Methodologies for Pipeline Leak Detection: a Multi-Sensor Inline Inspection Study

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Abstract

This study explores the viability of advanced sensor-based methodologies for the detection of pipeline leaks, an area receiving increased attention within pipeline integrity assessment. Employing a multi-sensor inline inspection arsenal, including acoustic, magnetometric, and pressure sensors, the research utilized a flow loop at the PRCI-TDC facility to establish a bespoke testing environment. A comprehensive test execution protocol was devised and implemented. Data were captured across multiple trials using equipment from two distinct vendors—referred to as Vendor A and Vendor B. Instances of leak detection were analyzed to evaluate the capability of these systems in detecting and pinpointing leaks, with a focus on determining the minimal leak size detectable with reliability by the sensors tested.

1. Introduction

The increasing demand for reliable pipeline leak detection systems has led to the development of advanced sensing methodologies. This paper details a study conducted using multi-sensor inline inspection tools to determine the smallest reliably detectable leak size in a controlled environment, contributing to the pipeline integrity assessment domain.

2. Methodology

A series of tests were conducted using a custom-built flow loop at the TDC facility, employing multi-sensor inline inspection tools from two vendors. The test protocol was structured to capture data across various leak sizes, at differing o'clock positions, and differing hole sizes (1/2" to 1/64"), with a focus on assessing the sensors' ability to detect and pinpoint the leaks reliably every time.

2.1 Leak Hole Setups

The study procured approximately one pipe joint length of 12" pipe, with 6 laser cut hole sizes (1/64, 1/32, 1/16, 1/8, ¼, ½), and 3/8 tap for a nozzle spray, calibrated orifice, for the same hole-size equivalents. The leak spool was oriented a 3 different o'clock positions (3, 6, 12) for the various leak sizes. A hole can be defined as any opening and is "un-calibrated orifice," of fluid flow (leaks). While a "calibrated orifice," is a specific type of hole that can give precise fluid flow (leaks) and control of fluid flow (leaks). A "calibrated orifice," has a known diameter, length, and geometry for the intended operation and giving precise metering of the fluid flow (leaks). This study provided a comparison of the differing hole setups.

3. Results and Discussion

3.1 Data Acquisition and Analysis

The data collected were analyzed using XaasLabs PipeHawk application, a data analytics tool, which streamlined the analysis process and highlighted the strengths and limitations of the sensors from both vendors. The analysis focused on correlating sensor data with known leak signatures to assess detection capability.

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Data received from both Vendors was comprehensive, encompassing multiple sensor readings from each test run. The data included measurements of distance, audio, pressure, temperature, accelerometer readings, and magnetometry. The magnetometry data in particular proved instrumental in identifying pipe joint locations, which were critical for accurate chainage computations.

The data acquisition process encountered a range of complexities, such as for Vendor A, the need to control for the stalling of the pig in the pipeline during testing. These stalls, particularly evident in areas where the control valves were modulated to maintain pressure, led to disparities in the reported and actual length of the flow loop, which needed to be dealt with in the post processing signal analysis phase.

A pivotal step in our data analysis was feature matching, which involved correlating the signal data with known pipeline features such as bends and flange joints. This process facilitated a more precise localization of the test spool, around which the subsequent analysis was centered.

Analysis methods employed for leak signature detection included the use of Hilbert-Huang Transform (HHT) and Short Time Fourier Transform (STFT) on audio signals. The research team faced challenges in conclusively identifying leak signatures due to either the noisiness of the audio data and sampling rate from the Vendors, and/or the PRCI TDC test loop setup environment. For example, vendor A, the audio sampling rate, capped at 1000 Hz, limited the frequency range that could be analyzed, potentially omitting higher-frequency leak signatures that are indicative of smaller leak sizes.
Several issues were noted during the test runs, most notably the proprietary nature of certain signals. Furthermore, the presence of background noise and its impact on audio signal clarity was a significant challenge.

3.2 Vendor Comparison

A comparative study between Vendor A and Vendor B's equipment provided insights into the efficacy of each system. The results indicated differences in sensitivity and reliability in detecting the smallest leaks.

3.2.1 Inferences derived from Vendor A Data

In-depth analysis of Vendor A's sensor data focused on the correlation of sensor signals around the test spool location. Initial examinations of audio and magnetometer signals did not reveal variations indicative of a leak, reflecting the subtlety of the leak signatures or potential limitations in the sensitivity of the sensors.

Pressure signals offered a glimmer of insight, with minor pressure drops observed around the test spool. These observations, however, lacked consistency across test runs, diminishing their reliability as leak indicators. The unique 'Envelope' signal provided by Vendor A also failed to yield definitive evidence of leaks.

An intriguing aspect of the analysis was the derivation of girth weld (GW) speed, hindered by the lack of direct velocity data from Vendor A. Through the use of chainage and time data, a pattern was discerned where the velocity around the test spool location exhibited a noticeable decrease, followed

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by a return to the average speed. Despite this, the lack of consistent correlation with leak presence across the data set precluded a definitive conclusion.

The analysis was further augmented by audio recordings, where advanced signal processing techniques like Hilbert-Huang Transform (HHT) and Short Time Fourier Transform (STFT) were employed. While these methods highlighted certain frequencies around the test spool location, the limited sampling rate restricted the analysis to frequencies below 500 Hz, potentially omitting significant leak-related frequencies.

Several challenges marred the data analysis process, including proprietary signals that could not be assessed, low audio sampling rates, and signal inconsistencies due to equipment stalling. These factors collectively affected the accuracy of the chainage calculations and may have masked leak signatures.

Vendor A signal plot

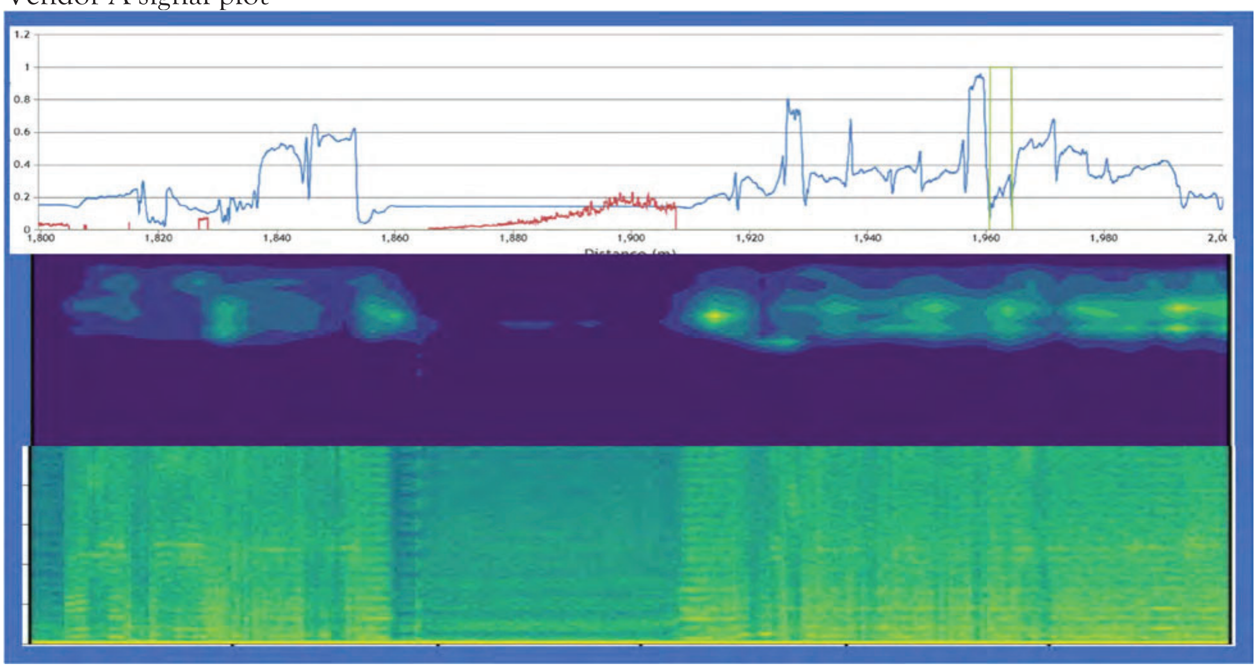

Figure 1. Chainage HHT and STFT - Vendor A

3.2.2 Inferences derived from Vendor B Data

Vendor B's data analysis process commenced with a review of the audio and pressure signals. The initial analysis did not reveal any distinct changes in the signals that could reliably indicate the presence of an anomaly, reflecting the complexity of detecting subtle leak signatures amidst variable background noise.

Further analysis involved inspecting velocity signals, where a marginal increase in velocity was noted prior to the test spool location. However, these signals were not unique to the vicinity of the test spool and were observed in other regions as well, rendering them non-conclusive for the purpose of leak detection.

The investigation then progressed to a detailed analysis of audio signals provided by the vendor. Four audio files, each approximately 75 seconds in length and sampled at a rate of 20 kHz, were examined,

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allowing for the analysis of higher frequency signals that could be indicative of leaks. Although the final audio file was disregarded due to a reported fault, the third audio file, associated with the largest leak size for which data was available, presented new insights.

Advanced signal processing techniques, including Short Time Fourier Transform (STFT) and Hilbert-Huang Transform (HHT), were employed on these audio files. These analyses revealed the presence of higher frequency components at and beyond the test spool location. Attempts to isolate these signals through high-pass filtering and noise reduction led to the identification of bursts of high-frequency signals at the test spool location, which persisted as a pattern distinct from other areas of the pipeline.

Despite the presence of similar high-frequency bursts at locations corresponding to pipeline features such as butterfly valves and bends, the consistent background signal in the 2-3 kHz range at the test spool differentiated it from these features. This observation suggests a potential correlation between these high-frequency signals and the presence of leaks, warranting further investigation.

Vendor B signal plot

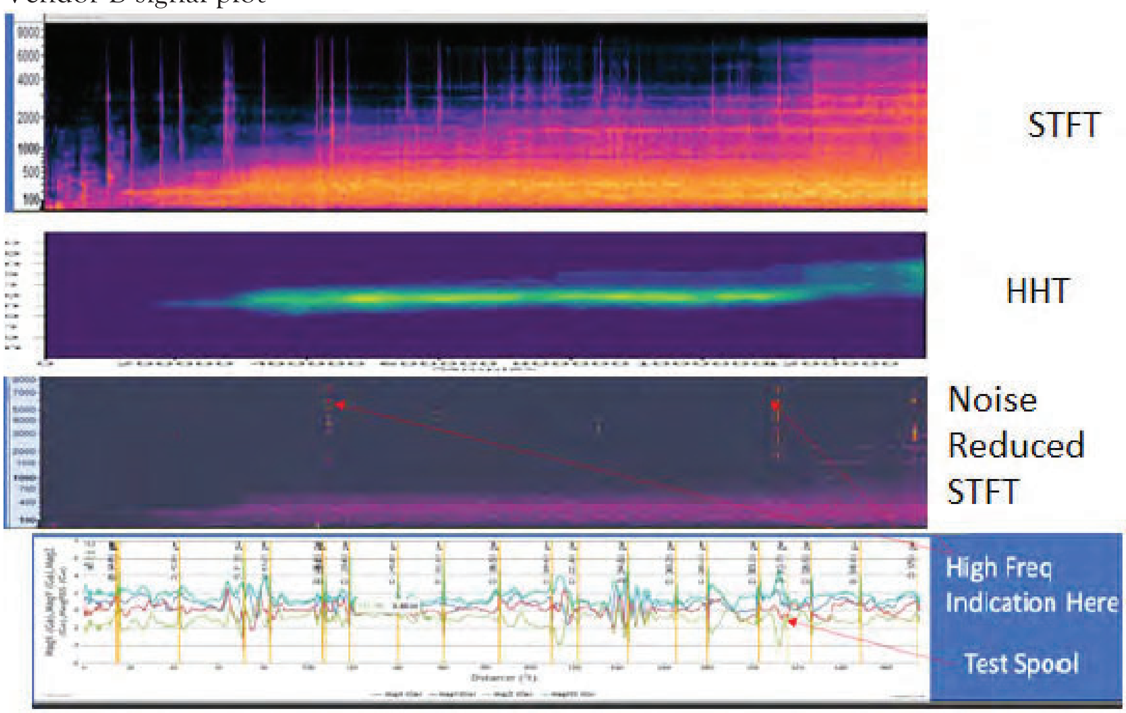

Figure 2. STFT, HHT, Noise Reduced STFT and Chainage Vendor B

4. Conclusions

The study found that there were variations in the minimal leak size each vendor could reliably detect. The multi-sensor approach proved beneficial in multiple ways (feature matching, run alignment, potential resolution of false positives etc.) suggesting a potential for these methodologies in real-world applications.

5. Future Work

Recommendations for future work include testing with finer leak sizes, acquiring real-world pipeline data for validation, and exploring the benefits of fusing ILI sensor data with other datasets like drone surveys and satellite data.

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