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Furthermore, Gas Technology Institute would like to thank Operations Technology Development (OTD) for co-sponsoring this effort and providing general feedback on the technology concept. OTD is a collaborative effort that develops advanced technologies for the natural gas industry. This consortium of utilities combines interests, expertise, and resources into focused R&D projects. Special thanks to our volunteer natural gas distribution companies who attended live demonstrations, provided access to pipelines for testing, and returned feedback on the mapping concept.

Lastly, thank you to the project team which comprised members from GTI, Reduct, Condux, and Prisum.

Executive Summary

The purpose of this project was to develop a tool to help mitigate third-party pipeline damage and cross bores at the earliest stages through the development and commercialization of a geospatial probe to map existing buried utilities. This probe will be capable of mapping live underground pipes 3-dimensionally and give accurate locations of utilities. This mapping technology will not interrupt service to downstream customers. Additionally, a cloud-based data collection system will be created to effortlessly collect and store data, so it is easily accessible to the utilities. This tool will directly improve the safety and planning of underground utility construction projects.

Figure ES 1: The Mapping Probe, Integrated System of Propulsion, and 3D Data Output

Through this research effort, an externally driven mapping probe was developed which can accurately map underground pipeline locations within a six-inch window of the centerline of the pipeline. The probe provides location data from inside the pipe, meaning that there is no reliance on acquiring location data from the surface to detail the coordinates of the pipe. It should be noted that the duct rod which propels the mapping probe was integrated with a tracer wire, so surface locates are possible if needed. The probe can enter 2-inch and larger diameter pipe at an upright 90° angle which enables two-way bi-directional travel. The integrated system achieved a total pushing length of 600 feet. During the length assessment, the probe travelled the entire length of pipe available for testing, therefore, the team is confident the probe can travel much further. Data collected from the mapping probe can be easily stored and viewed via Esri's web application tools. This will assist Geographic Information Systems (GIS) teams in updating databases with high accuracy data or provide accurate mapping data prior to construction work. The team successfully completed live demonstrations with four natural gas utilities including Pacific Gas & Electric, Peoples Gas, Ameren, and City Utilities – Springfield, MO; and one demonstration at the RoundTable Live Event at Manteno, IL.

Introduction

The installation of underground utilities such as electric, natural gas, water, cable, and sewer is a common practice. Underground installation provides protection from damage by surface activities, vehicles, and the weather. However, when local utilities need to excavate to maintain or install new facilities, the ground becomes a barrier to their ability to determine where the utilities are below the surface. Historically, identifying and recording the accurate positional location of utility infrastructure was neither formally required nor carried out in a consistent manner. As a result, many of the mapping records that do exist are inaccurate or obsolete.

Figure 1 Example of Congested Underground Infrastructure

While technology has improved in recent years enabling the accurate mapping of newly installed underground utilities, there remains millions of miles of older pipe and conduit buried with no precise mapping of where these utilities are located. The two major concerns arising from the lack of utility mapping are excavation damage and cross bores between the utilities.

When excavators dig in the vicinity of buried utilities without consulting the local One Call Centers as required or in an area where it is not known where the utilities are buried, excavators could potentially damage those buried utilities. If the excavator damages a gas utility, there is a potential for a significant gas leak and a potential explosion. According to the Department of Transportation, Pipeline and Hazardous Materials Administration (DOT PHMSA) Pipeline Safety Performance Measures, the leading cause of serious incidents on natural gas distribution systems is excavation damage. Within the noted excavation damage causes, third-party damage is responsible for 84% of the incidents. Third-party damage occurs when a person other than the pipeline operator or its contractor excavates and damages a pipeline system.

A cross bore is defined as an intersection of an existing underground utility or underground structure by a second utility resulting in direct contact between the intersections of the utilities, which compromises the integrity of either utility or underground structure. When new utilities are installed using trenchless installation methods and existing underground utilities are present, there is a potential for a cross bore to occur. When a newly installed gas pipe is bored through an existing sewer line, a potential immediate and long-term danger is created. The sewer line is more likely to clog over time and if a plumber is called to rod out the line, there is a potential for the gas line to be ruptured and fill the house and/or possibly the sewer system with natural gas.

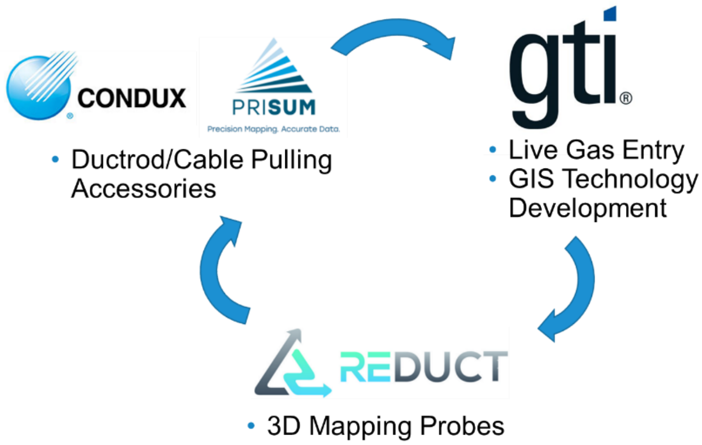

Figure 2 Relationship between Project Team Member's Expertise

To provide a new tool to assist with pipeline location needs, a diverse project team was assembled to develop a 3D mapping technology that could provide accurate geospatial data of gas assets. Key to success was that this technology must be able to map unlocatable plastic pipe, but still be transferable to other pipeline materials. In addition, the technology must not interrupt downstream service to the customer.

The team was led by GTI (Gas Technology Institute) who specializes in live gas entry and Geographic Information Systems (GIS). GTI previously developed the Jameson launch tool which allows for live-gas entry into distribution gas pipes. GTI brings a strong working knowledge of gas operations, GIS technology and mapping, and pipeline insertion technologies with cameras or bag stops to inspect the interior of a pipe or stop the flow of gas.

Figure 3 GTI Brings a Strong Background in Gas Operations and GIS Technology

Reduct is recognized as a global innovator in the field of underground utility network management and detection. Founded in 1990, the team recognized the need for a mapping solution for non-metallic underground pipes and ducts. In the second half of the 1990s, vast and rapidly deployed small-diameter HDPE data duct networks were installed. However, the accuracy of as-built data was poor. To provide a solution for this pipeline management challenge, Reduct launched the DuctRunner, which can provide accurate 3D mapping data with a suite of inertial measuring units (IMU) of unoccupied pipeline networks.

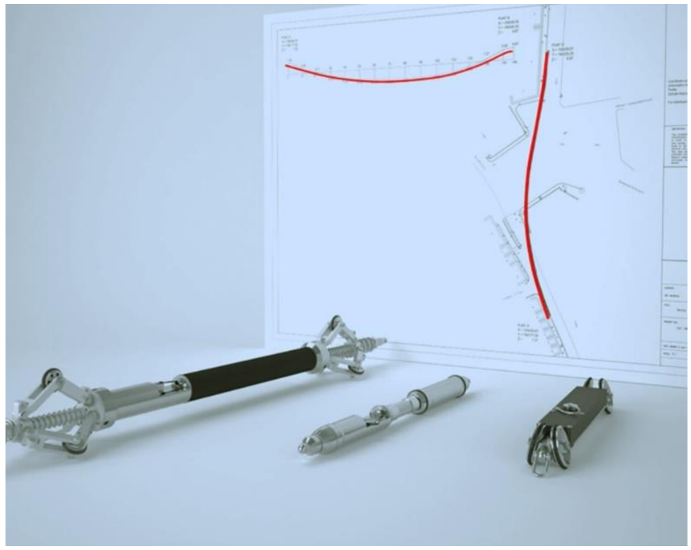

Figure 4 Reduct DuctRunner 3D Mapping Technology for Unoccupied Pipeline Networks

Condux International is the premier manufacturer of underground and overhead cable installation tools and equipment for the telecoms and electric power markets. Condux machines allow safe, quick and easy installation of fiber optic cable and power cables. Condux manufactures almost everything an installer needs to put fiber optic cable or copper cable in the ground or up a pole. With everything from large fiber optic blowers, handheld cable pushers to capstan-based cable pullers, every install method is catered for. Recently, Condux announced the formation of Prisum which will be the US-based 3D mapping subsidiary and commercializing entity of the live-gas 3D mapping probe developed in this project.

Figure 5 Condux Fiber Optic Cable Blower for Telecom Installation

With this composite knowledge of gas operations, GIS technology, 3D IMU-based mapping probes, and cable pushers, the team developed a novel integrated system for inserting and propelling a mapping probe into a live gas pipe to collect accurate 3D data. The system is comprised of a mapping probe, an external odometer, an off-the-shelf GNSS (Global Navigation Satellite System) receiver, a live-gas insertion Jameson Launch Tool, a duct rod pusher, and a duct rod spool with an integrated tracer wire as shown below in Figure 6.

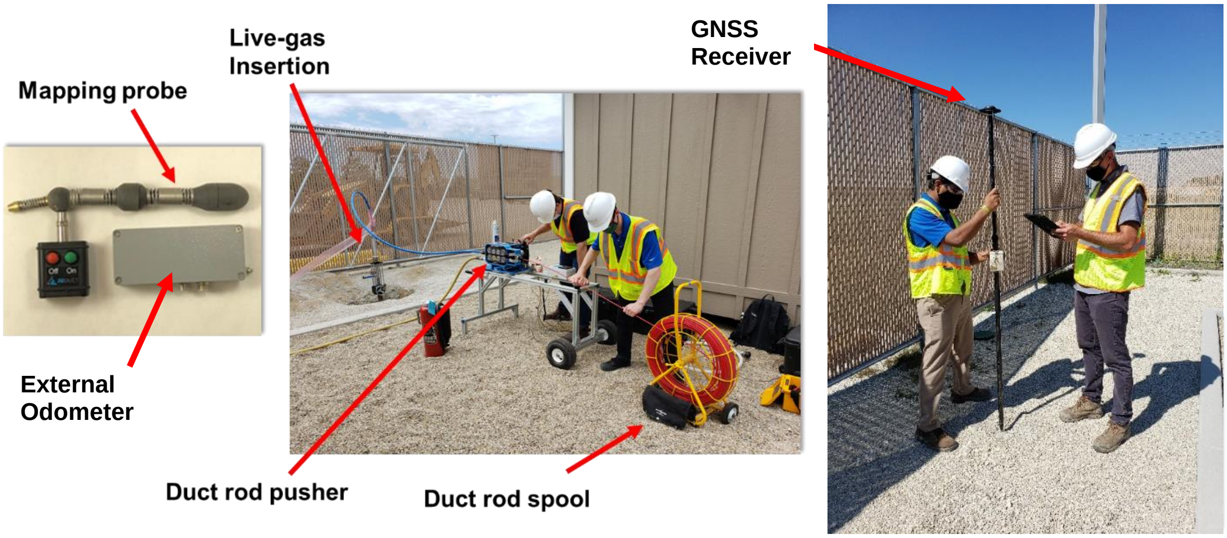

Figure 6 Example Image of Integrated Mapping System Operation

To collect 3D mapping data, the probe is interested into live natural gas pipelines and propelled through the asset with the duct rod pusher. The probe is attached to the duct rod spool which enables locomotion through the pusher. High accuracy GNSS positional starting and ending points are captured during operation. Once the mapping process is completed, the x, y, and z probe data, odometer data and GNSS location points are input to the accompanying extraction mapping software. Once the data is collected and extracted from the mapping probe, 2D and 3D renderings can be exported via CSV, KML, XML, and SCR files for as-built maps, AutoCAD renderings, and GIS data visualization and management.

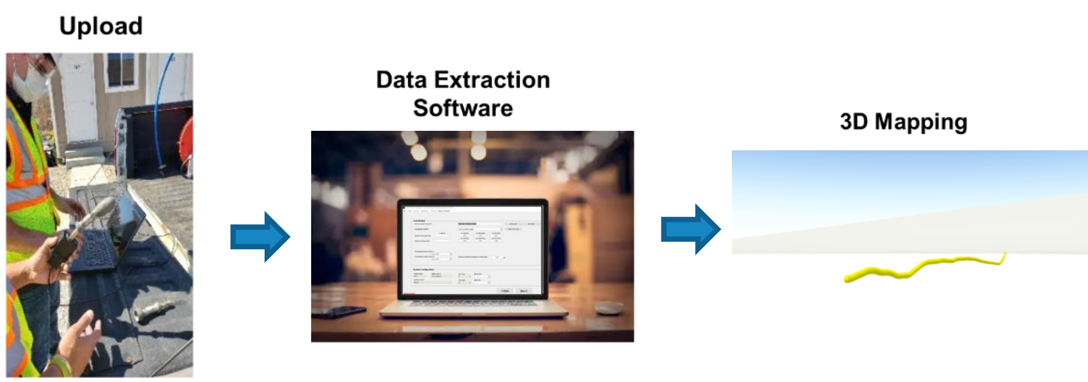

Figure 7 Data Extraction Workflow and Data Visualization example

The technical report is segmented by the 8 major milestone deliverables. The report will detail the progress of the overall technical design, development, and real-world use. Each section will detail the objective of the task and the ultimate solution. As shown in Figure 6, the project produced a new mapping technology that can provide accurate 3D location data in live gas piping, within a six-inch window of accuracy to the centerline of the underground facility. Data provide from this tool can assist in underground construction project planning, mapping accuracy initiatives, and preventing third-party damage of an underground facility during construction activities.

Results and Discussions

The Results and Discussions section has been divided according to project deliverables. Therefore, each deliverable will have a dedicated section with the associated Task and Item number specified in sub sections. It should be noted that deliverable 1 and 2 were quarterly reports. Technical deliverables began on deliverable 3.

Deliverable 3

To complete deliverable 3, there were two deliverables required of the team. These were Task 2, Item Number 4 and Task 4 Item Number 5. The results will be discussed in the sections below.

Task 2, Item Number 4

Task 2 objective: The objective of Task 2 “Enhance existing technology” is to enhance the existing smart probe design to allow it to be inserted into a live natural gas line.

This section presents a summary of Task 2, Item Number 4 – Develop alpha-prototype drawings based on comments from TAP. Procure parts and materials needed to build alpha prototype.

The goal of this task is to refine Reduct’s existing mapping tools to enter live gas pipelines at a 90° entry angle. Prior to technical work, the team distributed a survey to the Technical Advisory Panel (TAP) and members of Operations Technology Development (OTD) to learn about which pipe sizes presented the largest struggle. This survey indicated that 2” – 4” diameter plastic pipes were the largest mapping need among natural gas distribution companies. Therefore, conceptual computer-aided design (CAD) drawings were produced to begin designing the mapping probe for this sized pipeline. GTI provided dimensions of a potential launching shoe for insertion to Reduct. These dimensions were entered into Creo PTC 3D CAD software and conceptual drawings were produced as shown in Figure 8.

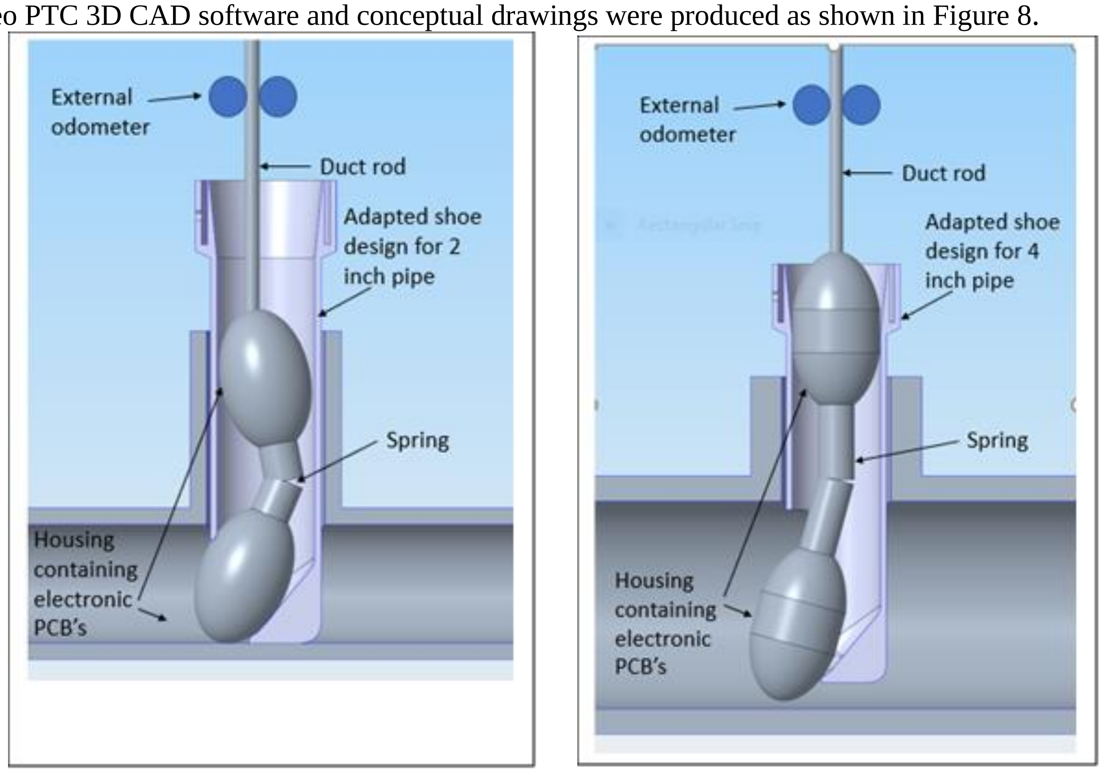

Figure 8 Simulated Computer Generated Design Concepts for 90° Pipeline Entry in 2” (Left) and 4” (Right) Diameter Pipe

These drawings helped the team study of the physical constraints of entering/exiting and maneuvering through 2-inch and 4-inch pipe.

Prior to this work, the circuit board for Reduct's existing product line was too large to enter 2-4" diameter pipe. Therefore, an international search for miniature sensor systems was commenced to meet spatial design limitations. This search comprised of identifying state of the art IMUs, CPUs, Power PCBs, and Odometer configurations.

In addition to the technology search for miniature sensors, a novel means of propelling the mapping probe was conceived. To begin this search, a design criteria was established for the propulsion mechanism as described in Table 1.

Table 1 Product Specifications

Description	Scope & Requirements
Pipeline Size	2" & 4"
Motors	Electrically or Pneumatically operated
Gas Pipeline pressure	60 psig
Safety	E- Stop & remote (optional)
Mechanism	Push and Retrieve
Overall weight target	Max 25lbs. (if mounted vertically on Gas line)
Speed of travel	3 feet/sec (reference)
Duct rod	¼" or 5/16"
Total Distance to map	1500 feet
Mapping Tool Weight	2 lb
Mapping Tool Length	18"

Tangential to the mapping probe and propulsion mechanism, additional components that required further development were the guide shoe, Tellus packing glands (stuffing box), and a duct rod connecting adapter.

Two design concepts were proposed for the propulsion mechanism. Ultimately proposal A was selected to limit additional weight on the launching apparatus potentially causing failure during pressurized live-gas mapping.

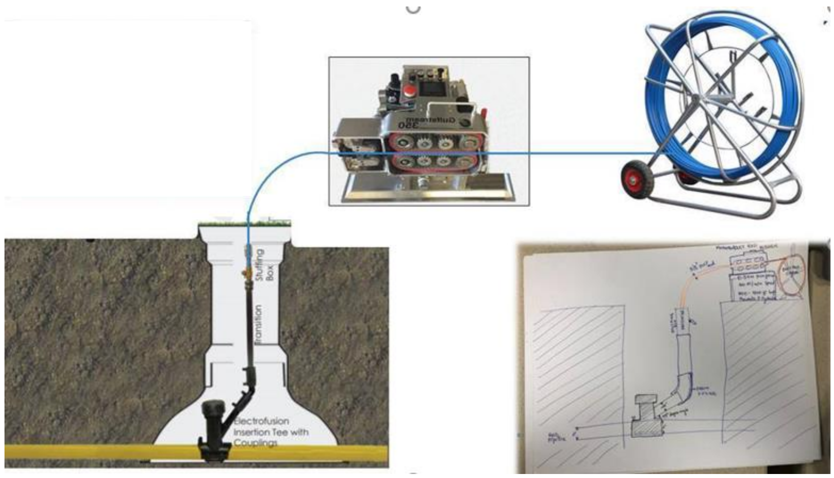

Figure 9 Proposal A: Utilizing GS350 (w/o air block) mounted on horizontal surface.

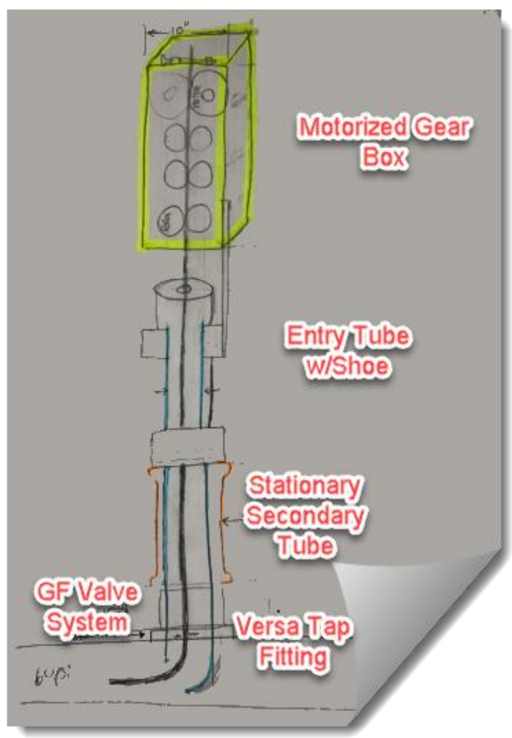

Figure 10 Proposal B: Vertically Mounted Motorized Duct Rod Pusher Mechanism

Task 4, Item Number 5

Task 4 objective: The objective of Task 4 “Cloud Based Data Collection and GIS Development” is to develop a system that can easily upload field data from the probe into the cloud and can be easily retrieved by utilities.

This section outlines a summary of Task 4, Item Number 5 (Deliverable 3) – Procure required software and develop a system flow diagram for cloud-based data collection system.

GTI developed a workflow to export data from the Reduct mapping probe, process the data and provide the results through a web-based mapping application utilizing Esri’s web-based tools. Many natural gas utilities use Esri GIS services to record location data of underground assets therefore the team chose this web application to manage, post-process and visualize the 3D mapping data. The process of converting the data from the mapping probe can be customized to provide additional capabilities as required by the end-user. The tool that was developed includes the following components:

Step 1 Field Data Collection: Project assigned work will detail where Reduct will perform underground asset mapping with their proprietary tools. Data will contain at a minimum X, Y, and Z coordinates and any other pertinent attributes defined in Reduct’s data collection schema. Data will be stored locally on the mapping probe and extracted later once the pipeline project has been completed.

Step 2 Field Data Extraction: Data that is collected and stored on the mapping probe will need to be manually extracted and loaded to a website or server location so that it can be prepared for post-processing. Data formats extracted from the devices should contain the same schema every time to ensure consistency and similar results after the extraction and conversion tools are run.

Step 3 Data Delivery: As data is extracted from the mapping probe it will need to be loaded onto a centralized server location for storage and access. This server location can be a client’s server or an online repository. Examples of online repositories might include (but are not excluded to) Dropbox, Google Drive, or Amazon S3.

Step 4 Data Conversion: Depending on what area the mapping probes operate; a local coordinate system might be applied to the data as it is collected. Using a standard coordinate system like WGS 84 will normalize the data and allow it to better integrate with the various coordinate systems that each client utilizes. The process of data conversion will allow for data collected in the field to be converted to a standard and then from that standard, it can be transformed into the proper coordinate system that each client employs in their Geographical Information Systems (GIS) database. A GeoProcessing tool, model or script will need to be developed to handle this data conversion process.

Deliverable 4

To complete deliverable 4, there were two deliverables required of the team. These were Task 2, Item Number 7 and Task 3 Item Number 8. The results will be discussed in the sections below.

Task 2, Item Number 7

Task 2 objective: The objective of Task 2 “Enhance existing technology” is to enhance the existing smart probe design to allow it to be inserted into a live natural gas line.

This section presents a summary of Task 2, Item Number 7 – Alpha-prototype and test rig will be assembled.

Taking multiple parameters into consideration, the team tested two and three egg mapping probes with flexible connections. Initial concepts were created for 2” diameter pipelines. The team completed work on creating an alpha-prototype for testing and made a 3D printed prototype of the mapping probe to demonstrate 90° entry into a 2” pipe.

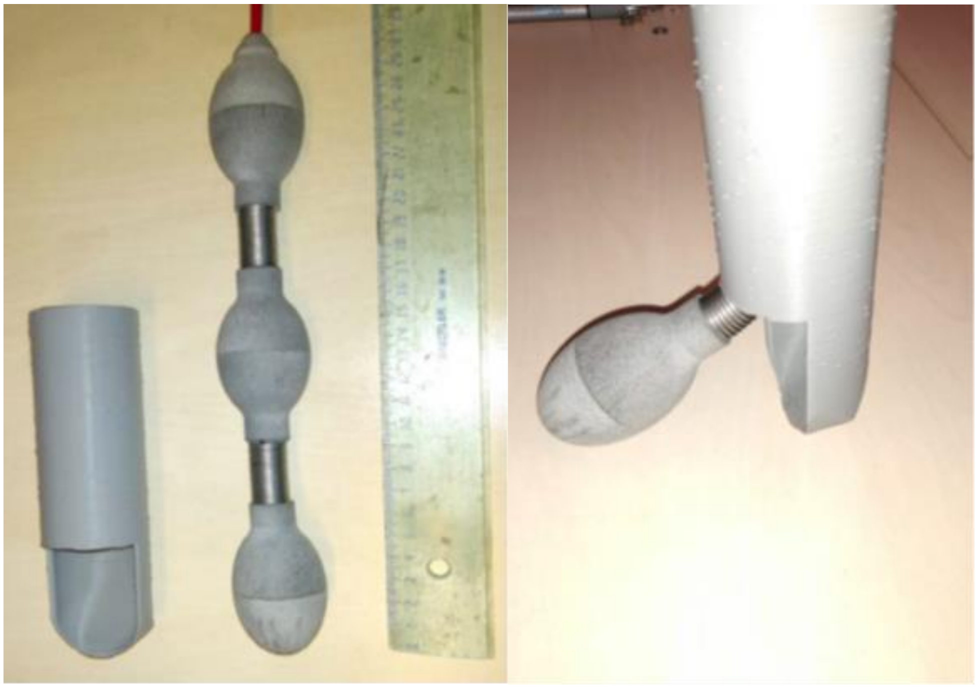

Figure 11 Initial Prototypes of Mapping Probe and Launching Shoe for 2” Pipeline.

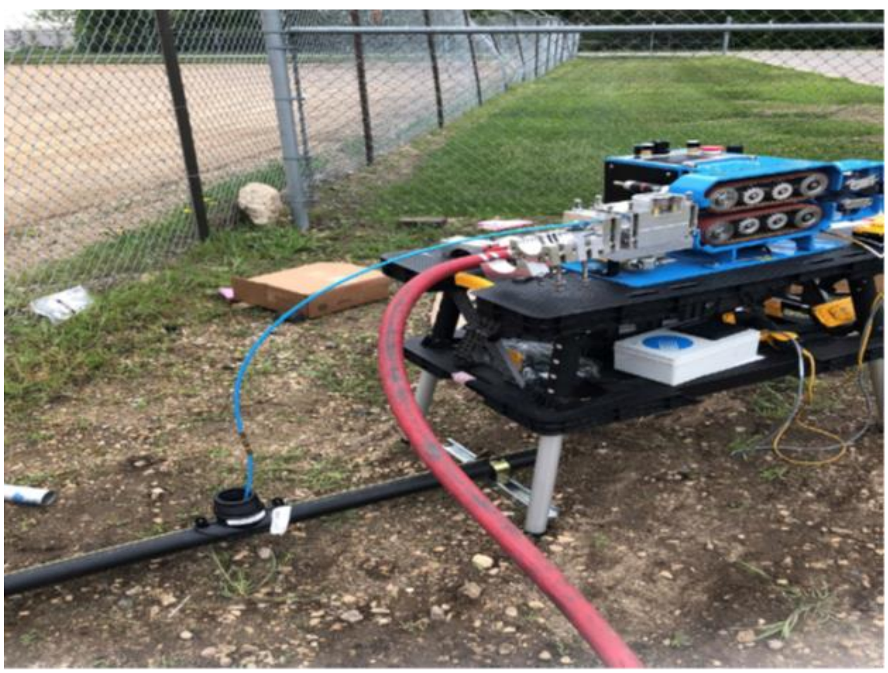

Figure 12 Prototype testing of Pneumatically Driven Duct Rod Pusher Propelling Duct Rod into a Pipeline

Condux began redesigning the Gulfstream 350 fiber optic cable blower to provide a clamp and driving force to propel the duct rod, with the mapping probe attached, through a live gas pipe. The device is driven pneumatically which limits electrical needs around live gas applications. An external odometer is mounted on the duct rod inlet to capture distance travelled as the pusher propels the duct rod through a pipeline.

Additionally, a test loop was designed and fabricated at Condux's facility. This was transferred to GTI during later stages of the project.

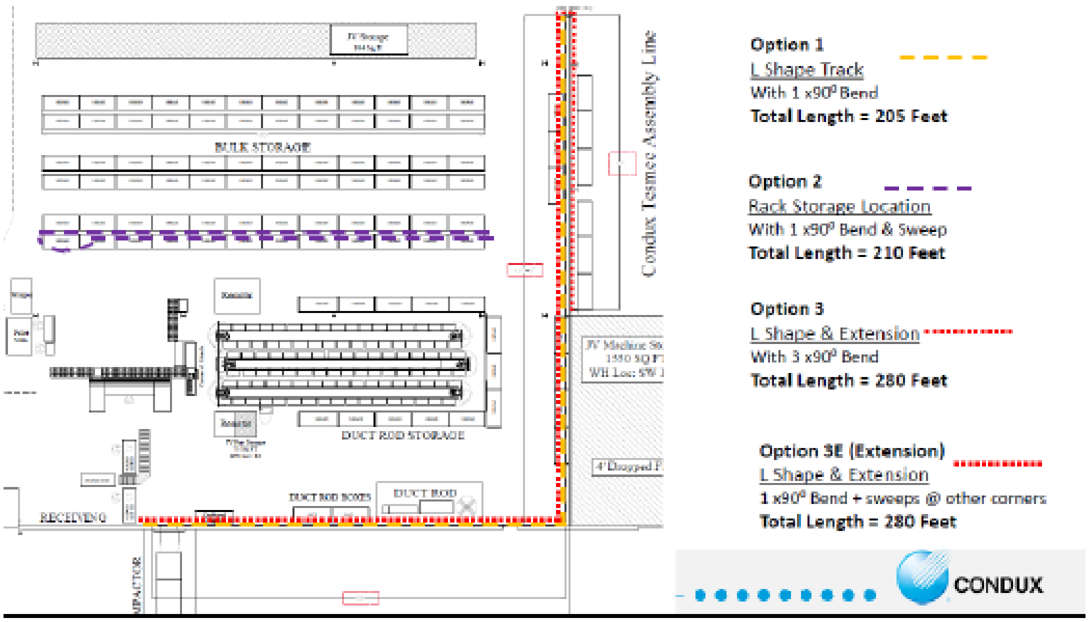

Figure 13 Test Rig Designs

Task 3, Item Number 8

Task 3 objective: The objective of Task 3 "Create a new access fitting" is to design and manufacture a 90° fitting that will allow the new probe to navigate into a live pipe.

This section presents a summary of Task 3, Item Number 8 – Identify/develop preliminary designs for the pipeline access fitting.

Initial design concepts were developed to study the insertion of the mapping probe into a live gas pipeline via the launching apparatus.

Figure 14 Initial Design Concept of Insertion Shoe for Live-gas Entry

Ultimately the shoe design was refined to be compatible with the Jameson live gas entry apparatus. The shoe will guide the probe in the direction of desired travel.

The spatial limitations imposed by 2” diameter entry was verified prior to testing in live-gas environments with the integrated system. The team ensured that the shoe could rotate to achieve 180° bi-directional mapping.

Figure 15 The Spatial Requirements and Fit Tolerance was Verified Prior to Live-gas Testing

Deliverable 5

To complete deliverable 5, there were four deliverables required of the team. These were Task 2, Item Number 10, Task 4 Item Number 11, Task 3 Item number 12, and Task 5 Item number 15. The results will be discussed in the sections below.

Task 2, Item Number 10

Task 2 objective: The objective of Task 2 “Enhance existing technology” is to enhance the existing smart probe design to allow it to be inserted into a live natural gas pipeline.

This section presents a summary of Task 2, Item Number 10 – The mapping probe alpha prototype will be functionally tested at Reduct’s headquarters and adjustments will be made prior to testing at GTI.

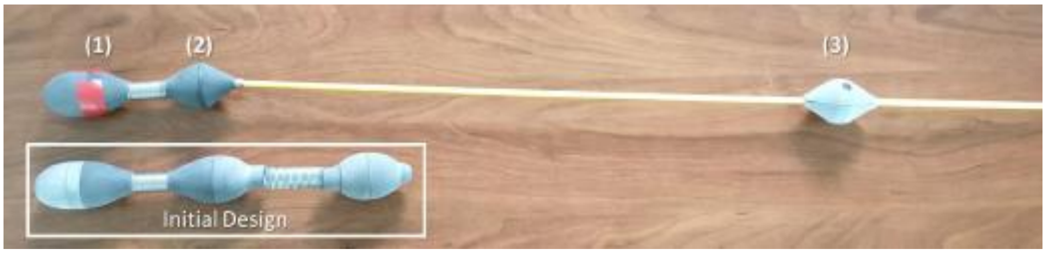

Figure 16 Alpha Prototype Design of Mapping Probe

Although initially favoring a three-egg design, the team attempted to perform live gas mapping with a two-egg design to simplify manufacturing. As will be discussed in later stages of the project, it was determined that a three-egg design eased the 90° entry. This enhancement was performed after lab-based testing and will be discussed during later sections.

Prior to live gas testing, the new miniature custom printed circuit board was calibrated and functionally tested.

To test the functionality, the misalignment angle of the sensors and the scale is calculated during calibration. Blue bars are before calibration, and red is with the calibration applied.

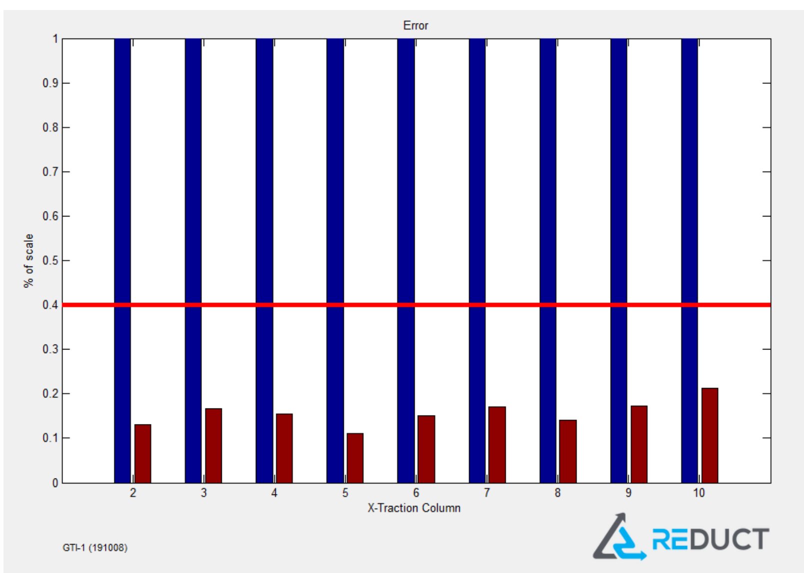

Figure 17. Calibration Data

According to Figure 17, testing of the sensor system was deemed a success because the red bars were below 0.4%. In this figure, the red line indicates the 0.4% threshold.

After calibration, Reduct tested the functionality of the new mapping probe with a new external odometer. 3D mapping data and external odometer data was collected in a 120-foot-long pipe.

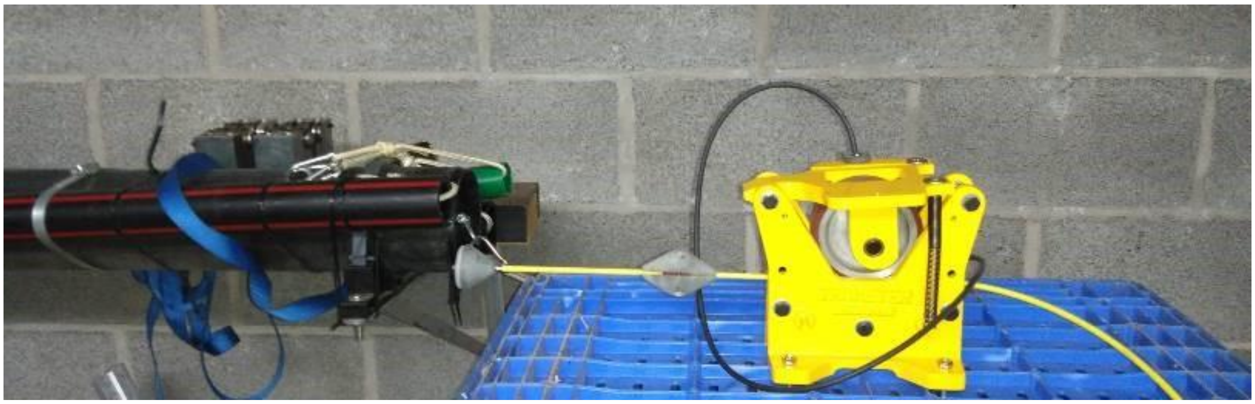

Figure 18 Alpha Prototype Testing

The software to merge the odometer data with the probe data was successfully tested. To test the merger of the odometer data with the software, data was collected with the accelerometer and gyroscope data from the probe, and the odometer.

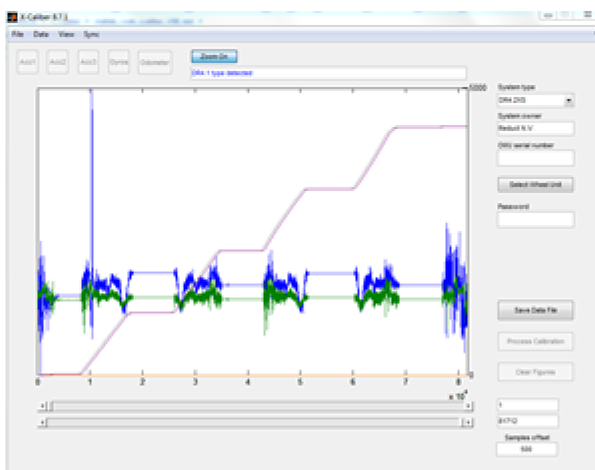

Figure 19. Positioning and displacement Data Merger

As shown in Figure 19, this data was combined in the software to form one dataset.

Task 4, Item Number 11

Task 4 objective: The objective of Task 4 "Cloud-Based Data Collection and GIS Development" is to develop a system that is able to easily upload field data from the probe into the cloud and can be easily retrieved by utilities.

This section outlines a summary of Task 4, Item Number 11 – Develop/enhance the Cloud Data Base Collection system.

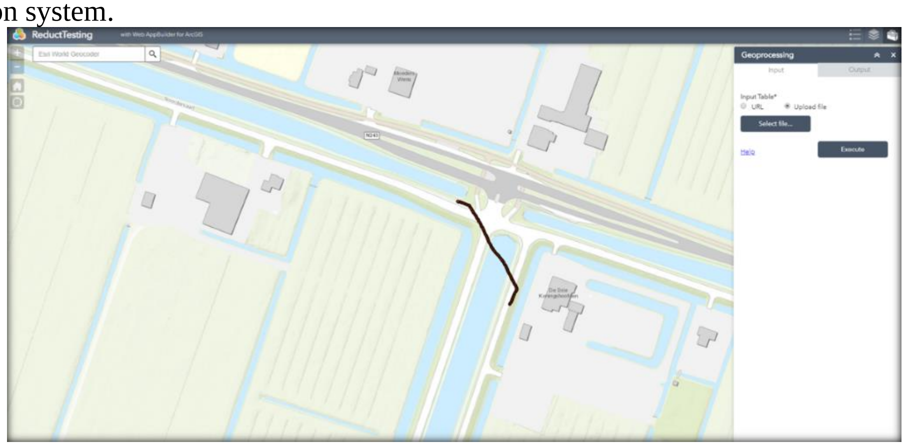

Figure 20 Mapping Probe Data Upload to Esri

Data collected from the Reduct mapping tool was uploaded to Esri GIS software for display. GTI facilitated a discussion with the technical advisory panel to streamline data provided by the Reduct mapping tool to the utilities. The utilities discussed that a method to quickly view the data in the field was desirable and that they would like the data in a structured manner so that utility GIS technicians can quickly view the data via Esri's mapping data viewing platform.

Currently, the data that is extracted from the Reduct's software can be exported to a CSV file format that works well with Geographic Information System (GIS) applications, both on a desktop and on a web interface. For this task of the project, GTI created a web application using Esri's (Environmental Systems Research Institute) Web App Builder. Using Web App Builder, GTI created a cloud-based web interface where specific tools were designed to allow a user to upload a file, map the data in that file based on latitude and longitudes and download the converted data in numerous file formats (i.e., GIS shapefile/geodatabase, Google Earth KML). Additionally, the user can email these files to the appropriate party simply by typing in the email address before conversion.

The engine running these conversion tools are Python scripts which are designed to use cloud servers on the back end to perform the work. This allows the user to interact with a web application rather than requiring the user to have access to a desktop GIS. Once the CSV file is uploaded to the web application, the Python script will initiate the process on the backend cloud server to complete the necessary conversion. Below are some tables and figures that describe this process in more detail:

The table below describes the typical data structure extracted from the mapping probe and then calibrated with Reduct's desktop software.

Table 2 Example of Reduct Mapping Data

Distance_From_WPA	Easting	Northing	Depth	Azimuth	Pitch
2	1095725.89	1950015.15	0.042	77.1	0.7
3	1095726.86	1950015.22	0.064	77.6	1.3

4	1095727.84	1950015.64	0.108	78	2.5
5	1095728.81	1950015.84	0.135	78.9	1.6
6	1095729.79	1950015.99	0.148	80.9	0.7
7	1095730.78	1950016.11	0.15	83.1	0.1

Once the data is extracted, it is then ready to be uploaded to the web application. The image below shows the web application and the different widgets (red box in the upper right corner) that were built to convert the data from a CSV file to a GIS compatible format using backend cloud server processing:

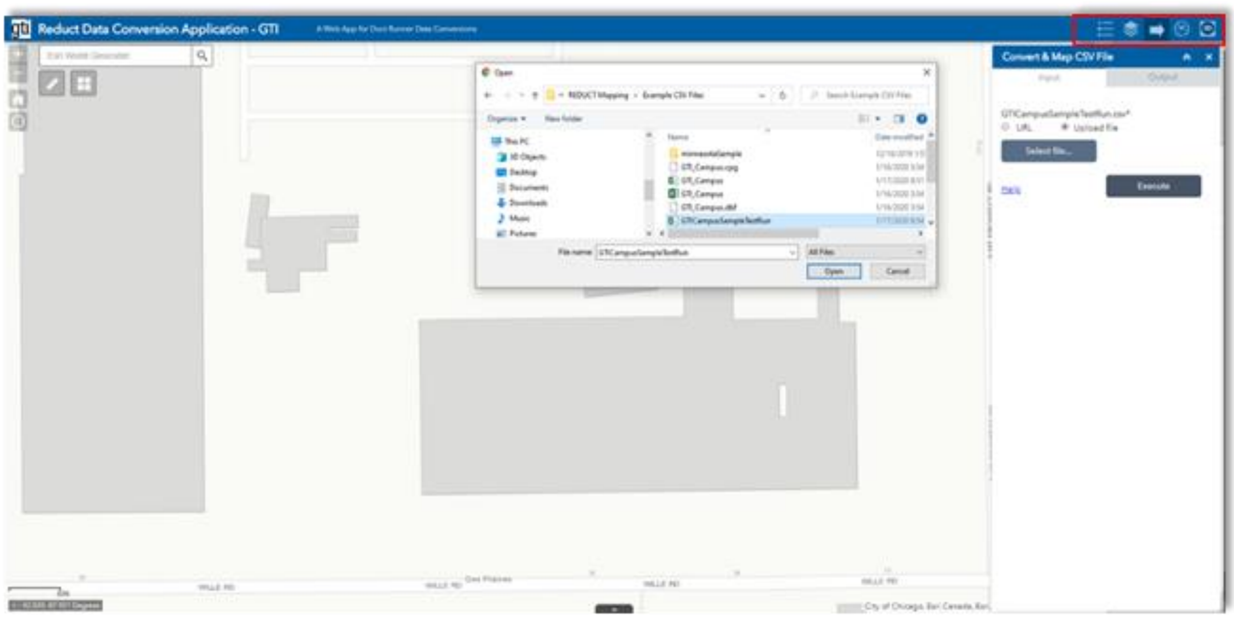

Figure 21 Example of CSV File Conversion to a GIS format on the Web Application

After the data is converted using the proper widget, it will then display the data on the map. The user can then choose to use another widget to extract and download the data or review the output for validation purposes. Figure 22 below shows the data extraction tool:

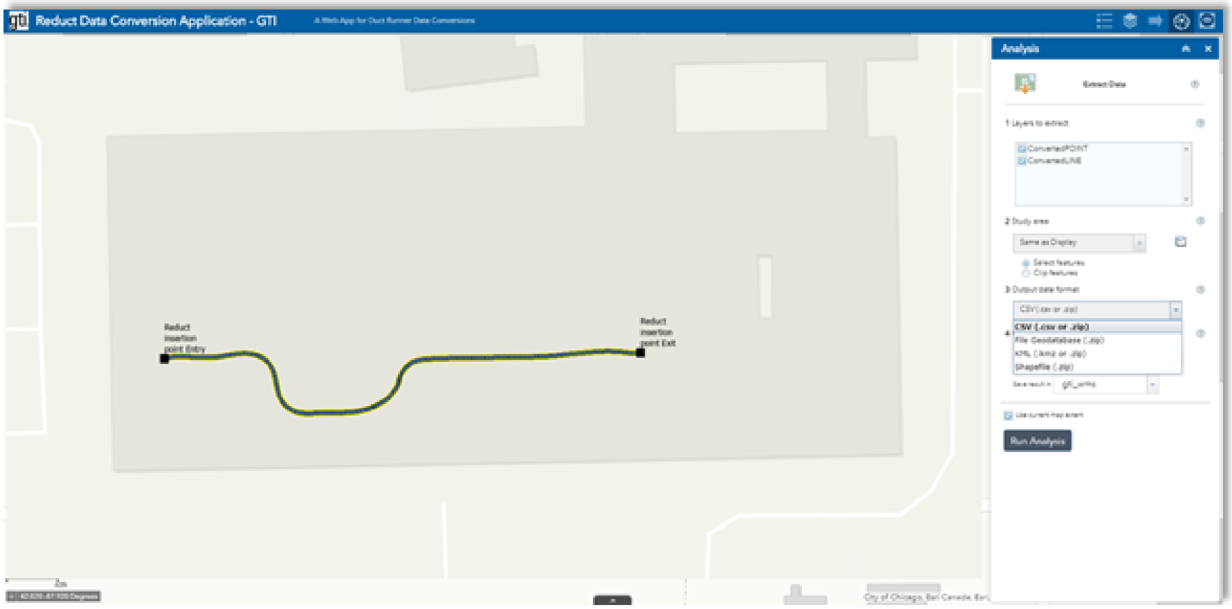

Figure 22 Example of the Extract Data Widget on the Web Application

Once the user clicks on the Extract Data Widget, they can choose which data layers they would like to export and which file format they need. After extraction, the data is then hosted on a cloud service portal for the user to access and download, as seen in Figure 23 below:

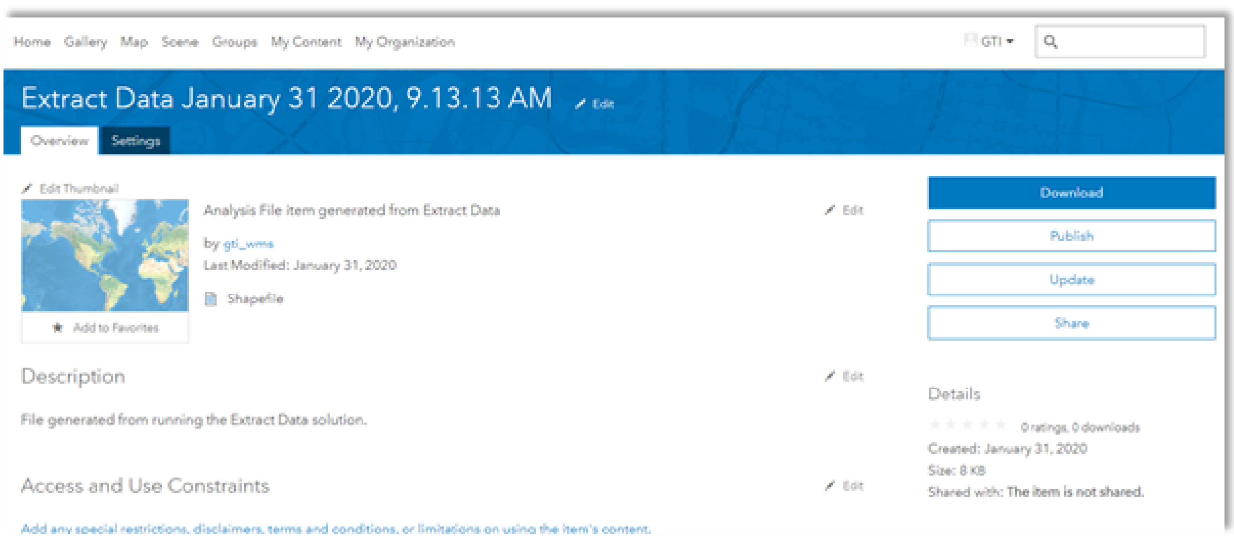

Figure 23 Example of Cloud Service Portal where the Data is Stored for Download

If the user does not want to download the data, they can send the converted data as a zip file attached to an email. For this operation, the user selects a different widget where they can upload the CSV file and perform the conversion like before, but they will be prompted to include an email address. During conversion, the backend server process will convert the CSV file, draw it on the map and then automatically send an email to the address provided with an attached zip file, including the data. Figure 24 depicts an image of this operation:

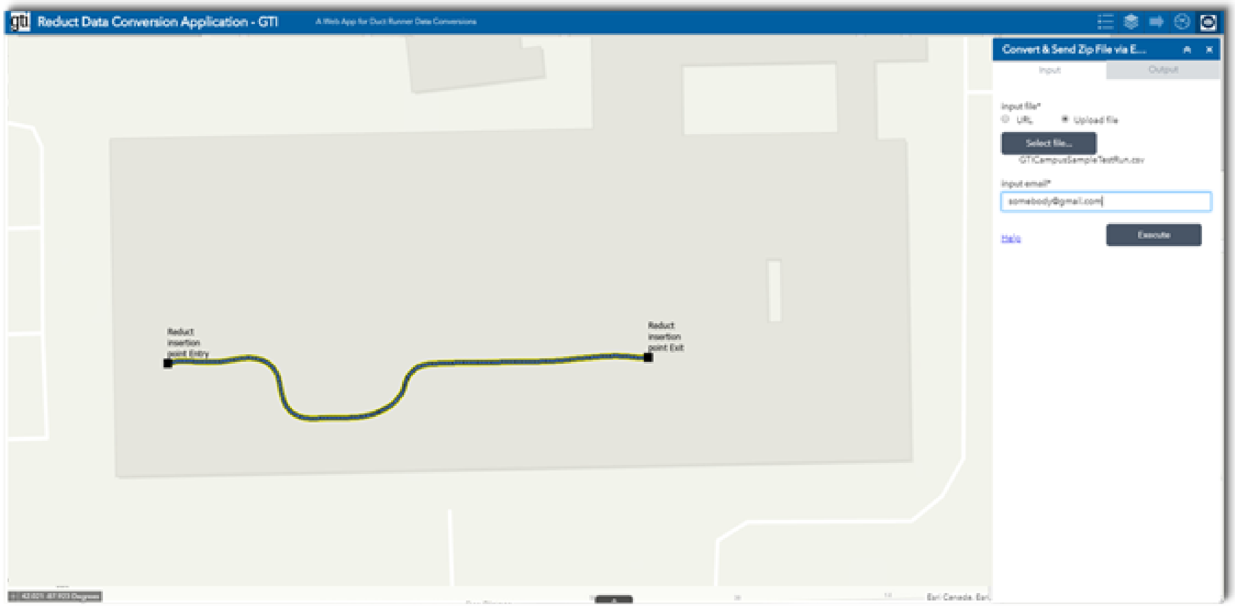

Figure 24 Example of Data Conversion with Email Option

Task 3, Item Number 12

Task 3 objective: The objective of Task 3 "Create a new access fitting" is to design and manufacture a 90° fitting that will allow the new probe to navigate into a live pipe.

This section presents a summary of Task 3, Item Number 12 – Develop the new access fitting to use during lab testing.

The performance of an access shoe was verified with 90-degree access to a pipeline when attached to the Jameson Launch tool (imaged below).

Figure 25 Jameson Live-Gas Launch Tool and Pipeline Access Fittings

The launch shoe and an example of how the shoe fits within an existing access port are shown below.

Figure 26 Pipe Access "Shoe" with 90° entry

Figure 27 shows several still frame images of the mapping probe entering a pipeline via the pipeline access shoe.

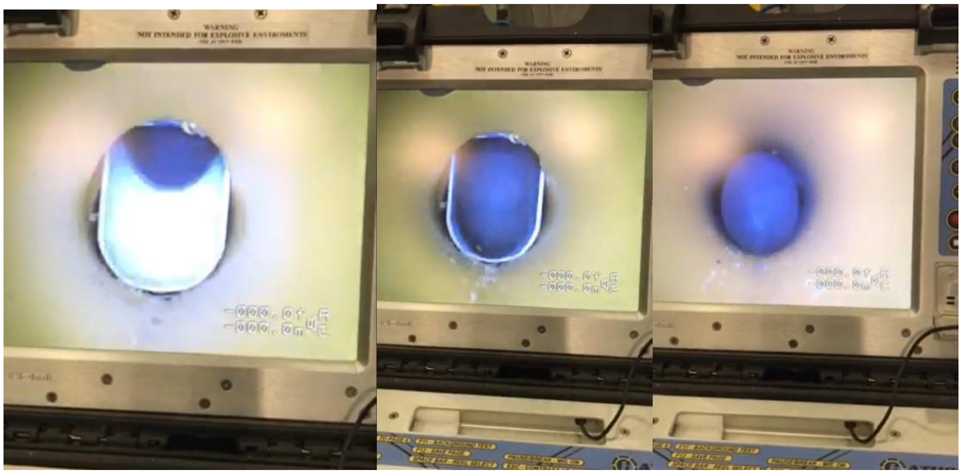

Figure 27 Still Frames of Gyroscope Video Detailing Mapping Probe Access

Task 5, Item Number 13

Task 5 objective: The objective of Task 5 "System Evaluation" is to conduct pipeline mapping in a live pressurized gas pipe.

This section will outline the work to complete Item Number 13, Task 5: Procure and set up equipment needed for a full lab test to be performed.

A launch apparatus and shoe were prepared for mapping probe pipeline access.

Figure 28 Pipe Access fitting

Functionality of the alpha prototype was validated by completing a 90° insertion into a pipeline and traveling 301.8ft.

Figure 29 Test Rig Set-up

Figure 29 displays the test set up, each component will be discussed individually in the following images.

Figure 30 Stuffing Box with Mapping Tool Pipeline Entry

The mapping tool was loaded into the stuffing box and inserted into the pipeline.

Figure 31 Pneumatic Duct Rod Pusher Mechanism

The mapping tool was pushed by the pneumatic duct rod pusher with visual readout of distance travelled.

Figure 32 Image of Duct Rod Spool used for Propulsion

The duct rod was fed into the pneumatic duct rod pusher to push the mapping tool the necessary distance.

Figure 33 Image of Final Measurement Display crossing 300' Threshold

The measurement provided by the pneumatic duct rod pusher validated the total distance of 300 ft.

Figure 34 Image of Integrated Mapping System used for Lab Trials.

Overall testing determined areas to improve the technology concept. Namely, the team focused on improving the performance of the motors for additional lab testing under pressurized conditions.

Deliverable 6

To complete deliverable 6, there was one deliverable required of the team. This was Task 5, Item Number 15.

Task 5, Item Number 15

Task 5 objective: The objective of Task 5 “System Evaluation” is to conduct pipeline mapping in a live pressurized gas pipe.

This section presents a summary of Task 5, Item Number 15 – Conduct lab testing of initial prototypes at GTI’s Des Plaines facility, where the prototype will transverse hundreds of feet of pipe under pressure.

In this task, testing was performed to evaluate and validate the performance of the mapping probe and pneumatic duct rod pusher. The team sought to map 2” polyethylene pipe under pressurized conditions. This would require 90° insertion and retraction of the mapping probe, data collection, and achieve a push length of 300 ft.

In preparation for these tests based on observations from the previously reported mapping probe and pushrod experiments, several enhancements to the pneumatic duct rod pusher were performed.

In order to meet the 300 ft distance more effectively, the pneumatic motors were upgraded to achieve higher push forces. Atlas Copco LZB22 motors were selected which have higher torque performance (Figure 35).

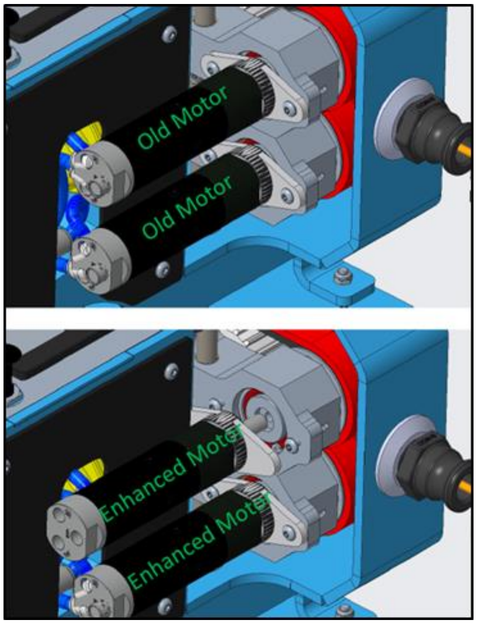

Figure 35 Upgraded Pneumatic Duct Rod Pusher Motors

As a result, the new enhanced motors have 47% increased push force as shown in Figure 36.

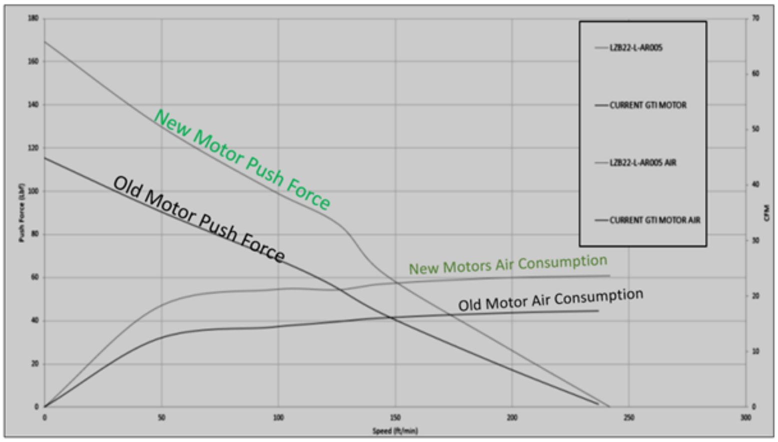

Figure 36 Comparison of Push Forces

The duct rod pusher was equipped with a solid-state magnetic proximity sensor which has electrical immunity protection.

The new encoder, mount, and wheel have been relocated from the top roller to the bottom roller location shown in Figure 37.

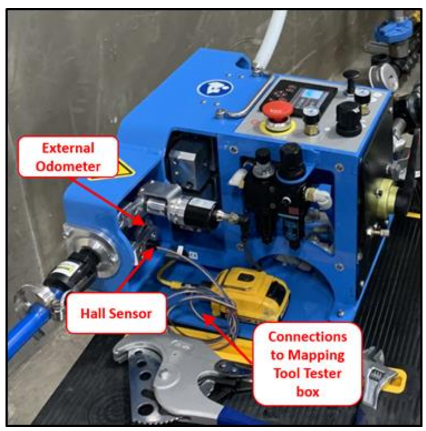

Figure 37 Location and Wiring Diagram of Odometer Sensors

For testing, Reduct provided an Alpha-Prototype mapping probe, odometer data logger, and control unit, as shown in Figure 38.

Figure 38 Alpha-Prototype Hardware Provided by Reduct

A 300 ft test track was arranged to test the ability of the mapping probe to travel through various geometries and record geospatial data under increasing pipeline pressure. As shown in Figure 45 – 47, different pipe configurations of snaking, bends, and changes in height were evaluated.

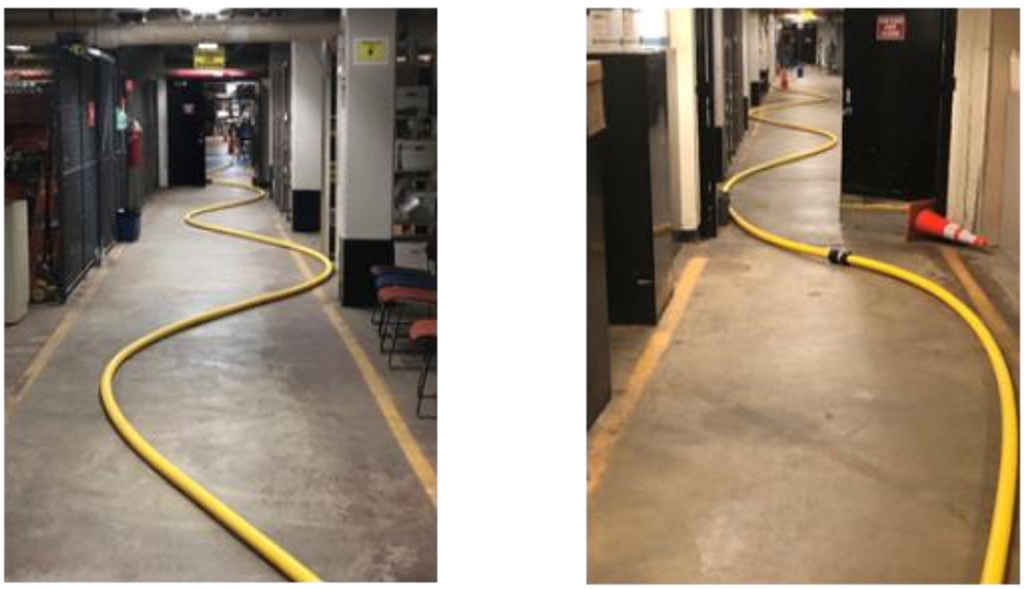
Figure 39 "Snaking" Pipeline (Configuration 1)

Figure 40 Height Differential (Configuration 2)

Figure 41 Multiple 90° Bending Elbows (Configuration 3)

To begin testing, pressure of the system was regulated. Typically, conditions comprised of 0 psig, 30 psig, or 60 psig. An example of an experiment conducted at 60 psig is shown in Figure 42.

Figure 42 Pipeline Operating Pressure

After pipeline pressure was set, the mapping probe was powered on with the control unit and attached to the duct rod.

With the probe attached to the ductrod cable, the mapping probe was fed through the Jameson launch tool. The probe was then pushed through the 90° entry shoe and allowed to sit for 30-60 seconds to initiate system mapping (Figure 43).

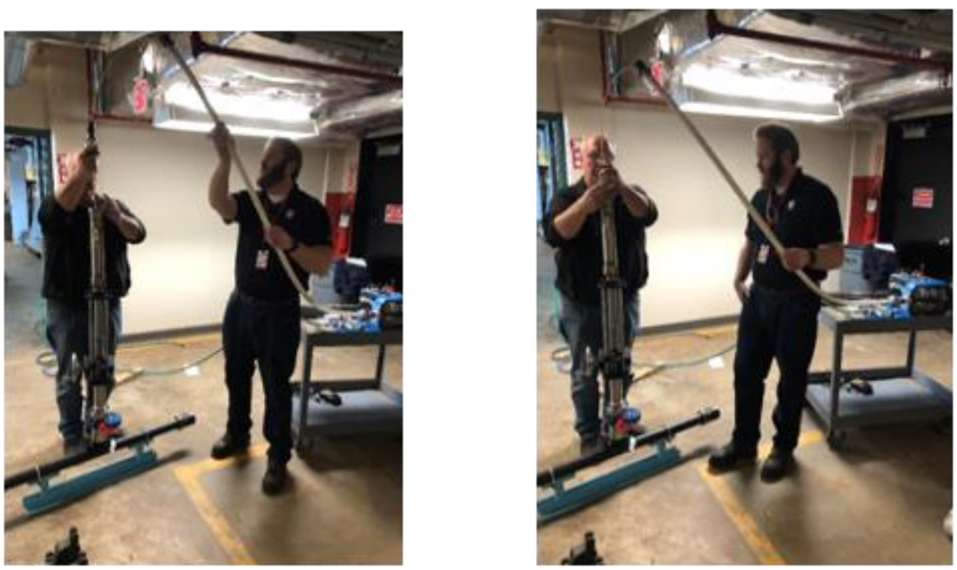

Figure 43 Assembly and Launch of the Mapping Probe

As shown in Figure 44, mapping operations were successfully performed with a 90° launch, data collection, and 90° retraction. The pneumatic duct rod pusher successfully pushed the probe 300 ft regardless of track configuration. Examples of the data collected were shown previously in Figure 22 and Figure 24.

Figure 44 Evaluation of Mapping System and Operation of the Pneumatic Duct Rod Pusher

Thus, the project team was able to validate the mapping concept successfully in pressurized pipe. Enhancements to pneumatic duct rod pusher allowed the system to achieve 300 ft of travel with ease. It should be noted that due to the 90° insertion method, by retracting the probe and revolving the Jameson launch tool 180° in the opposite direction an additional 300 ft can be mapped. Therefore, upwards of 600ft of live gas pipeline mapping could be performed. The probe withstood 60 psig of pressure as well as the stresses caused by 90° entry/exit. The probe successfully recorded data during these trials and improvements to the software workflow allowed for a seamless transition of data viewing on Esri GIS software.

Deliverable 7

To complete deliverable 7, there were two deliverables required of the team. These were Task 5 Item Number 17, and Task 6 Item Number 18.

Task 5, Item Number 17

Task 5 objective: The objective of Task 5 "System Evaluation" is to conduct pipeline mapping in a live pressurized gas pipe.

This section will outline the work performed to complete Task 5, Item 17 – Refine designs of the alpha prototype, cloud data base, and access fitting.

GTI worked to enhance the spatial web mapping application by creating a process that takes the CSV file output from the Reduct duct runner probe and converts it to a 3D enabled line. The process works much like the other widgets on the web application, where the user can manually upload a CSV file from their computer and then launch the tool. The tool then utilizes a python script on the back-end cloud server to map the latitude and longitude of the points in the provided file, converts them into a 3D format, and then stitches the points into a line 3D line feature. The current Esri web application does not support the viewing of 3D data, but they do provide a separate online application called a Web Scene. The workflow from the user's perspective is that they would use a widget/tool on the existing web application to convert the CSV to a 3D format and then log into the Web Scene application to view the data. The data layer in the Web Scene will store all 3D data conversions. The user can then navigate to any of the files that have been converted. The web scenes also allow for separate file uploads should the user want to see how this line interacts with other utilities underground, such as water and sewer lines. An image of a converted 3D line can be seen in the image below:

Figure 45 Image of the converted 3D line

In an effort to smooth the entry of the probe into the pipe, the team added an additional spring in the egg design. The three-egg design is shown in Figure 46.

Figure 46 Three Egg Design

Additionally, the team optimized the space on the printed circuit board to remove some unused connections. This has shrunk the diameter of the egg approximately 3 mm. An overlay of the new front egg (solid) on the old egg (transparent) is shown in Figure 47.

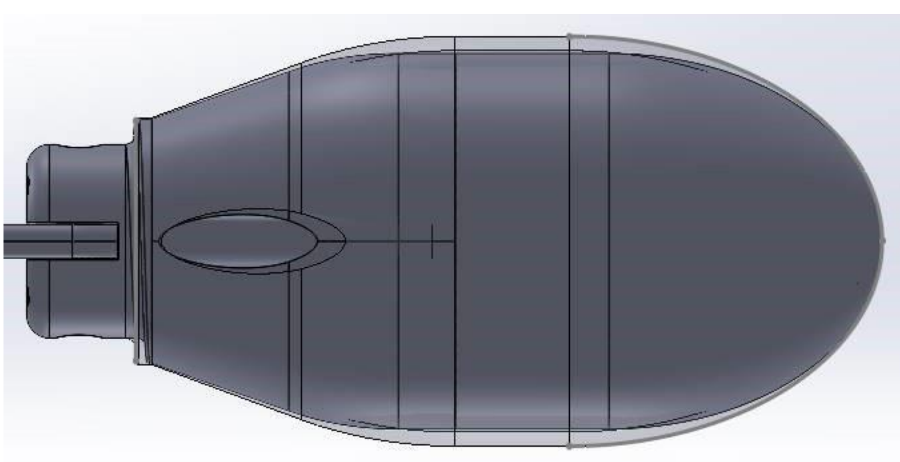

Figure 47 Size Comparison between Old (Shaded) and New (Dark) Front Egg

The team also verified the accuracy of the mapping probe. Results indicated that the probe is accurate within six inches of the centerline its intended structure, more information on GTI’s evaluation is below.

Before the probe is inserted inside the pipe for a run, it is essential to collect the probe's entry point where the probe will start its run. It is recommended to collect this entry data point using a high accuracy GNSS receiver that is connected to an RTK (Real-time kinematic) base station. A high accuracy GNSS receiver can receive corrected data from a base station and then use that corrected information to produce a latitude and longitude coordinate with a precision in the centimeter to inch accuracy level depending on how close the receiver is to the base station. The high accuracy data point collected is later used as the starting point within the mapping probe's accompanying software. Should the user have access to a known stopping, or exit point, for the run, they can then collect a second point with high accuracy at this location. These two data points collected with high accuracy will then feed the Reduct software with the proper information to orient the probe's data its real location on the earth's surface. An example of a high accuracy GNSS Receiver with a tablet for data collection is displayed in Figure 48 below:

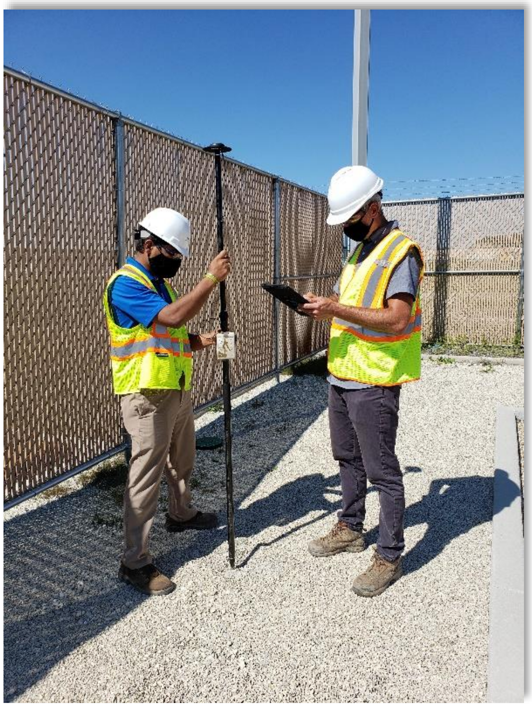

Figure 48: A high accuracy GNSS Receiver attached to a survey pole and accompanying tablet

To test the accuracy of the recorded mapping probe data based off these GPS point, GTI created a small testing scenario on aboveground pipe. This scenario consisted of mapping a 2-inch plastic pipe with a high accuracy every two to three feet on both sides of the pipe using a conventional high accuracy GNSS receiver providing data from GTI’s inhouse RTK base station. These data points were then stitched together to construct a polygon representation of the pipe itself. The high accuracy data points collected along the pipe were in the range of two-three centimeters of accuracy. The polygon generated was not completely true to the two-inch pipe's dimensions, but it was quite close and gave GTI a place to start. After the pipe was mapped using the high accuracy GNSS device, the probe was then run through the same pipe, and that data was mapped as well. The two datasets were then placed side by side within a mapping software and measurements were made between the two at different locations along the pipe. In general, the data sets were very closely aligned with maximum deviations between four to six inches of each other, proving the probe to be accurate at mapping the pipeline infrastructure. This process was repeated two more times using the same aboveground two-inch pipe placed in different locations and varying elevations. These additional tests were in line with the results from the first test proving the probe could be trusted to provide a utility company with an accurate location of their underground pipeline. Figure 49 below shows a snapshot of the data comparison process. Furthermore, it displays the centerline of the data collected from the probe well within the two-inch-wide mapped polygon of the pipe.

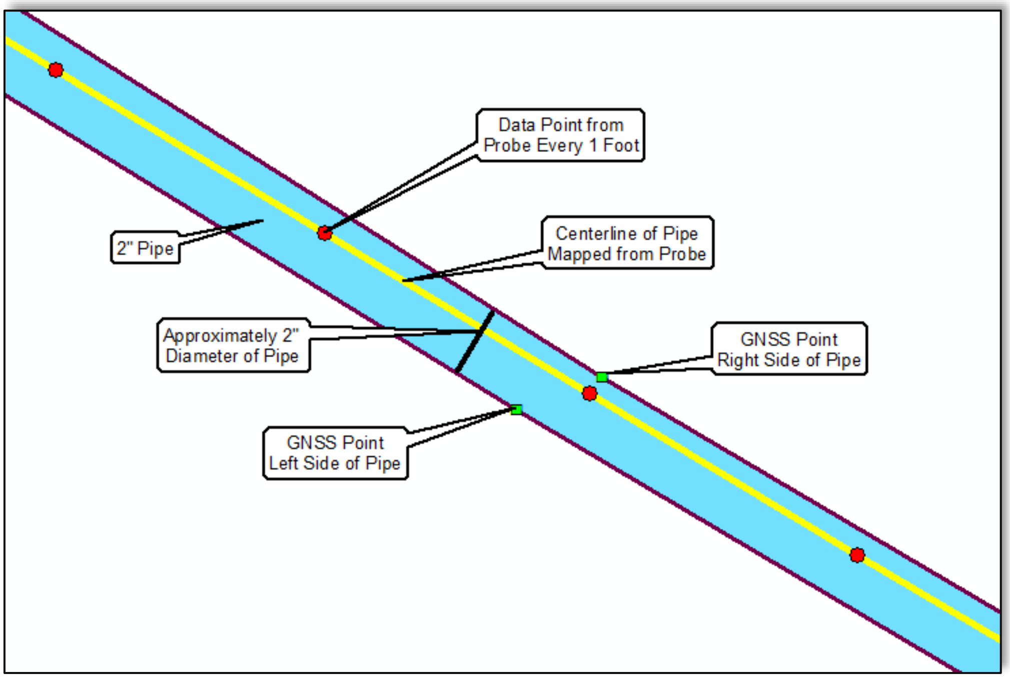

Figure 49: Breakdown of accuracy testing analysis – probe data mapped within the two-inch pipe polygon

Other locations along the data run may display the probe being mapped just outside of the two-inch pipe polygon but still within a four to six-inch tolerance of the actual centerline of the two-inch plastic pipe.

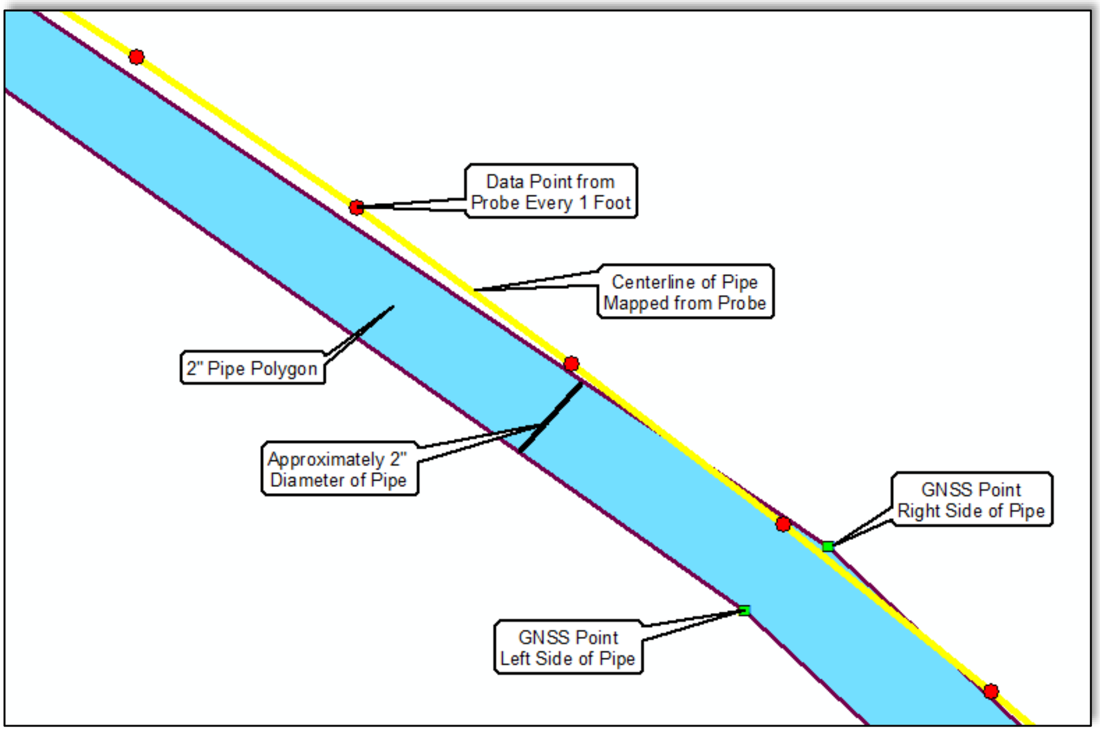

Figure 50: Breakdown of accuracy testing analysis – probe data mapped just outside of the two-inch pipe polygon

Task 6 Item Number 18

Task 6 objective: The objective of Task 6 "Utility Testing of Geospatial Technology" is to conduct field trials with the enhanced prototype at one additional local gas distributors live gas lines.

This section presents a summary of Task 6, Item Number 18 – conduct field trials with the enhanced prototype at one additional local gas distributors live gas lines.

On March 27th, 2020 GTI and PHMSA held a conference call to discuss the implications of COVID-19 on project work. The use of virtual demonstrations was discussed as a means to continue the progression of project work while social isolation restrictions are in place. At later stages of the project to proceed with live demonstrations, GTI developed an off-site field work protocol to perform live demonstrations with potential end-users in a safe manner. In all 1 virtual demonstration and 4 live demonstrations took place over the course of the project.

On March 17th, 2020, as the initial pandemic lockdowns began, the team performed a virtual demonstration with PG&E to showcase the new mapping technology. The team arranged an outdoor track and "live-streamed" an explanation and demonstration of the technology via a webcam. The PG&E team could observe the launch, probe navigation, and retrieval, as shown in the track configuration in Figure 51.

Figure 51 Outdoor Track Arrangement for Virtual Demonstration

After demonstrating the process, the team had a chance to receive live feedback and questions from the PG&E team. To accommodate the mapping probe, the PG&E team noted that an electromagnetically identifiable signal from the surface was important. An integrated copper wire was included in future pushes with the duct rod spool.

Deliverable 8

To complete deliverable 8, there were two deliverables required of the team. These were Task 6 Item Number 20, and Task 6 Item Number 21.

Task 6, Item Number 20

Task 6 objective: The objective of Task 6 "Utility Testing of Geospatial Technology" is to conduct a field trial of the enhanced prototype at one local gas distributor sponsored site.

This section presents a summary of Task 6, Item Number 20 – conduct field trials with the enhanced prototype at one additional local gas distributors live gas lines.

GTI successfully performed a live natural gas mapping demonstration at Peoples Energy Training Center in Chicago, IL on July 28th, 2020. Representatives from Nicor Gas/Southern Company were also in attendance. The team inserted the mapping probe and pushed ~160ft in one direction, retracted the probe, extracted the data, and then repeated this to map an additional ~100ft in the opposite direction. A photo of the launch site is shown in Figure 52. The data was then processed by the Reduct software and then viewed in Esri web application software. This test validated the general work flow to perform live natural gas mapping and validated that the 90° entry angle through the Jameson launch tool can effectively double the length of the process by mapping in one direction, and then pivoting the Jameson launch tool 180° in the opposite direction to continue mapping. Utilizing previous testing data which validated the probe could travel at least 300 ft, this test confirmed that the probe could travel up 600 ft and provide accurate x, y, and z mapping data in a live gas setting without disrupting the flow of natural gas to downstream customers.

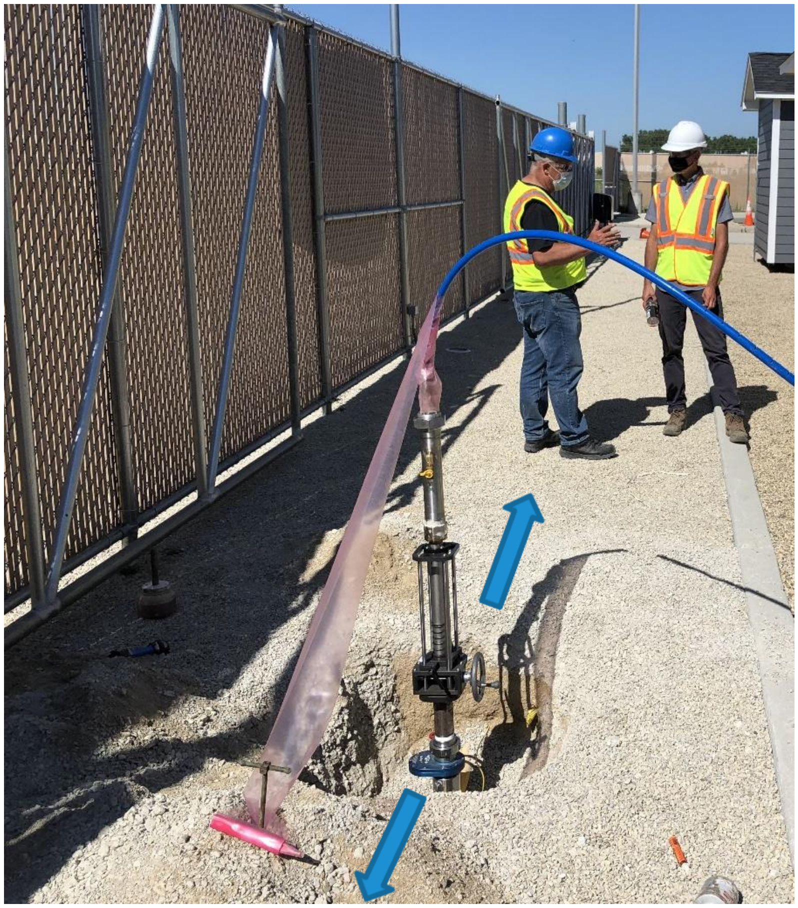

Figure 52 Launch Site for 90° Live Natural Gas Pipeline Entry and Mapping

The following will outline the general workflow of the entire mapping process and areas for possible enhancements in a potential second live natural gas mapping demonstration. To enter the live natural gas pipeline, a George Fischer Central Plastics (GFCP) 2" IPS VersaTap fitting was electrofused onto the 2-inch plastic pipe, and a GFCP knife valve was threaded onto the fitting. To test the electrofusion fitting and joint, the fitting was pressurized to ~ 110 psig for 15 minutes. No visible leaks from a leak check solution or loss in pressure were observed.

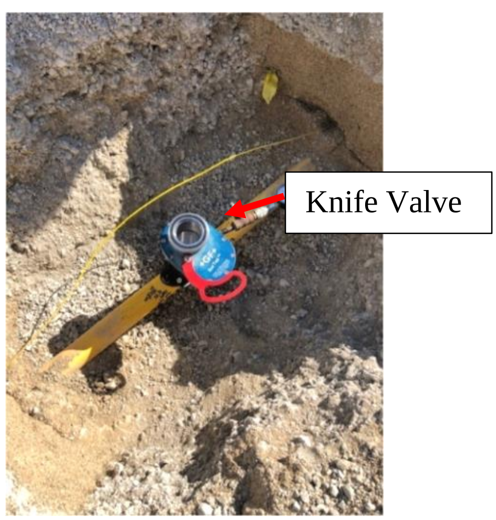

Figure 53 Pressure Testing of Versatap Electrofusion Fitting

A hot tap was performed with the GFCP SurTap tapping tool to provide access for the Jameson launch tool to enter the natural gas pipeline.

Figure 54 Hot Tap of Plastic Pipe for Live Natural Gas Mapping Launch

While this was ongoing, the mapping system comprised of the duct rod cable, duct rod pusher, guiding cable, Tellus stuffing box, and mapping probe was assembled as shown in Figure 55.

Figure 55 Assembly of the live natural gas pipeline mapping system

When the system was fully assembled, the knife valve was opened and the system was pressurized. A leak check was performed as shown in Figure 56. The team learned that the fittings can loosen during transport and continued use. It is important to remember to leak check and tighten all components.

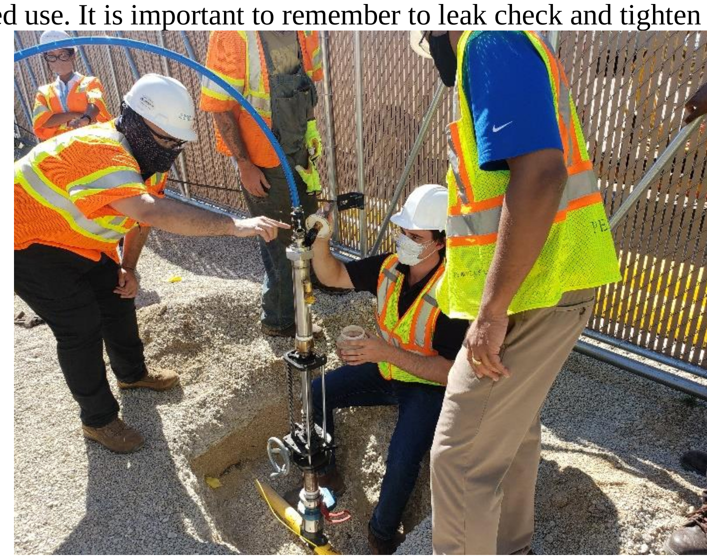
Figure 56 Leak Check of Launch Tool Prior to Mapping Activities

It is important to note that to improve flexibility of the probe through the 90° entry angle into a live natural gas pipeline through the Jameson launch tool, the team added a third egg. The previous probe is shown on the left, and the enhanced probe is shown on the right in Figure 57.

Figure 57 (Left) Prior Design of Mapping Probe (Right) Enhanced Design of Mapping Probe

The probe was inserted, and the duct rod pusher was operated to push the probe in both directions. Normac anti-static plastic wrap and spray was used to prevent any potential build-up of static electricity. An example of system operation can be shown in Figure 58.

Figure 58 Operation of Live Natural Gas Pipeline Mapping System

High accuracy GNSS location data was captured at the entry site and at points along the probe path for reference. Several of these points were captured by energizing the tracer wire in the duct rod and performing a locate on the surface. The team learned that the tracer wire was useful in determining guide points for the collection of GNSS positioning data, but landmarks such as a valve box, could also be used to collect guide points. This test showed that collecting mapping data from inside the pipe is very valuable and can improve confidence in locates from the surface. Incorporating a tracer wire was valuable addition from the previous mapping demonstration.

Figure 59 Collection of High Accuracy GPS Location along the Probe Path

After operation of the mapping system, the probe was retracted through the Jameson launch tool and the mapping data was extracted from the probe as shown in Figure 60.

Figure 60 Extraction and Visualization of Mapping Data

The data was uploaded into Google Earth for onsite verification (Figure 61), and also through the data viewing widgets in Esri's web application interface (Figure 62) and ArcScene (Figure 63) which would be used for cloud-based data collection, viewing, staging, and distribution.

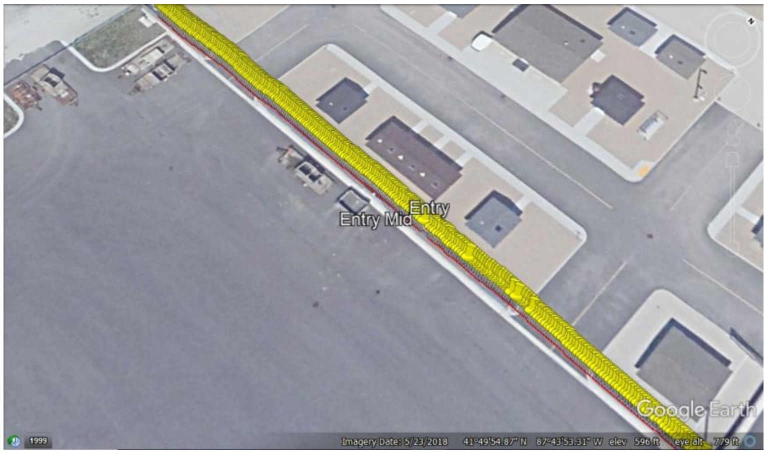

Figure 61 Data Visualization via Direct Upload from KML File Output on Google Earth

Figure 62 2D Data Visualization via ArcGIS Data Viewing Application

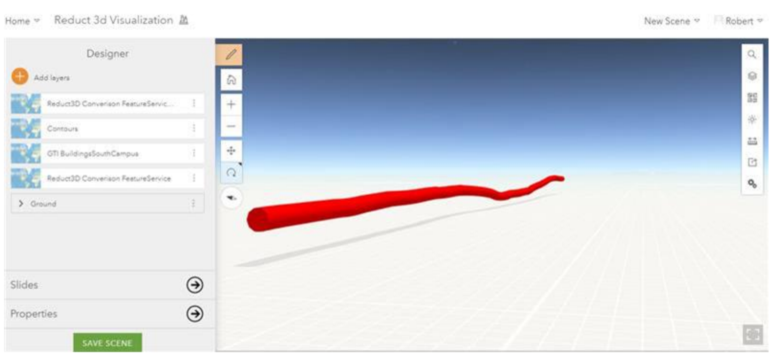

Figure 63 3D Data Visualization via ArcScene

Task 6, Item Number 21

Task 6 objective: The objective of Task 6 “Utility Testing of Geospatial Technology” is to conduct a field trial of the enhanced prototype at one local gas distributor sponsored site.

This section presents a summary of Task 6, Item Number 21 – conduct field trials with the enhanced prototype at one additional local gas distributors live gas lines.

Although this task only sought one additional live demonstration, the team executed three demonstrations in this task. Including virtual and live, five total demonstrations were performed. Example images and locations are provided below.

The next live demonstration occurred at Planet Underground. During this event, The team presented this 3D data collection technology among pipeline construction, 811, excavation, locating, GIS analysts and natural gas distribution companies. A new challenge for the team, the probe was inserted and pushed in 300 feet 4” diameter plastic pipe. All previous trials were performed in 2” diameter pipes. Example photos from the demonstration, and mapping data are shown below.

Figure 64 Photo of 3D Mapping Probe Demonstration in 4” PE Pipe.

Figure 65 Example 2D (Left) and 3D (Right) Mapping Data Extracted from the Probe during the Demonstration

The next demonstration occurred with City Utilities in Springfield, MO. This demonstration occurred on a live 2-inch vintage PE (aldyl-a) natural gas main in a residential neighborhood operating at ~35 psig. The tracer wire on the existing underground asset had been severed, and GTI used the probe to locate the buried pipeline in the neighborhood.

Figure 66 Hot Tap of Live Pressurized 2" Diameter Main

Once the hot tap was performed, the Jameson Launch Tool was installed on the pressurized live gas main and the mapping probe was inserted. The probe was pushed ~210 feet and provided the team with a 3D visualization of the underground.

Figure 67 Insertion and Operation of the 3D Mapping Technology

The use of the tracer wire for surface locating proved useful during the demonstration. The team was able to collect high accuracy location points for the mapping probe software to calculate the underground position of the pipe by locating the energized tracer on the surface and collecting GNSS positional data.

Figure 68 GNSS Geospatial Data Collection Via an Underground Energized Tracer Wire with a Surface Locator

After the mapping demonstration was complete, the 3D mapping data was extracted from the probe for analysis. Example data is shown below.

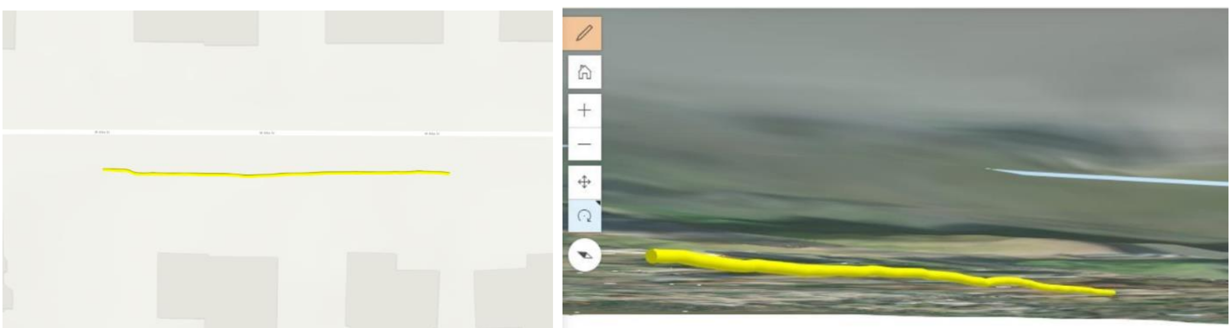

Figure 69 Example 2D (Left) and 3D (Right) Mapping Data Collected from the City Utility Mapping Demonstration

The last demonstration occurred at Ameren's Gas Training Center in Pawnee, IL. The team tapped into a live gas pipeline operating at ~35 psig to map ~181 feet of 2" plastic pipe.

Figure 70 Example Photo of System Operation during Ameren Mapping Demonstration

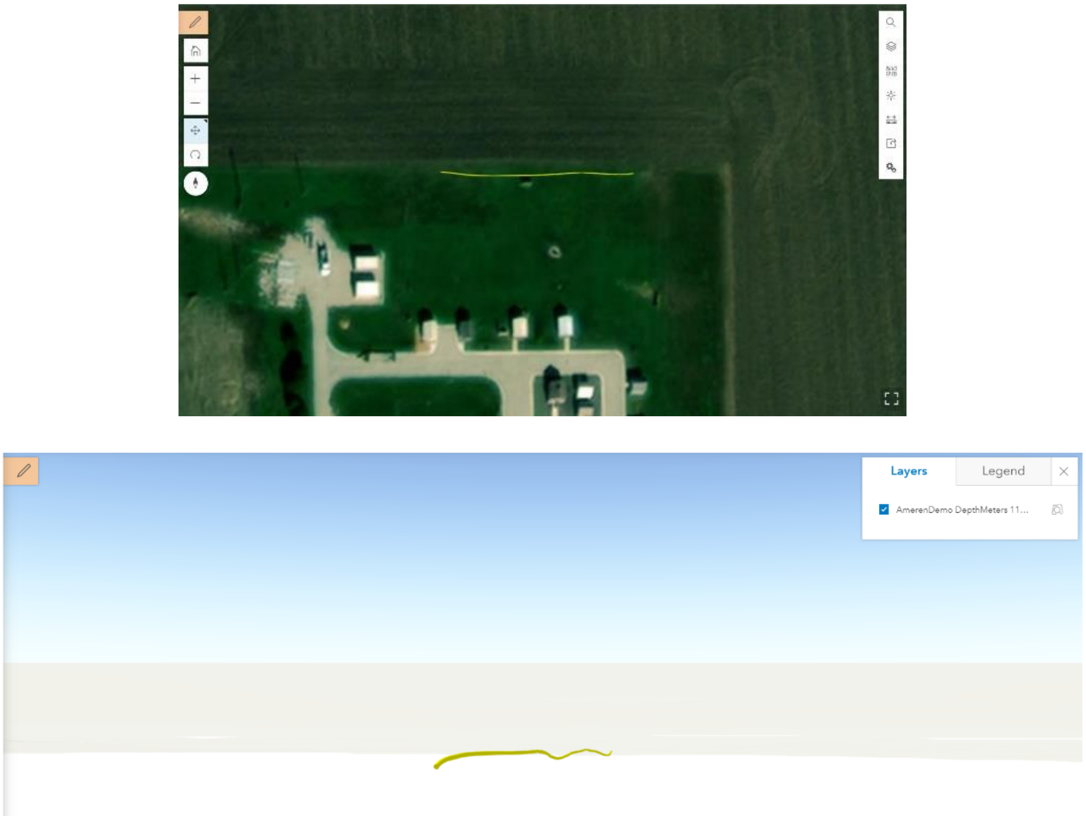

Figure 71 Example 2D and 3D Mapping Data from the Technology Demonstration

During this demonstration the team had a discussion on potential uses of this technology. The discussion lead to the determination of two valuable potential use cases for the mapping technology. Ameren is already familiar with temporarily inserting tracer wires for surface locating. The mapping probe could be easily integrated with existing operations to confirm information collected from the surface. Additionally, the live-gas mapping technology could be deployed during construction operations when excavations must be performed to verify the location of underground assets. Since an excavation site is already opened, Ameren could insert the probe and collect 3D geospatial data without significant interruption of existing operations, and the location of longer segments of pipe can be verified during a single excavation.

Impact from Research Results

This research has brought a positive change to the areas of pipeline damage prevention. This section will discuss how the research impacts these focus areas. Several specific examples of net improvements will be outlined as a result of this work.

- A novel solution for locating unlocatable plastic pipe was produced from this work. When tracer wires are broken or location data is inaccurate, this mapping solution can provide pipeline operators with the location of underground gas pipes without interrupting the flow of gas to downstream customers.
- IMU-based mapping technology available in the telecom, water, and sewage industries was adapted to accommodate the needs of the natural gas industry.
- A locating solution was developed that captures geospatial from inside the pipe. This technology does not solely rely on capturing data from the surface, although incorporating a tracer wire did improve the overall technology. With the probe collecting location data from inside the pipe, information gathered on the surface can be verified. The probe can also provide an accurate measurement for the depth of the probe which can be limited in existing surface technologies if the pipe is buried too deep or soil conditions block the passage of detection signals.
- A pipeline mapping solution was developed that can accurately depict 3D data and help prevent cross bores from adjacent utility construction operations. With the roll out of 5G networks, underground construction operations will have a new tool to improve overall safety.
- A new workflow was developed to collect, post-process, store, and view valuable 3D underground pipeline data. This workflow was developed with the intention to make 3D data more readily accessible to utilities. As 3D technology becomes more mainstream, this workflow to store, manage, and view 3D data will be a foundational tool to maximize the value of this data.

Conclusions

A novel mapping solution was developed to assist gas pipeline operators locate and map underground assets in three dimensions.

Figure 72 Live-Gas Insertion and Integrated Mapping System Operation

The mapping solution provides a new tool to locate unlocatable plastic pipes where tracer wires have been broken. The tool is applicable to steel assets as well. The probe also provides a depth measurement which can further assist construction operations prevent accidental underground cross bores. The probe is accurate within six inches of the centerline of the pipeline. This tool can provide valuable location data of at least 600 feet segments of underground pipes although the team anticipates this can be extended much further. With this information, underground pipeline excavation damage can be prevented with high accuracy location data provided by the probe. The following list of accomplishments was achieved during this work:

- A method and system were developed to insert a mapping probe into live gas pipes at an upright 90° entry angle. This enables bi-directional mapping from one hot tap.
- IMU-based mapping technology available in other underground utility industries was adapted for use in the natural gas industry.
- The seal of live-gas entry apparatus was verified up to 60 psig operating pressure.
- The probe is accurate within a six-inch window from the centerline of a pipeline.
- The team verified the probe can travel at least 300 feet in one direction. Due to the bi-directional insertion method, this yields a travel capability of at least 600 feet. It should be noted that the 300 feet threshold was a project goal that the team exceeded and that the team is confident it can travel much further.
- Real-world demonstrations were conducted on live-natural gas pipelines.
- A workflow as developed to improve accessibility of 3D data collected by the probe to the gas utilities by leverage Esri’s online web tools.

Based off these results, the project team has collected enough operational and end-use feedback to refine the overall design for a commercial product. The project team will continue to meet and discuss these final enhancements. Once these are incorporated, GTI recommends the following next steps and use cases of the mapping probe:

- Additional demonstration among utilities to showcase the final commercial ready solution.
- When using a Jameson launch tool for surface locates or camera inspections, the mapping probe should be considered as part of the workflow. Since the launch tool is already installed, additional probe work will not significantly alter operations work.
- When performing excavations to verify underground locations of gas pipes, consider using the mapping probe to collect bi-directional mapping data since the site is already open.
- When tracer wires are broken, consider using this mapping solution to collect 3D data for unlocatable plastic pipe.
- For deep small diameter pipe, the probe can be used when surface technologies cannot find the underground asset, and tracer wires cannot emit a powerful enough signal to reach location equipment on the surface.
- In congested undergrounds, this mapping technology can provide asset specific location data without interference from adjacent underground facilities.
- When mapping 3D data, the Esri web tools can be used to view the underground layout. With this information, construction activities can more efficient and safer with improved knowledge of asset location and depth.

List of Acronyms

Acronym	Description
GTI	Gas Technology Institute
IMU	Inertial Measuring Unit
PCB	Printed Circuit Board
CPU	Central Processing Unit
ESRI	Environmental Research System Institute
GNSS	Global Navigation Satellite System
RTK	Real-time Kinematic

END OF REPORT