**CAAP Annual Report**

**09/30/2022**

*Project Name:* *Easy Deployed Distributed Acoustic Sensing System for Remotely Assessing Potential and Existing Risks to Pipeline Integrity*

*Contract Number:* *693JK3215002CAAP*

*Prime University:* *Colorado School of Mines*

*Prepared By:* *Yilin Fan, yilinfan@mines.edu, 303-273-3749;*
*Ge Jin, gjin@mines.edu, 303-273-3455;*
*Ali Tura, alitura@mines.edu, 303-273-3454;*
*Jennifer Miskimins, jmiskimi@mines.edu, 303-384-2607*

*Reporting Period:* *[9/30/2021 – 09/30/2022]*

**Project Activities for Reporting Period:**

This section summarizes the major project activities accomplished during the first year in two aspects, technical and educational activities.

Technical Activities

Overall, the technical activities completed during the first year were all on track. Detailed information can be found in the quarterly report. In this annual report, we only provide a summary of the major accomplishments during the first year, given below:

1. Activities completed during the reported period for Tasks#1&2: Detection of Liquid Accumulation and Dynamic Intermittent (Slug) Structures
   - We have finished the construction of the flow loop for Tasks#1&2 in the first year. The flow loop has now been equipped with all five different fiber optic cables as originally proposed, including external helically wrapped and straight cables, along with internal flat, thin, and thick cables.
   - Sandbags have been used to prompt the flow loop in the inclined sections to minimize the noise in the dataset as a result of the pipe vibration. Additionally, moving blankets were put in place to help protect jacket fiber cable from rough surfaces (Fig. 1a).
   - Tests were conducted to evaluate the integrity of the splicing and signal path along the entire length of the cables, using Optical Time Domain Reflectometer (OTDR). We identified and fixed multiple damaged points in the helically wrapped cable. Tap tests were also conducted without any fluid flowing through the pipeline to further evaluate the integrity of the cable setup. The internal thin and flat cables unfortunately have been identified to be broken at the location of the sealing point. We will redo the sealing or use another method to fix the broken cables at the sealing point.
   - We also conducted preliminary experimental studies using two different gas flow rates without liquid accumulation, and the results are shown in Fig. 2. The data was acquired

from external wrapped fiber, internal thick fiber, and external straight fiber, from the bottom to top, respectively. One can notice the differences in the processed DAS data for the two different flow rates. The frequency spectrum of the data from the internal thick cable shown in Fig. 3, further demonstrates the significantly stronger amplitude of cable vibration at higher flow rates. This implies the potential of DAS to estimate the flow rate.


Fig. 1. (a) Photograph of the clear PVC section for Tasks#1 & 2 with hellically wrapped cable (yellow) and straight cable covered by blue tape. Sand bags and moving blanckets are used to prevent vibration and protect cable. (b) Photograph of a splice at a damaged point in the helically wrapped fiber. (c) Photograph of the sealing for internal cable deployment located at the entrance of the Orica drift in Edgar Mine. All cables are permanently deployed using epoxy compound. Flat and thin cables are damaged at this location.

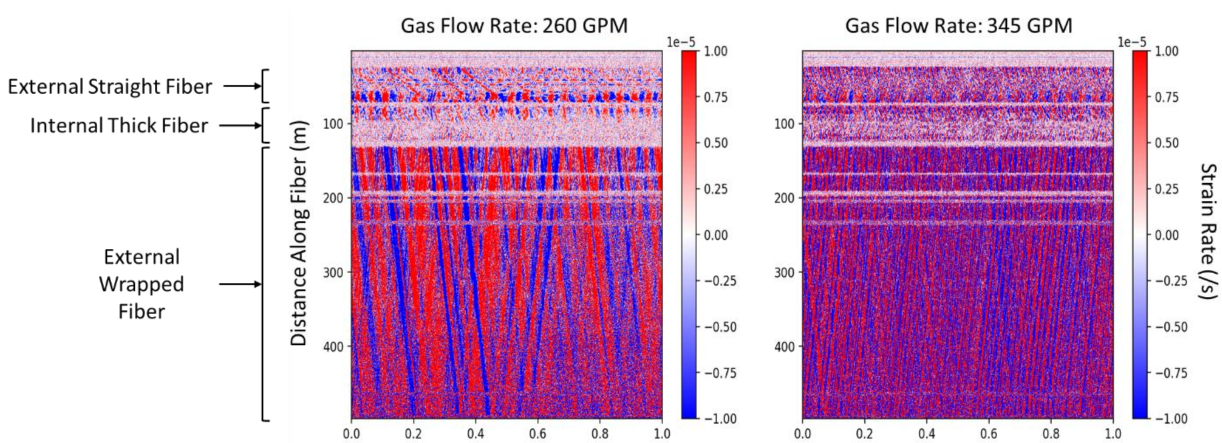


Fig. 2. Processed DAS signals from preliminary single-phase gas flow tests with two different flow rates

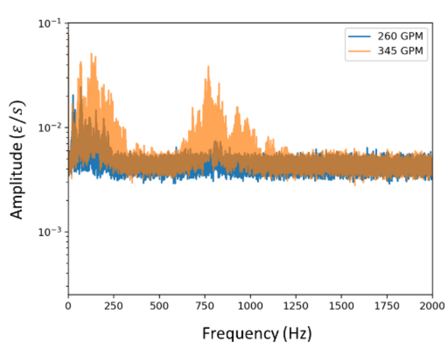


Fig. 3. Frequency spectrum of internal thick cable recording for the two different gas flow rates

2. Activities completed during the reported period for Tasks#3-6: Detection of Corroded Spots, Deformation, Infrastructure Damage, and Leakage.
   - We have started the construction of the steel pipeline using carbon steel seamless pipes (API 5L, schedule 40 NPS 4-in, grade X65), as shown in Fig. 4. The pipeline is composed of four pieces of 5 m sections, with a 1 m gap in the middle to be filled by a 1 m test section with different defects to be tested in Tasks#3,4,6. We have ordered and received totally 12 pieces of 1 m test section made of the same material mentioned above (Fig. 5).
   - We have also accomplished the lab corrosion tests for Task#3 and determined the method and procedure to prepare the corroded surface in the 1 m test section. Details can be found in the 3rd and 4th quarterly reports. In summary, hydrochloric acid will be used and replaced every 24 hours to create corrosion inside the 1 m test section at the 6 O'clock position. A general corroded depth will be generated, and mechanical griding will be used to create scratches along the same surface, increasing the wall roughness. A heating system (Fig. 6ab) will be employed to increase the temperature of the acid deployed inside the testing rings to achieve a higher corrosion rate. An optimum 65°C has been identified and will be used for the corroded surface preparation.

Fig. 4. Photograph of the steel pipeline during and after the construction. A 1 m gap is left for testing different defects in Tasks3-6.

Fig. 5. Photograph of the 12 pieces of 1 m test section to be tested for Tasks#3-6 (four of them shown on the left are now in the mine, the other seven shown on the right are now in Dr. Fan's lab)

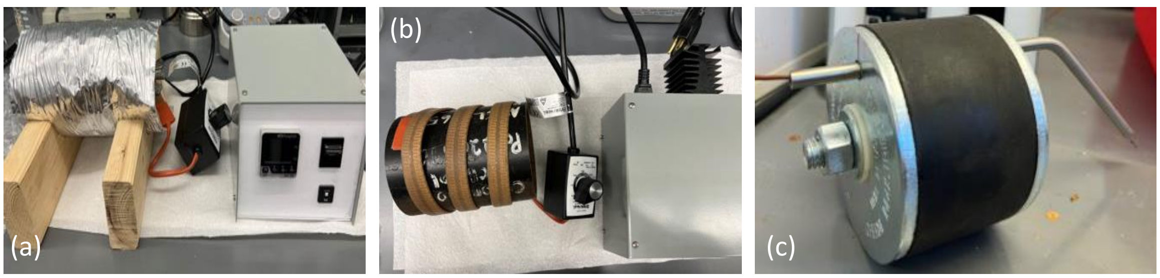


Fig. 6. (a,b) Photograph of the heating system. (c) Picture of the plug to be used for corrosion creation in the 1 m test section

<u>Educational Activities</u>

*Student monitoring*: The project is sponsoring 2 Ph.D. students starting from 2022S. They are Ana Garcia-Ceballos (Ph.D. student in Geophysics at Mines, advisor Dr. Ge Jin) and Mouna Keltoum Benabid (Ph.D. student in Petroleum Engineering at Mines, advisor Dr. Yilin Fan). The project sponsors their tuition and graduate salaries starting from 2022S. In addition, we did an hourly contract with a Ph.D. student, Peiyao Li, during 2022 summer to help with the flow loop construction which required a lot of effort and labor. Overall, the students' salaries and tuition fit our budget for the first year.

*Student internship*: no student involved in this project participated in any internship during the past year.

*Educational activities*: no.

*Career employed*: no.

*Dissemination of project outcomes*: no publications occurred during the first year.

*Citations of the publications*: no.

**Project Activities with Cost Share Partners:** The cost shares are the AY efforts of the PI and co-PIs. Activities are the same as above.

**Project Activities with External Partners:** No external partners.

**Potential Project Risks:**

1. Since the project started immediately after the announcement in September, we did not have a chance to hire students in advance. The two Ph.D. students hired for this project started their studies in January 2022. Due to the late start, we anticipate a delay to the timeline proposed in the original proposal. However, it is still possible to complete the project by the end date of the project. Discussion of the modified timeline is in the next section.
2. There is a possibility of delay due to weather, especially during the snow season. Edgar Mine will be closed if there is heavy snow for safety concerns. In such a case, the students will not be able to work at the Mine during that period. Please note that the weather will not damage our facilities and equipment since they are inside the Mine.
3. The prices for pipes/equipment and other associated costs have been increased dramatically since the submission of the proposal. We will try to balance the total experimental expenses to keep it within our total budget for the experimental expenses, as much possible as we can at the current stage.
4. There is another possibility of delay due to the break of fiber cables. We have totally five cables deployed, including two external cables (helically wrapped and straight cables) and three internally deployed cables (thin, flat, and thick cables). The internal thin cable will be used as a reference to be compared with the results from the thick cable that is more suitable for field applications, because the thin cable theoretically can provide stronger signals due to its better response to the fluid flow inside the pipeline. However, the thin cable is fragile and has a higher risk to be broken. It will take some time to find and fix the broken points, or replace the cable. Because the cable is internally deployed, it further makes the repair more difficult. The flat cable is stronger than the thin cable, however, it may break at the sealing point (Fig. 1c). It will also take some time to repair the cable and the seal if it happens again in the future. Fortunately, the thick cable, which is more suitable for actual field applications, is working fine based on our preliminary tests.
5. Besides, one of the Ph.D. students involved in this project has an injury in her ankle late September 2022 which will take sometime for recovery. This potentially increase the risk of delay in the experimental work. The other student and the PIs will take more responsiblities in the experimental work, hoping to decrease its impact on the project schedule.

**Project Modifications:**

There is no modification to the technical components of this project. The only modification is the timeline to the original proposal, mainly due to two reasons. The first one is related to the late involvement of the students in this project, as mentioned previously in the first risk item. Secondly, to avoid frequent changes in the pipeline installation method ("buried", "unburied", "densely supported", or "sparsely supported") in Tasks#3-6 that require a lot of human effort and may also lead to some other uncertainties and safety concerns, we propose to do the experiments by installation method instead of the task. Our current setup for the steel pipeline is "supported" as shown in Fig. 4, to ease the flow loop construction. To minimize the efforts of changing installation methods that may lead to other uncertainties or safety concerns, we propose to start the tasks with the "supported" configuration first, followed by "unburied" and "buried". More specifically, we will do the tasks with the installation methods in the order of "densely supported" – "sparsely supported" – "unburied" – “buried". The modified timeline is shown in the table below. The activities during the first year were all on time.

| Tasks | Year 1 | | | | Year 2 | | | | Year 3 | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Q1 | Q2 | Q3 | Q4 | Q1 | Q2 | Q3 | Q4 | Q1 | Q2 | Q3 | Q4 |
| | 2021 | 2022 | | | | 2023 | | | | 2024 | | |
| | O-D | J-M | A-J | J-S | O-D | J-M | A-J | J-S | O-D | J-M | A-J | J-S |
| **Task#1. Detection of Liquid Accumulation at Pipeline Lower Spots** | | | | | | | | | | | | |
| 1.1 Facility modification and preparation | | | | | | | | | | | | |
| 1.2 Flow loop test without liquid accumulation | | | | | | | | | | | | |
| 1.3 Flow loop tests with liquid accumulation | | | | | | | | | | | | |
| **Task#2. Detection of Dynamic Intermittent (Slug) Structure** | | | | | | | | | | | | |
| 2.1 Flow loop tests with Interminttent Structure | | | | | | | | | | | | |
| **Task#3. Detection of Corroded Spots on Pipeline Interior** | | | | | | | | | | | | |
| 3.1 Facility modification and preparation | | | | | | | | | | | | |
| 3.2 Lab tests of corrosion using speciman to determine acid type, concentration, and corrosion rate | | | | | | | | | | | | |
| 3.3 Flow loop test in buried pipe | | | | | | | | | | | | |
| 3.4 Flow loop test in unburied pipe | | | | | | | | | | | | |
| 3.5 Flow loop test in densely supported pipe | | | | | | | | | | | | |
| 3.6 Flow loop test in sparsely supported pipe | | | | | | | | | | | | |
| **Task#4. Detection of Dent/Deformation on Pipeline** | | | | | | | | | | | | |
| 4.1 Flow loop test in buried pipe | | | | | | | | | | | | |
| 4.2 Flow loop test in sparsely supported pipe | | | | | | | | | | | | |
| **Task#5. Detection of Infrastructure Damage** | | | | | | | | | | | | |
| 5.1 Flow loop test in densly supported pipe | | | | | | | | | | | | |
| 5.2 Flow loop test in sparsely supported pipe | | | | | | | | | | | | |
| **Task#6. Detection of Leakage** | | | | | | | | | | | | |
| 6.1 Flow loop test in buried pipe | | | | | | | | | | | | |
| 6.2 Flow loop test in sparsely supported pipe | | | | | | | | | | | | |

densly supported unburried burried
sparsely supported

## Financial Activities:

This report only provides a summary of the financial activities during the first year. More detailed information on the specific numbers will be provided in the financial report that is due in a month. Overall, the financial activities during the first year aligned well with the ones in the original proposal. They include:

- Faculty salaries and wages for the four faculty members involved in this project.
- Graduate student salaries for the two Ph.D. students involved in this project who started their study in 2022S, and one Ph.D. student contracted during 2022Summer.
- Graduate student tuitions for the two Ph.D. students involved in this project.
- Fringe benefits.
- Expenses for the experimental work, including fiber optic cables, steel and PVC pipes, lab supplies such as chemicals, gloves, etc., coupling and supplies for flow loop construction

and cable deployment, equipment maintenance, and some small temporary hourly contracts with students to help with the flow loop construction, etc.

- Travels.
- Indirect costs.