CAAP Quarterly Report

03/30/2024

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*

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Reporting Period: *[01/01/2024 – 03/30/2024]*

Project Activities for Reporting Period:

During this period, we had our midterm summary meeting on February 13th, 2024. The team presented the project progresses and discussed the remaining tasks and some other relevant problems. The presentation has been uploaded.

Besides, we have made noticeable progresses on the remaining tasks (Tasks#2, #3, #4, #6), which are discussed in the following:

Task#2. Detection of Dynamic Intermittent (Slug) Structure

In Task#2, our focus centered on characterizing dynamic intermittent (slug) structures. Data processing and analysis were carried out, detailed below alongside the results obtained.

- Utilizing the helically wrapped cable, which provides the highest resolution dataset, we observed the dynamic behavior of slugs as they traverse the pipeline, employing filtered raw DAS data for visualization within a 40-second time window. **Figure 1** showcases the evolution of two slug structures. The first one is a weak pseudo-slug, which sometimes is also referred to as a large wave structure, that forms and dissipates cyclically along the pipeline. The second slug structure is a robust one, that can travel for long distances in the pipeline. It can also be noticed that the stronger slug gives a higher DAS signal magnitude and travels at a faster speed. DAS also enables us to understand the links between multiple slugs and how they evolve with time. In this example, the first weak slug structure eventually decays, that makes the following slug stronger.
- A slug catalog was created to extract pertinent characteristics. Employing the helical cable dataset, slug velocities were computed via polynomial fitting for each identified slug. Furthermore, DAS signal amplitudes (also referred to as slug amplitudes), which reflect the slug size, were estimated by identifying local minimum strain values across each DAS channel within the slug window and averaging them to characterize the slug's amplitude.

- Within the realm of internal cables (thin, flat, and thick), the extracted characteristics primarily revolved slug frequency and magnitude over temporal windows and their spatial evolution along the pipeline. Leveraging standard-deviated processed DAS data for internal cables, as previously documented, highlighted the flat cable's heightened sensitivity to slug detection. Conversely, the thin cable yielded more qualitative results in slug detection for our pipeline length. This distinction is best illustrated in **Figure 2**, juxtaposing pressure sensor data atop both thin and flat cables. While the flat cable exhibited a heightened amplitude response to slugs, the delineation of slug patterns was more pronounced in the thin cable, evincing a clearer sloping trend. This discrepancy may be attributed to flat cable twisting or coupling effects with other cables, particularly the influence of the thick cable, which may propagate slug flow vibrations to neighboring channels more readily in the flat cable.
- To facilitate slug detection using internal cables, the algorithm employed a threshold mechanism, categorizing values above a specified threshold as slugs for each channel. Additionally, a gap size was defined to consolidate adjacent slugs occurring within a 3-second timeframe into a single slug, mitigating the risk of slugs being erroneously counted as individual entities. Subsequently, the thin internal cable was deployed to extract slug count and magnitude characteristics across the entire pipeline testing section. It has been observed that smaller but more uniform slugs occur near the inlet of the upward inclined pipe, while stronger but more diverge slugs sustain in the pipeline.

<u>Task#3. Detection of Corroded Spots on Pipeline Interior Surface</u>

During this reporting period following up from our last submitted report and planned activities, we have implemented a series of tests attempting to enhance the detectability of the minor leakage at the bottom of the corroded pipe. Initially, a pressure sensor was installed at the beginning of the steel pipe to monitor the in-situ pipeline pressure. Subsequently, we tested different manual valve openings at the steel pipe's end (fully open, half open, and fully closed) while maintaining a constant in-situ flow rate in the pipeline. The flow velocity tested was the maximum achievable velocity under safe conditions, 11m/s, aimed at having the highest achievable differential pressure across the leakage that enhances the detectability of the minor leakage by the cables.

The data processing workflow was consistent with the one used for Task#6 detailed in the last quarterly report. We first analyzed the standard deviation data to investigate the detection of the minor leakage at the bottom of the corroded pipe. Initially, the calculated STD data did not clearly reveal the leakage. However, after optimizing the display parameters and scale, we improved the detection of the minor leakage. Particularly, the black, and flat cables exhibited detectability, especially when the valve at the end of the steel pipeline was closed. This configuration increases differential pressure across the leakage, helping in leakage detection. This observation is supported by data illustrated in **Figure 3** and **Figure 4**, indicating that an increased pressure difference improves the cables' ability to detect the leakage. In these figures, the leakage is positioned near the middle of the cable section and indicated by the black transparent dashed lines at each waterfall plot. Given that the operating pressures in actual field conditions are significantly higher than those in our tests, we are optimistic about the black cable's potential to identify and detect minor leakage spots in the field more effectively. Notably, the black cable exhibited the highest sensitivity to the minor leakage present at the bottom of the corroded pipe.

For further analysis, we conducted a baseline experiment with the new pipe couplings, as previously reported, to ensure the data from the corroded pipeline is more comparable to that of the control experiment. Observations from this experiment were similar to our expectations: the corrosion has reduced the material in the pipe, resulting in a thinner wall and a lighter weight of the 1-meter section, which could potentially alter the resonant frequencies of the entire pipe. The data has shown changes in the frequency modes between the control and corroded cases.

In the upcoming quarter, we aim to replicate the experiments to double confirm our findings. Additionally, we plan to test the 5 mm corroded pipe and retest the 3mm corroded pipe to arrive at more definitive conclusions.

Activities for Unburied and Buried Pipeline Installation Configuration for Task#3,4 & 6.
During the current reporting period, we have initiated preparations for modifying the facility to enable testing of different pipeline defects in unburied and buried configurations. For this purpose, wooden boxes were ordered and subsequently modified at the mine to secure the pipes within them. Furthermore, bags of sand were acquired to fill these boxes (**Figure 5**). In the unburied setup, the pipe will be laying on the sand, and after conducting tests on the unburied pipe, it will then be buried under the sand to mimic the buried pipe condition.

Project Financial Activities Incurred during the Reporting Period:
The following table summarizes the financial activities and the corresponding expenses during the reporting period. Also shown are the total budget and the total expenses so far. Please note that the actual amount for the expenses might be slightly different from the numbers in the final financial report, since some of the expenses occurring in late of the quarter may not be included in the university's financial system that we use for managing the funds and expenses by the time the report is submitted. Normally, it takes several days for an expense to be shown in the system after its occurrence.

	Items\Budget and Expenses	**Total Budget for Year 3**	**Total Expenses in Year 3**	**Expenses During Reporting Period**
1	Faculty Salaries and Wages including Fringe Benefits	$29,471	$0	$0
2	Student Salaries	$33,949	$32,242	$14,239
3	Graduate Student Tuition	$47,186	$17,504	$17,886
4	Experimental Expenses (experimental work supplies, services, maintenance, cables, etc.)	$27,000	$2896	$1224
5	Travel	$3,000	$0	$0
6	Indirect Costs (51.5%)	$48,578	$18,096	$7963
	Total	**$189,183**	**$70,738**	**$41,312**

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:
Same as the previous reports. The most influential factors that can potentially delay the project progress in this coming quarter are the snowy weather, Edgar Mines' operating schedule, and students' course/exam schedule, which limit the days the students can work at the Edgar Mine. The team is trying the best to keep the progress on track, but there are still risks of delay because of the factors mentioned above. Based on the discussion during the midterm summary meeting, we will apply for a no-cost extension. We will initiate the effort in this coming quarter.

Future Project Work:
In the next 30 days, we will repeat some of the tests in Task#3 for supported pipes and conduct some additional ones as needed. In the next 60-90 days, in addition to the previous tasks, we will start the experiments for unburied and buried pipelines.

Potential Impacts to Pipeline Safety:
Tasks#1 and #2 can potentially help identify and characterize the possible liquid accumulation in a gas gathering or transmission pipeline using DAS, while Tasks#3-6 will potentially help detect the internally corroded surface, deformation, infrastructure damage, and leakage in a gas pipeline.

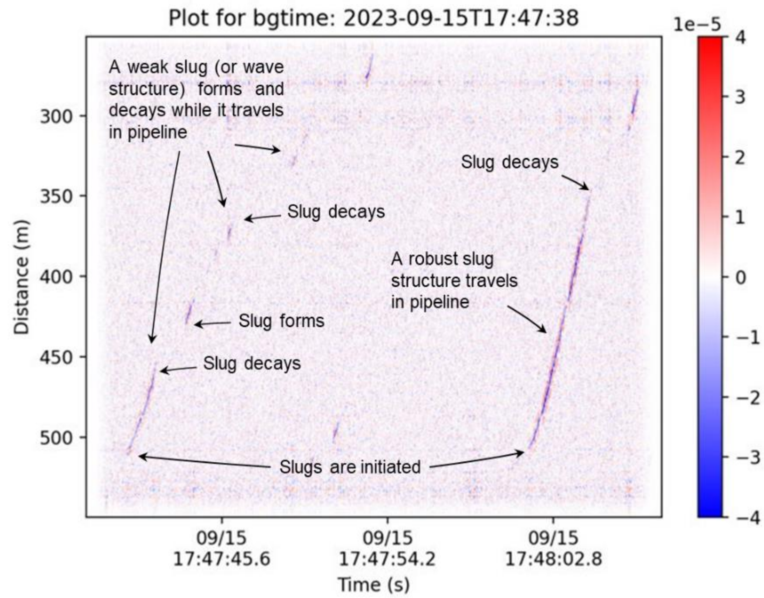

Figure 1. DAS filtered data depicting a 40-second temporal window captured by the helically wrapped cable. Observables are two slugs. The first one is a weak pseudo-slug that forms and dissipates cyclically along the pipeline. The second slug structure is a robust one, that can travel for long distances in the pipeline. It can also be noticed that the stronger slug gives a higher DAS signal magnitude and travels at a faster speed. DAS also enables us to understand the links between multiple slugs and how they evolve with time. In this example, the first weak slug structure eventually decays, that makes the following slug stronger.

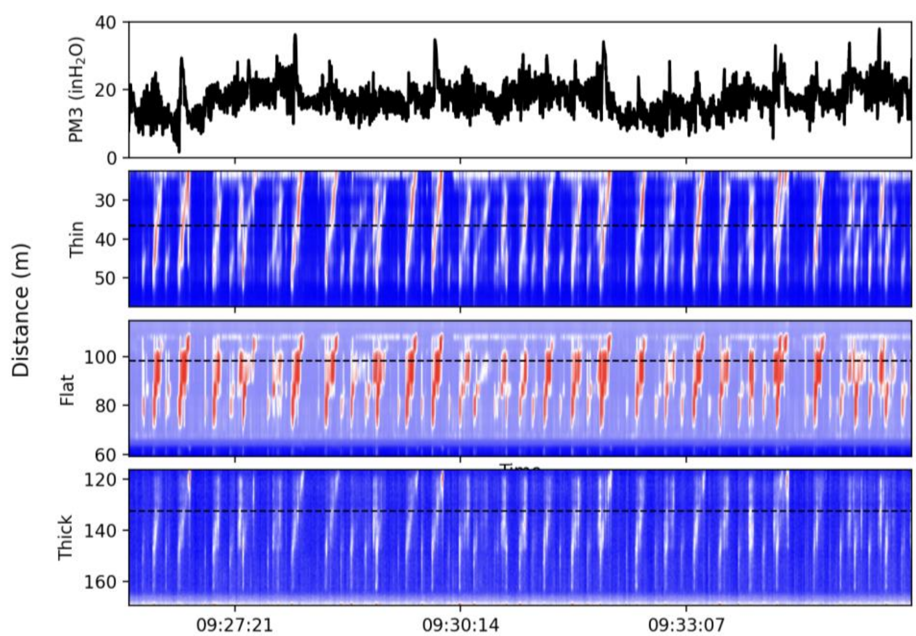

Figure 2. Visualization of processed standard deviation DAS data encompassing thin, flat, and thick cable sections, overlaid with pressure sensor data (top). The black dashed lines denote the positioning of pressure sensors within each cable section. Notably, the observed slugging behavior manifests as subtle, sloping trends. The thin cable exhibits clearer delineation of slug behavior

compared to the flat cable. The data presented corresponds to superficial gas velocity of 2 m/s at a liquid flow rate of 0.6 GPM.

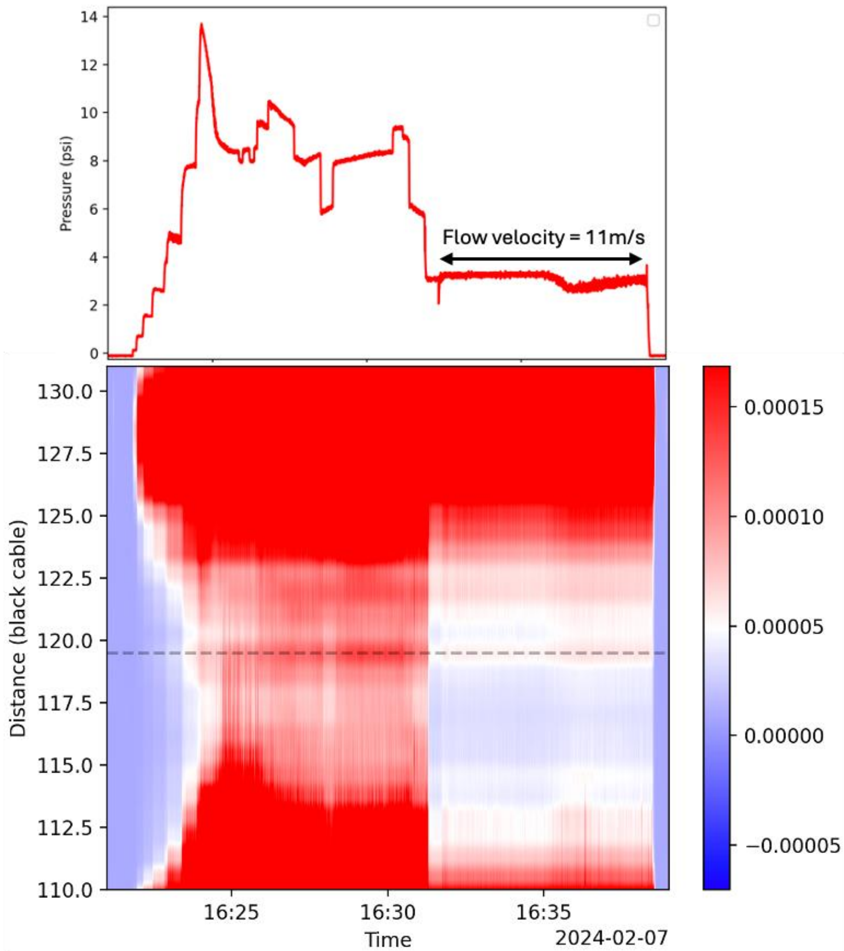

Figure 3. Top, the pressure within the pipeline; bottom, the DAS standard deviation data along the black cable. Flow direction is from bottom to top. The location of the leakage is marked by a dashed, black transparent line. The valve at the end of the pipeline is closed. Note that, from around 16:22 to 16:32, we tried to adjust the inlet gas valve to achieve the desired velocity 11m/s, which was achieved at around 16:32. We showed the data in this entire period, because it shows interestingly how the DAS signal corresponds to the pressure and/or flow rate changes. It also shows that the higher differential pressure across the leakage point, the better its detectability using fiber cables.

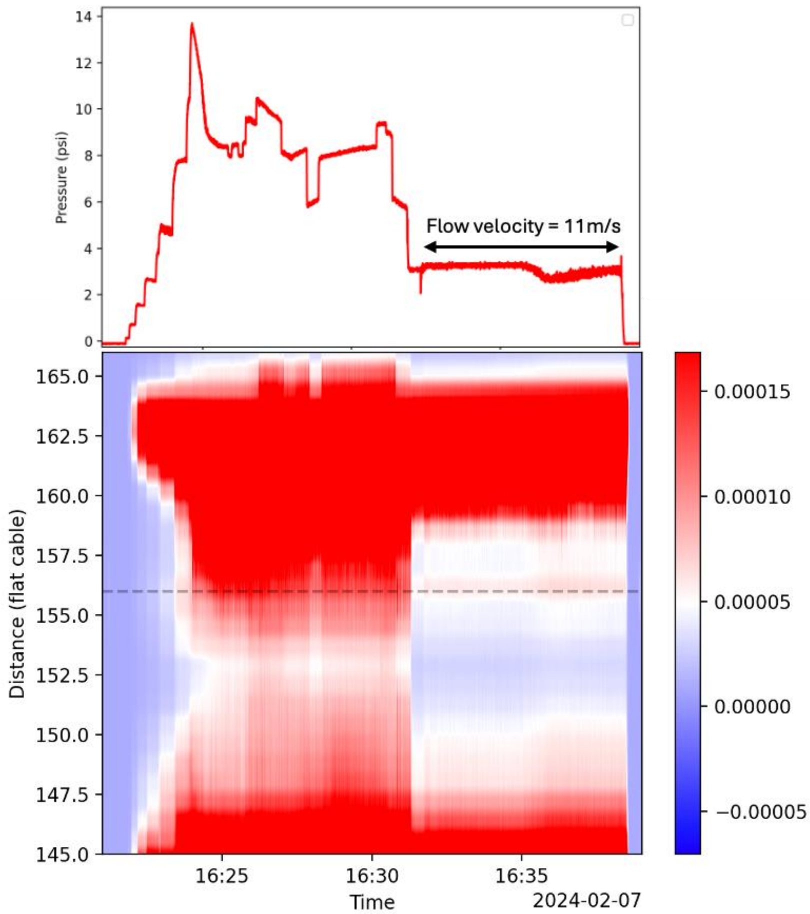

Figure 4. Top, the pressure within the pipeline; bottom, the DAS standard deviation data along the flat cable. Flow direction is from top to bottom. The location of the leakage is marked by a dashed, black transparent line. The valve at the end of the pipeline is closed.

Figure 5. Photograph of the unburied/buried pipe supplies (sandbags on the left and wooden boxes on the right that will hold the sand and the steel pipe)