Multi-Sensor Inspection: Advanced condition Assessment of Sewer Forcemains using MSI Technology

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Abstract

SewerVUE introduces the ability to scan, map, and localize large-diameter underground pipelines with an unprecedented combination of speed and precision.

Pipeline stakeholders often require detailed analyses of their assets' geometries and internal surface conditions. Precise pipeline analysis presents unique challenges: global positioning systems will not work in underground pipes and wheel-based odometry is unreliable, precluding external sensor localization. This paper explains how the multi-sensor condition assessment technique has overcome these obstacles using light detection and ranging devices, and other sensors mounted to a remotely driven vehicle through the pipeline, along with novel reconstruction algorithms.

This paper presents a case study wherein this workflow was used for digitizing, localizing, and mapping 16,860 linear feet with a 48-inch pipe that makes up the South Shore Force Main in Milwaukee, Wisconsin. Here we inspected the interior of this asset with 3D LiDAR and Video analysis. Advanced data processing methods allowed for unprecedented accuracy in reconstructing a digital double of this asset. Despite efforts to ventilate the pipe, visual conditions were limited during the inspection. This paper discusses the difference between a visual-only inspection and the insights learned from LiDAR intensity mapping in low visibility conditions.

Introduction

Over two days, SewerVUE and a subcontractor completed an advanced condition assessment of pipes totaling 16,860 LF:

- 10,700 LF of 48-inch reinforced concrete pipe (RCP)
- 5,800 LF of 48-inch prestressed concrete cylinder pipe (PCCP)
- 360 LF of 48-inch ductile iron pipe (DIP).

To complete the project's scope in the 72-hour shutdown period, we partnered with Pure Technologies Ltd and split the data collection scope. We were responsible for the reporting and data processing of the South Shore Force Main (SSFM) inspection. To keep data collection consistent, a remotely operated vehicle is equipped with a closed-circuit television camera and with an advanced sensor platform while scanning from manhole openings.

This inspection used a remotely operated vehicle, Multi-Sensor Inspection (MSI) system The primary data came in high-resolution 3-D LiDAR measurements, with CCTV footage for visual correlation. LiDAR is light, and radar is a multi-sensor inspection method. LiDAR surveys are done by projecting a laser and measuring its time to reach a target and reflect the sensor, used to measure the pipe above the flow line and collect detailed information regarding ovality, deformations, offset joints, and lateral size.

MSI Overview

The Multi-Sensor Inspection system used is an advanced condition assessment tool that measures the physical shape of a pipe's interior at a high resolution and produces a 3D point cloud and other representations of this geometry. The system deployed for this project used several LiDAR devices to build a detailed three-dimensional model of the inside of the pipe.

Both teams used a visual Closed-circuit television and an advanced sensor platform "Black Box" to inspect underground pipes. The "black box" shown in figure 1 consists of:

- 2x2D planar LiDAR
- 1x3D LiDAR
- MEMS-based; Micro-Electro-Mechanical Systems
- Barometer
- Inertial measurements unit
- Redundant data collection software
- GUI; a user interface
- Daemon; imaging type software

Figure 1: ***SewerVUE Technology Corp. "Black Box" on Pure Technologies Ltd. ROV.***

What is Multi-Sensor Inspection and LiDAR

LiDAR (Light Detection and Ranging) is an optical remote sensing technology that identifies the range and reflectivity of a distant target by measuring the return time and intensity of the laser light it emits. Our sensor package contains two types of LiDARs: a planar LiDAR, which spins a single beam and receives reflected pulses along a two-dimensional plane, and a 3D LiDAR, which projects multiple beams from a spinning platform with different pitches and can provide three-dimensional positions of reflection points. The advantage of the planar LiDARs is the precision. LiDARs can only measure distances of objects from themselves. To get absolute positions of objects they observe or to produce a coherent map from LiDARs attached to a moving platform such as a remotely operated vehicle, the positions, and orientations of the LiDARs must be known at all times to create points of origin for every observation.

The Multi-Sensor Inspection system can keep track of its position within the pipe relative to the start point without the need for external references by using an IMU and tether odometry. An **inertial measurement unit** (IMU) is a device that integrates multi-axis, accelerometers, gyroscopes, and other sensors to provide an estimation of an object's orientation in space. Measurements of acceleration, angular rate, and attitude are typical data outputs.

The IMU used for this work was a Yocto 3D made by Yoctopuce, able to measure linear acceleration in three orthogonal directions, rotation rate along with the three orthogonal axes, and its orientation relative to the Earth's magnetic field.

The data provided by the IMU used has the ability to give a rough estimate of speed, orientation, and position over short distances and time. This is achieved by the tether used to power the robot, further aiding with the localization efforts

Figure 2: The SewerVUE's remotely-operated vehicle Multi-Sensor Inspection entering the pipe.

The results

The visual component of the survey discovered a small number of notable defects but was otherwise unremarkable. There were several instances of excessive sediment, including some frozen sediment. More notably, there was a lengthy section of visibly sagging pipe in one of the inspected lines. The sag was identifiable over a length of 200 feet.

SewerVUE's video reviewers did not see any indication of cracks within the pipe. The LiDAR data painted a different picture with evidence of widespread cracking throughout four of the surveyed segments, totaling dozens of instances. Most of the cracks ranged from 4-8 feet long and were present at many clock positions.

Upon review of the video footage, SewerVUE notes the following visual defects. The results of the inspection are shown in figures 3 and 4:

Pipe ID	MH35141 - DV0103	Clock Position	
		Crack 1	
Distance (Ft)	**Code**	**From**	**To**
1968	N/A		

Pipe ID	ARV103 - MH35141	Clock Position	
		Crack 1	
Distance (Ft)	**Code**	**From**	**To**
1811	Excess of sediments		
500	Loose pipe		

Pipe ID	ARV103 - DV0102	Clock Position	
		Crack 1	
Distance (Ft)	**Code**	**From**	**To**
690-890	Pipe sagging		

Pipe ID	JIHT - ARV101	Clock Position	
		Crack 1	
Distance (Ft)	**Code**	**From**	**To**
8-583	Large sediments		

Figure 3: The Results

SewerVUE Technology Corp. video reviewers could not find any visual evidence of cracks. Upon further review of the multi-sensor data, cracks were identified in the LiDAR intensity map at the following locations:

Pipe ID	MH ARV102 - MH DV0101	Clock Position	
		Crack 1	
Distance (Ft)	**Code**	**From**	**To**
295 ft	Circumferential Crack	7	9

Pipe ID	MH ARV101 - MH DV0101		
		Crack 1	
Distance (Ft)	**Code**	**From**	**To**
5	Circumferential Crack	4	6
18-26	Mulitple Cracks	4	12
42	Circumferential Crack	1	4
48-56	Multiple Cracks	4	8
96 - 102	Multiple Cracks	2	5
146 - 152	Multiple Cracks	2	4
180 - 188	Multiple Cracks	12	5
212-216	Multiple Cracks	12	3

Pipe ID	MH ARV101 - JIHT		
		Crack 1	
Distance (Ft)	**Code**	**From**	**To**
40	Circumferential Crack	7	11
120-125	Mulitple Cracks	4	7
250	Circumferential Crack	10	12
296-300	Multiple Cracks	9	2
656	Circumferential Crack	6	8
744	Circumferential Crack	3	12
748-793	Multiple Cracks	3	6
804-808	Multiple Cracks	3	6
846-856	Multiple Cracks	5	6
876-884	Multiple Cracks	7	1
963	Circumferential Crack	3	4
972	Circumferential Crack	3	5
1008-1012	Circumferential Crack	6	8
2494-2500	Circumferential Crack	12	3

Pipe ID	MH ARV102 - MH DV0101	Clock Position	
		Crack 1	
Distance (Ft)	**Code**	**From**	**To**
232	Circumferential Crack	7	9

Figure 4: The Results

Despite the prevalence of the cracking, it was not visible on the CCTV footage. Upon analysis of the LiDAR data, SewerVUE discovered it. figure 5

The report was delivered following the survey detailed the locations of each observed crack. LiDAR data can be reported in several fashions, three of which were included in this project:

- cross-sections of the pipe
- a 3D point cloud
- “snakeskin” imagery.

Snakeskin charts show an unwrapped 2D representation of the pipe’s internal geometry. The chart displays observed variance from the standard dimensions through color gradation. Figure 5 below shows an example of this.

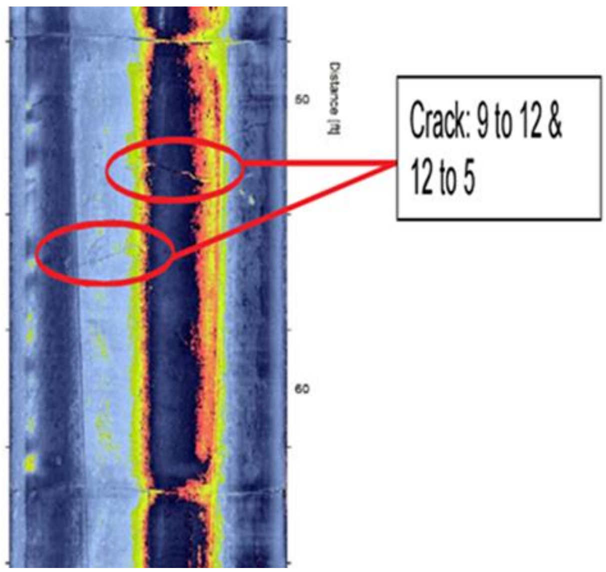

Figure 5*: Example: snakeskin chart showing cracks.*

Conclusion

Before SewerVUE's surveys, the condition of the surveyed segments was not well known. Following the report, the SSFM owner and contractors had what they needed to accurately gauge the condition of the pipeline and prioritize maintenance budgets accordingly. Advanced condition assessment methods such as the Multi-Sensor Inspection system provide detailed, quantitative data that can form the basis of a robust condition assessment and asset management program.