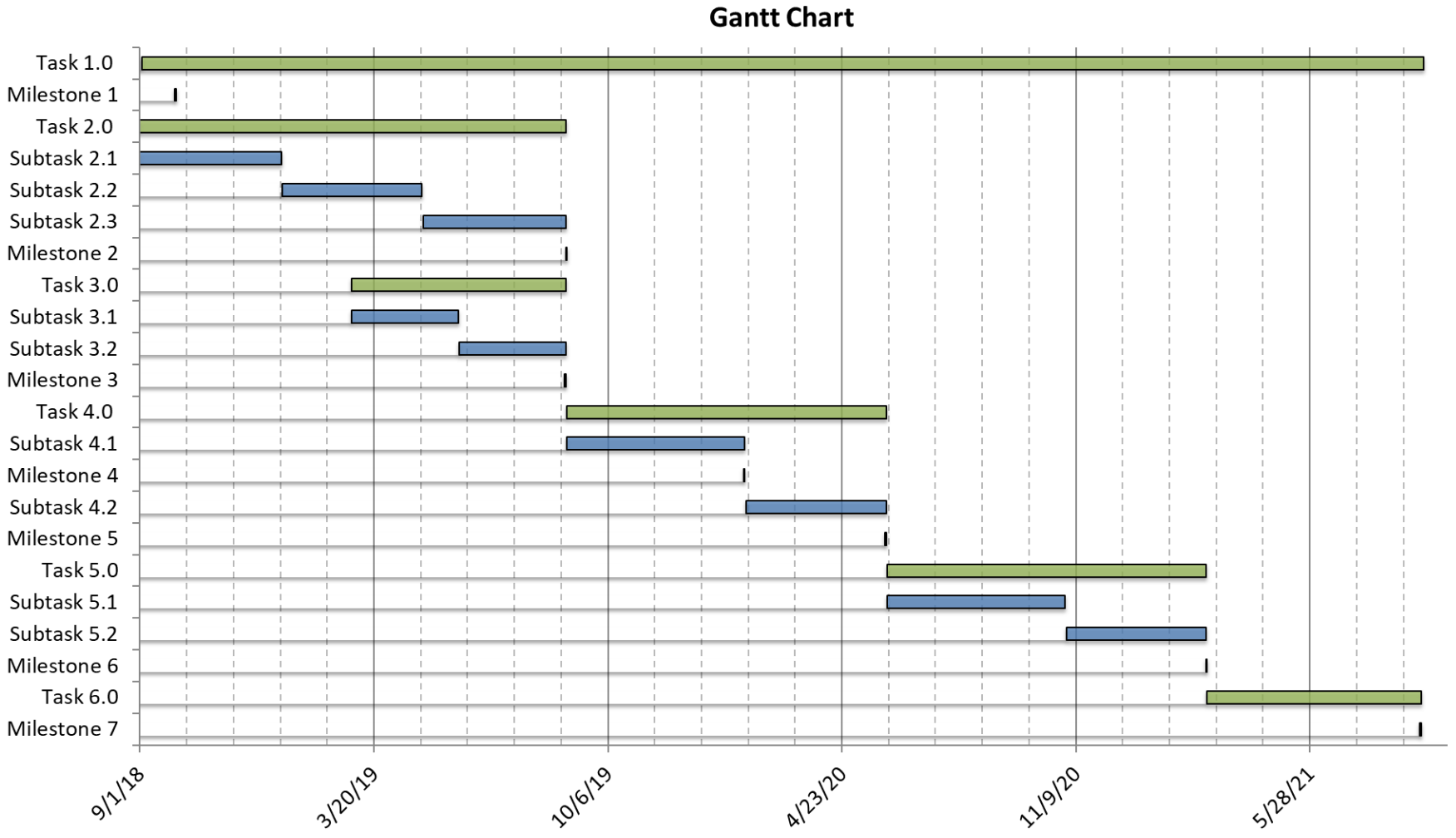
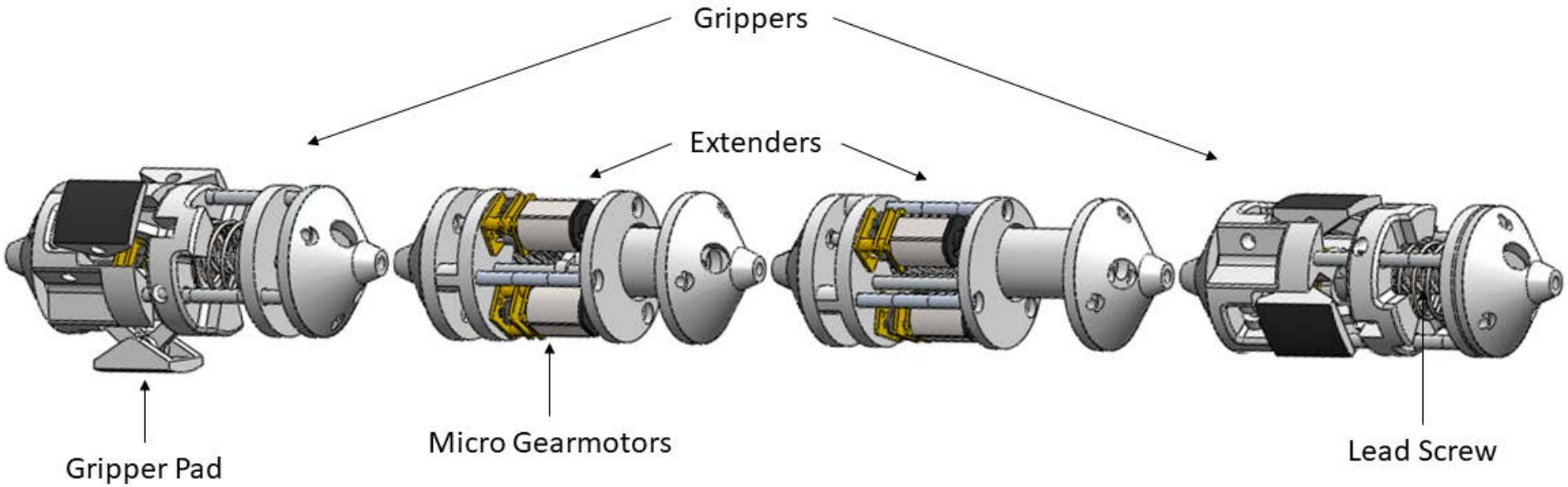
Project Description and Objectives

Tasks to be Performed



Project Update

Moving Platform



Peristaltic Motion to Travel Through Pipe

- Extender modules expand and contract linearly
- Linear actuation controlled by rotating lead screw
- A 3D printed prototype has been developed with nylon, tough PLA, polycarbonate

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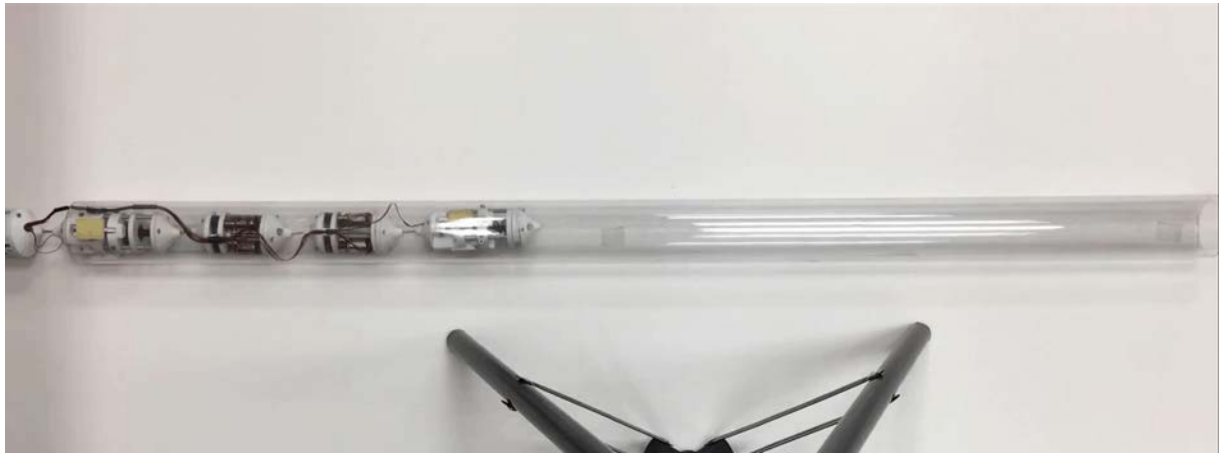
Project Update

Moving Platform

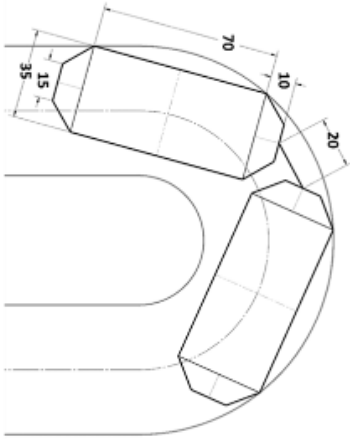
Straight Pipe Section Test



180-degree Bend test

Challenges

- Wire management
- Maximizing pull-force (current force is ~9 lbs)
- Finding appropriate dimensions for sharp turns



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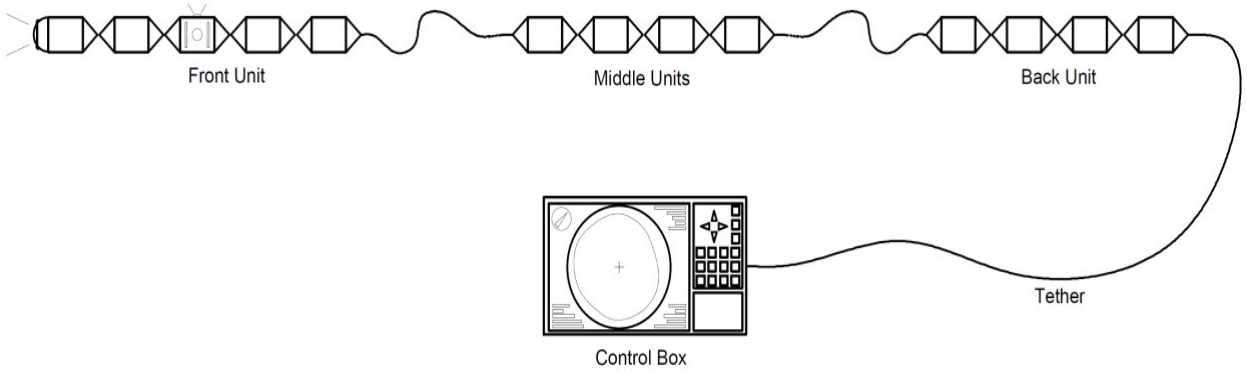
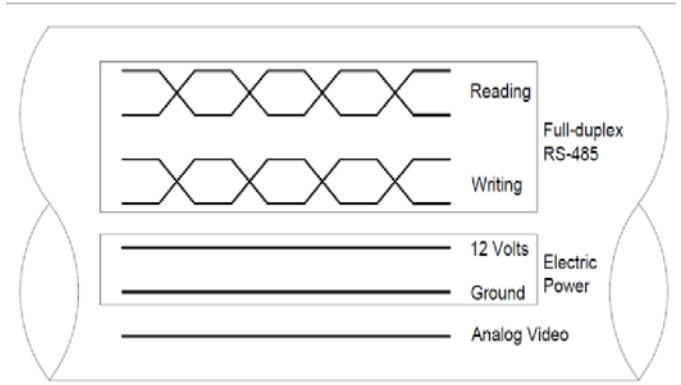
Project Update

Electronics and Communication System

- The peristaltic movement is fully automated and remotely controlled.
- Each unit will contain at least one microcontroller and others may be added for the sensors.
- The movement of each module is controlled by sensing the electrical current in the motors
- Long-distance communication tether to the crawler via serial network





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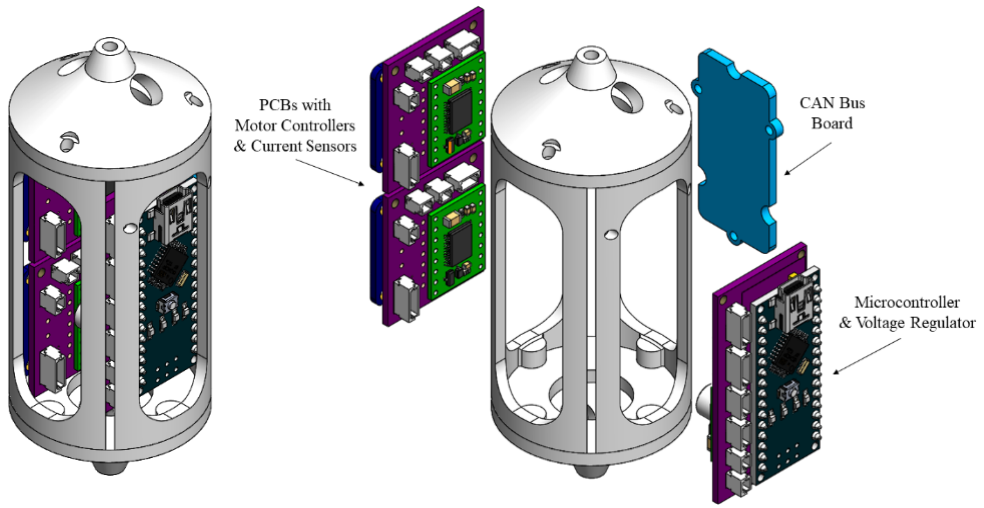
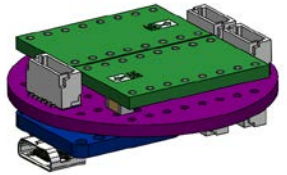
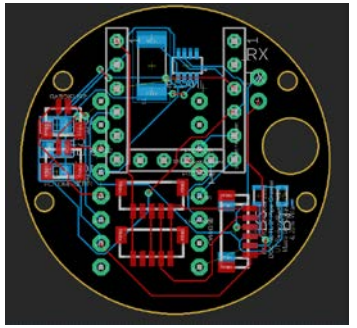
Project Update

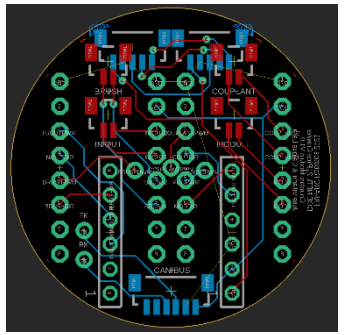
Electronics and Communication System

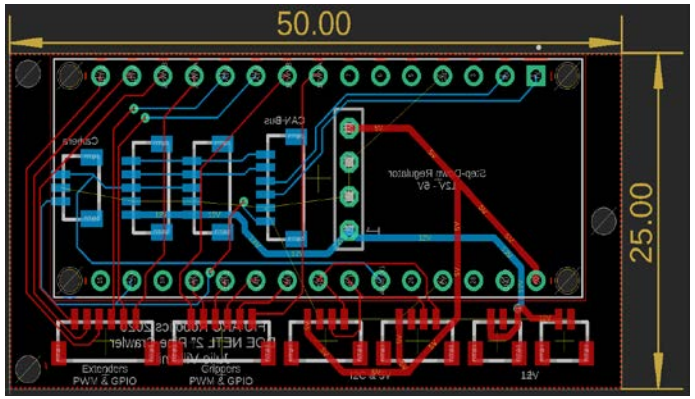
- Development of printed circuit boards (PCBs) to mount the electronics
- PCBs have been designed to house the receiver chips, microcontrollers, and voltage regulators
- Electronics module is currently being developed.
- Slip ring for rotating sensor modules

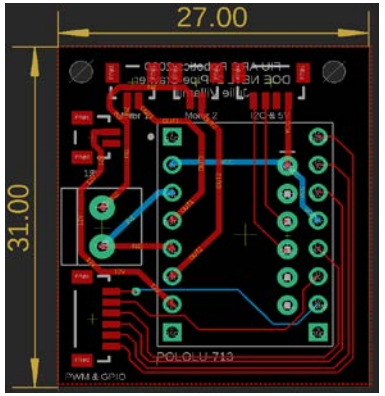












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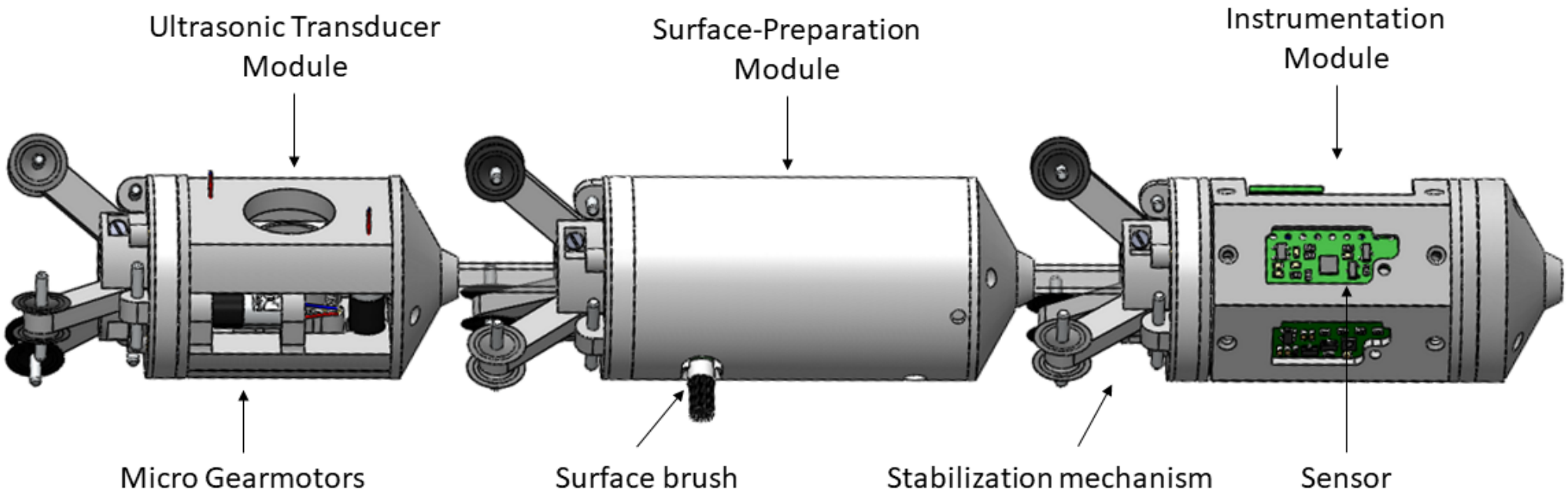
Sensor Modules



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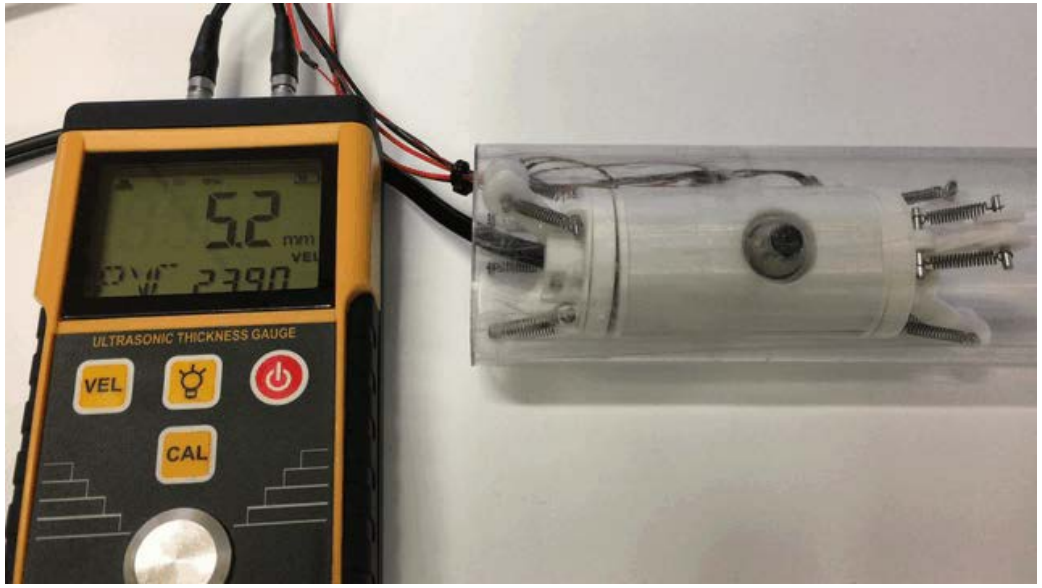
Project Update

UT Sensor Module

- UT sensor module includes an ultrasonic probe for wall thickness measurements
- Module contains a linear actuator that provides the prismatic movement of the UT sensor probe



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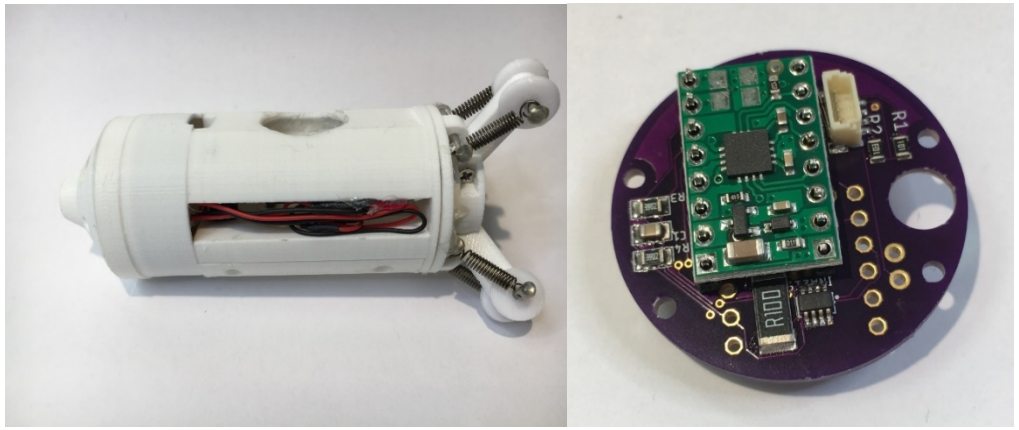
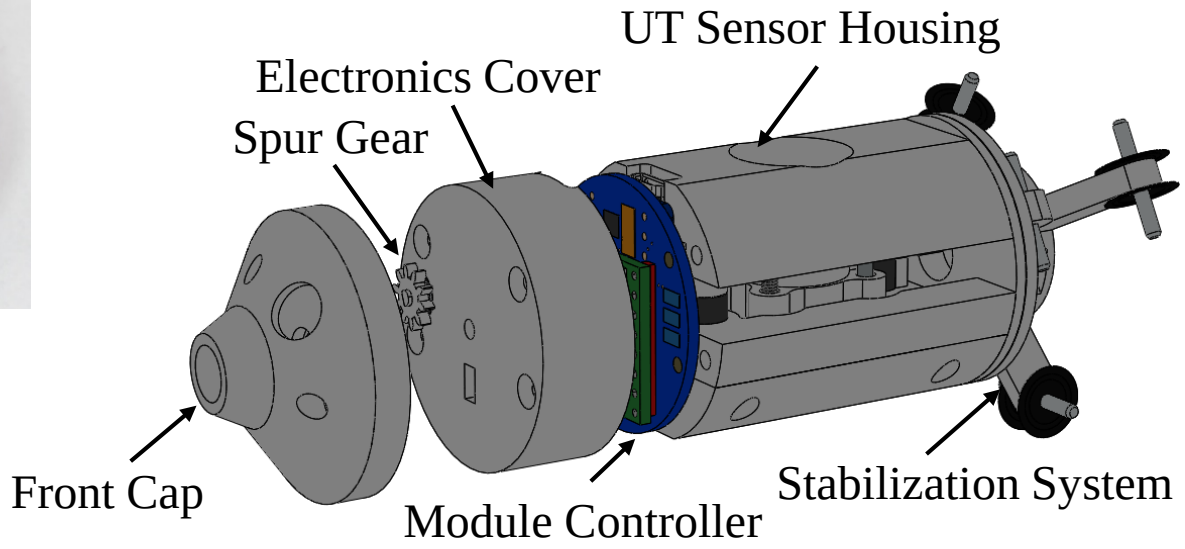
Project Update

UT Sensor Module

- Printed Circuit Board (PCB) connect the microcontroller to sensor and motors
- Control unit integrated to the front-end
- Uses CAN-Bus to communicate with other modules





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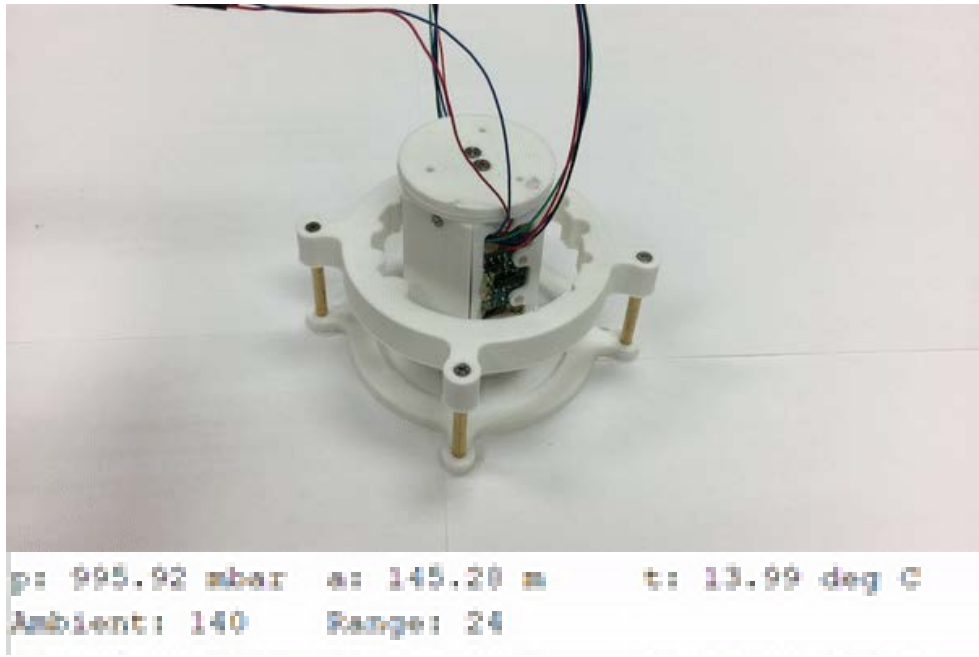
Instrumentation Module

- Evaluates the internal surface of the pipe and includes 3 sensors: LiDAR, IMU, and environmental
- Carrousel-like device that rotates with a planetary and spur gear set



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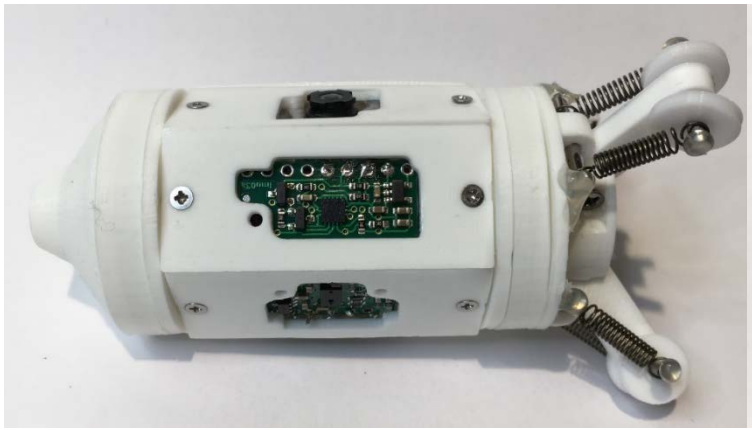
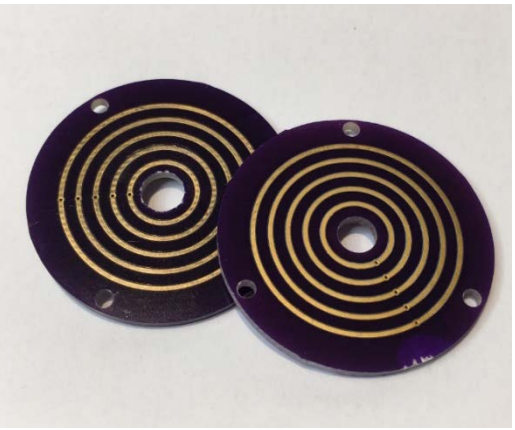
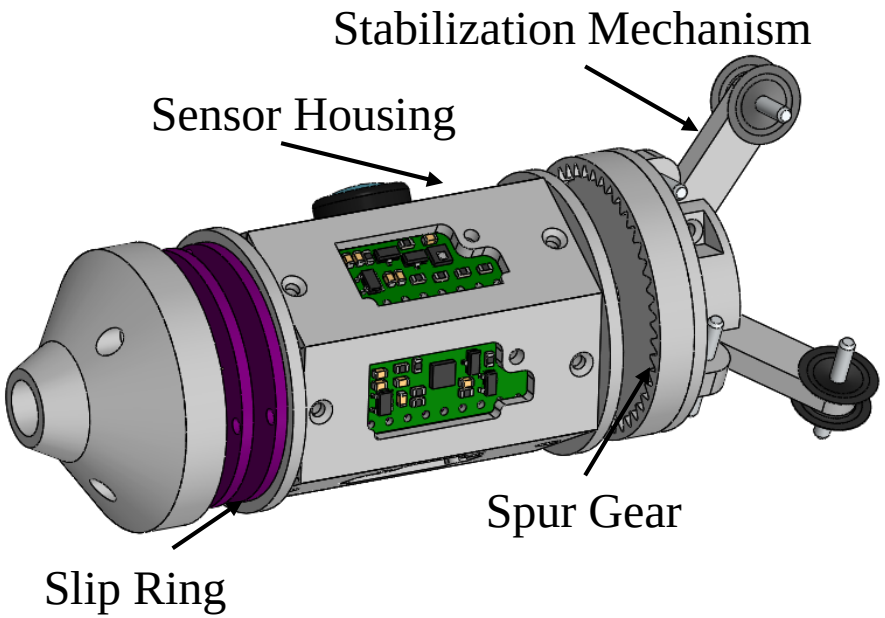
Instrumentation Module

- A Slip Ring was developed to enhance the wire management during rotation
- A PCB connect the sensors with the microcontroller
- Communicate with other modules using CAN-Bus







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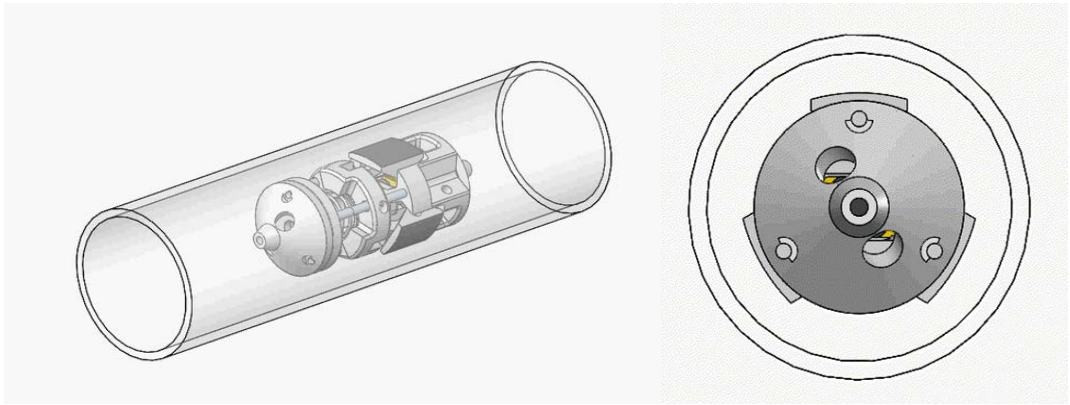
Project Update

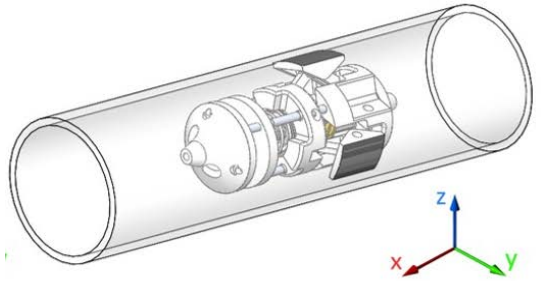
Development of High-Fidelity Simulation Module

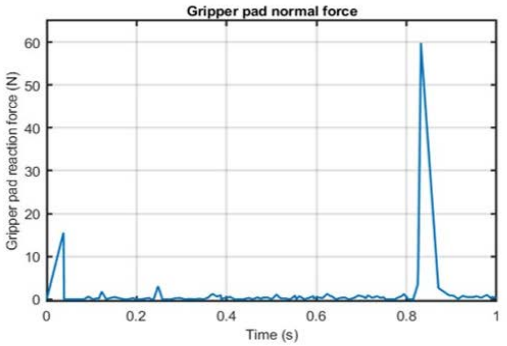
- Effort are being made to generate a high-fidelity simulation of the crawler that will provide a platform to analyze different aspects and control strategies, virtually.

- Initially, a basic motion analysis, was conducted in SOLIDWORKS. Gripper and extender modules were generated and simulated.

- The force of contact between the gripper pads and the tube was analyzed to find the pull force of the gripper, that holds the tube when the gripper pads are extended.







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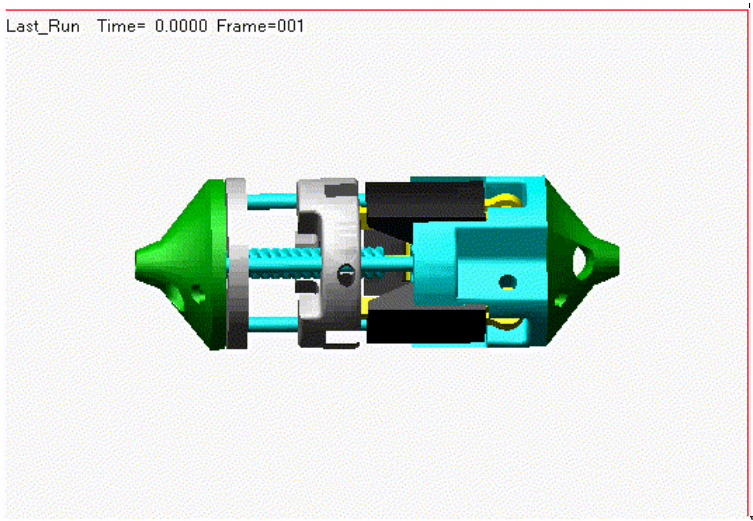
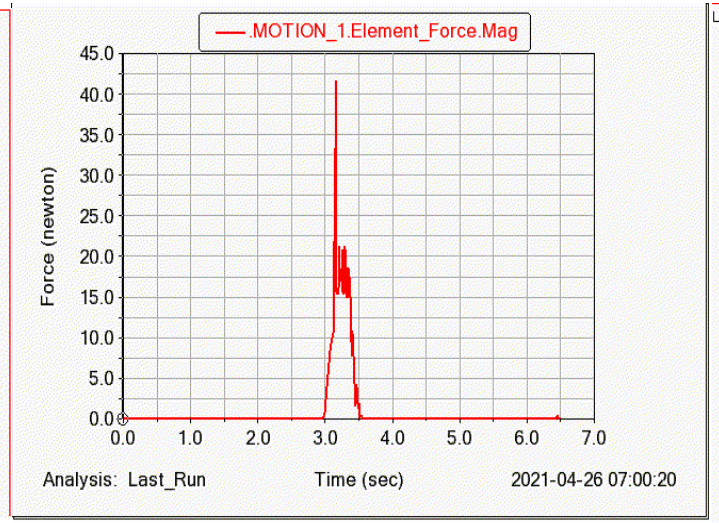
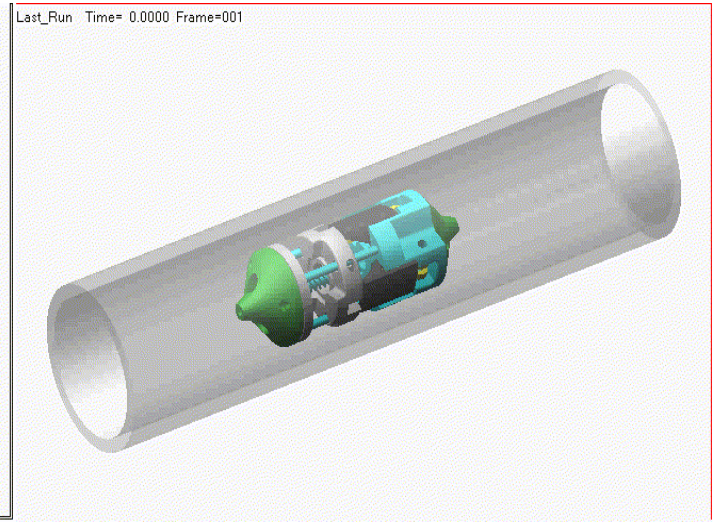
Project Update

Development of High-Fidelity Simulation Module







Dynamic motion analysis of gripper

- Efforts switched to utilizing ADAMS which is a Multibody Dynamic Motion Simulation Software, to analyze and perform the high-fidelity virtual simulation.
- ADAMS provides a larger database of tools and functionality which will be useful in developing a control strategy for the high-fidelity simulation.

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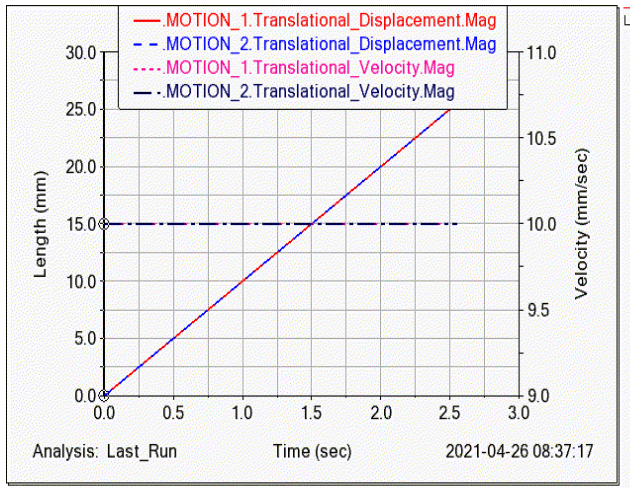
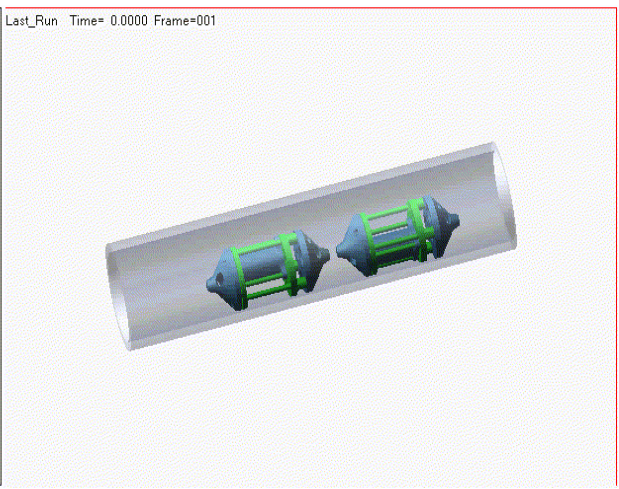
Project Update

Development of High-Fidelity Simulation Module

- A motion analysis of both extenders was conducted in ADAMS. The simulation was designed to have a maximum extension of 25 mm and a constant operating speed of 10 mm/sec.

- The extension/retraction of the extenders occurs after either the rear gripper or front gripper engages the pipe wall.





Motion analysis of Extender in ADAMS

- A complete simulation of the combined grippers and extenders will be performed using MATLAB/Simulink with ADAMS to implement control strategies.

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Project Update

Engineering Scale Testing

- 2- inch Mockup for evaluation of tether loads using clear PVC for visualization. A similar metal mockup is currently being constructed.
- Determine optimal strategies for multiple crawlers to distribute the tether load.
- Potential collaboration with industry partners for deployment and demonstration in super heater tubes

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Preparing Project for Next Steps

Challenges

- Inspection of longer pipe lengths
- Wire management
- Data acquisition system
- Maximizing the pull force

Future Plans

- Integration of UT, couplant and sensor modules
- Create a second crawler to assist in distributing tether load
- Integrate additional crawler with the robotic system
- Durability evaluation
- Engineering scale testing in a boiler tube mockup

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Concluding Remarks

Market Benefits/Assessment

- Current technologies are limited in their abilities to provide thickness measurements and other data related to the structural health of complex piping systems with small diameters similar to those found in fossil energy power plants.
- This research effort bridges the gap for these inspections and can reduce plant down time and increase plant efficiency while keeping employees out of harms way.

Technology-to-Market Pat

- The inspection tool developed in this research effort demonstrates the concept of a semi-autonomous system that achieves a mid-level TRL (technical readiness level). Working with engineers at power plants will assist in it's continued development and ultimately, demonstration and testing in the field.
- Additional research areas include developing a deployment mechanism specific to a facility and improving reliability with custom design components.
- Collaborators are needed for the demonstration of the system. Currently, we are working with engineers at Portland General Electric.

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Concluding Remarks

- The crawler is being used as a case study to assist in the development of a standard with ASME's Crawlers for Inspection Committee
- In discussions with FIU to submit a provisional patent on various elements of the crawler
- Manuscript recently accepted in *Materials Evaluation* titled, "Development of an Innovative Inspection Tool for Superheater Tubes in Fossil Energy Power Plants"

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Acknowledgment & Disclaimer

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Questions

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