New Developments in Multi-sensor Condition Assessment Using LiDAR, Sonar and CCTV

Csaba Ékes
SewerVUE Technology Corp., 7993 Enterprise St., Burnaby, BC, Canada
V5A 1V5; Tel: 1- 888-973-9378, e mail: info@sewervue.com

ABSTRACT

This paper describes the development and successful applications of a closed circuit television (CCTV), LiDAR (Light + radar) and sonar based pipe inspection system that is robust to gather quantitative data for critical underground pipe condition assessment. The system that can be deployed on a ROV or on a float produces accurate cross-sectional analysis and sediment volume. This capacity is increasingly critical in large diameter pipes with high level of flow. The system employs a time of flight LIDAR that is sub cm accurate.

Results from recent projects are discussed in detail. The North Surrey Interceptor in Surrey, British Columbia, Canada is a critical line in the municipality's wastewater system. This reinforced concrete box culvert is 1500 mm × 1750 mm, and often operates at full capacity. The owner has experienced failures on this pipe, and it was recently rehabilitated. The sonar results provided accurate sediment volumes and cross sectional restrictions. This information was used to infer the location of defects and gather the necessary information for a subsequent pipe penetrating radar (PPR) deployment.

The TEES Tunnel in Tolo Harbor, Hong Kong is a 7 km long, 3.18 m diameter reinforced concrete sewer tunnel. It has been in service for 15 years and was in need of a quantitative condition assessment. Due to safety concerns man entry was not an option. A long-range multi-sensor robot was deployed to traverse 1 km from both access portals and to gather CCTV and LiDAR data. Due to limits to flow diversion the project had to be completed in a 24 hr time frame. The CCTV and LiDAR data revealed quantitative information on the condition of this critical tunnel.

Advanced pipe condition assessment technologies, such as the CCTV, LiDAR and sonar system described in this paper are cost-effective, non-destructive methods that are able to help better refine estimated remaining life of an interceptor, accurately determine overall severity of pipe degradation, as well as provide a basis for improved cost allocation and timing of rehabilitation efforts.

INTRODUCTION

Obtaining quantitative data which allows for objective assessment of pipes is of increasing interest to engineers, contractors, and municipalities. Conventional closed-circuit television inspection technologies cannot adequately meet this need due to the subjective and imprecise nature of the assessment process. Laser profiling is an emerging technology that has been shown to provide precise quantitative measurements of pipe parameters such as ovality, unobstructed cross-sectional area, pipe deformations, lateral size, offset joints, and flow levels.

The laser profiling concept as well as its inherent measurement errors are described by Dettmer (2007) and by Dettmer et al. (2005). There are several commercially available models on the market. Their reliance on accurate calibration, and unreliable field accuracy were pointed out in a seminal paper by Shelton and Travis (2012).

The approach outlined in this paper employs LiDAR (Light and raDAR), an optical remote sensing technology that measures properties of scattered light to find range and/or other information of a distant target. The prevalent method to determine distance to an object or surface is to use laser pulses. Like the similar radar technology, which uses radio waves, the range to an object is determined by measuring the time delay between transmission of a pulse and detection of the reflected signal. The MPIS's LiDAR data is correlated with an onboard inertial navigation system (INS) that uses a computer, motion sensors (accelerometers), and rotation sensors (gyroscopes) to continuously calculate via dead reckoning the position, orientation, and velocity (direction and speed of movement) of the inspection platform without the need for external references. This technology is commonly used on vehicles such as submarines and guided missiles and is specially adapted for the use of multi-sensor inspections for underground infrastructure surveys where LiDAR is utilized and location and time measurement data is necessary. The multi-sensor system can be deployed from an autonomous robot (or ROV) or from a floating platform. Successful applications for each are described in the following case studies.

METHODOLOGY

LiDAR Theory

LiDAR (also written Lidar or LIDAR) is a remote sensing technology that measures distance by illuminating a target with a laser and analyzing the reflected light. LIDAR uses ultraviolet, visible, or near infrared light to image objects. It can target a wide range of materials, including non-metallic objects, rocks, rain, aerosols, clouds and even single molecules. A narrow laser-beam can map physical features with very high resolution.

Wavelengths vary to suit the target: from about 10 micrometers to the UV (ca. 250 nm) range.

Understanding how each laser profiler works, is imperative for engineers in charge of pipe specification, installation, maintenance or testing. Output from laser profiling systems vary greatly. For example, the difference in results even from the same ring laser profilers operated by different contractors can be significant (Shelton and Travis, 2012). Municipalities and engineers must carefully assess the repeatability, accuracy and calibration of the employed systems.

Continuous-ring profilers use a planar laser whose light rays emanate radially outward from a fixed focal point. *LIDAR systems* use a scanning laser that moves back and forth in a single plane. Salik and Conow (2012) describe the key characteristics for the two systems in an easy to understand paper.

CASE STUDY #1: SURREY, BC, CANADA

The North Surrey interceptor is a critical trunk line in Metro Vancouver's collection system. The 1500 mm x 1750 mm reinforced box culvert has experienced failures in the past. The owner of the pipe commissioned a multi-senor inspection to ascertain the condition of the pipe.

Since the pipe flows close to full capacity and the upstream manhole is very deep (9.5 m) a multi sensor CCTV and sonar inspection was the first phase of the project. The objective of the inspection was to determine the condition of the inspected pipes by mapping out the accumulated sediments and any potential restrictions at the bottom of the pipe over a 172 m distance between MH 7 and MH 8.

The Multi-sensor Pipe Inspector System (MPIS) used for the project is a float based inspection system that uses visual and quantitative technologies (CCTV, LiDAR, and Sonar) to inspect the condition of underground pipes. This tethered, modular and customizable second generation MPIS was powered through a 1010 m long tether cable (Figure 1). CCTV, LIDAR and sonar data is acquired simultaneously in both in and out directions. First a guide rope was installed then the inspection platform is pulled through.

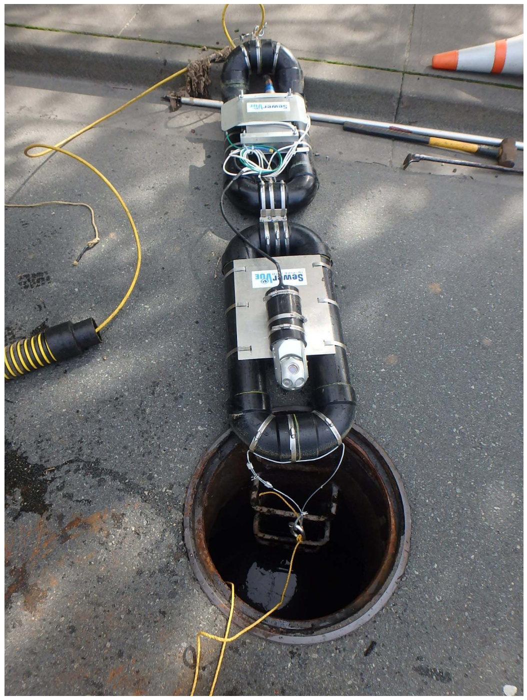

Figure 1**.** The second generation SewerVUE Multi-sensor Pipe Inspection System (MPIS) before deployment.

The primary objective was to measure the height, volume and distribution of deposited sediment (Figure 2) for the subsequent PPR inspection. Knowing the sediment depth and its distribution was critical for designing the suitable antenna enclosure for the subsequent PPR survey.

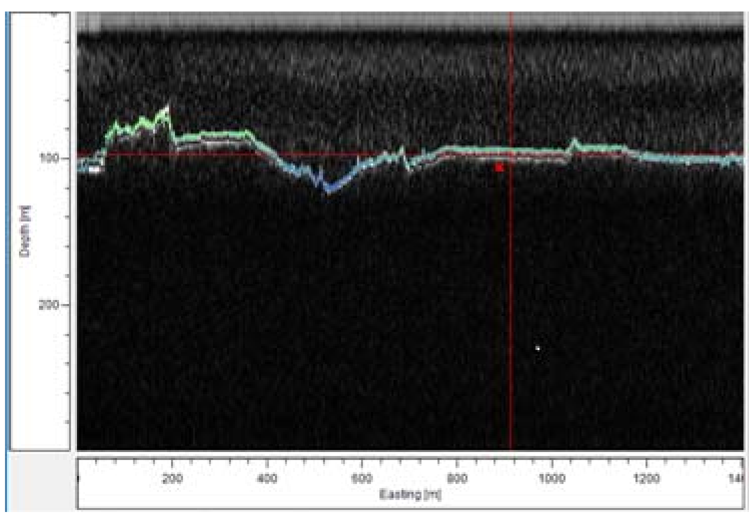

Figure 2. Sediment level and distribution in the North Surrey, BC, Canada interceptor.

In phase two of the project a dual frequency underwater PPR antenna was deployed to locate and measure any cracks at the invert of the pipe. Due to high flow conditions during the day the work was carried out at night.

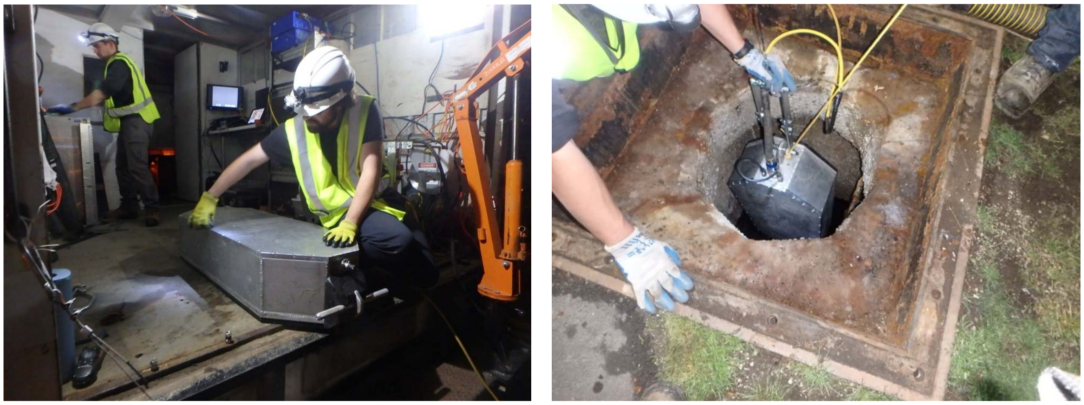

Figure 3. The dual frequency underwater PPR antenna before and during deployment.

The dual frequency antennae operate on a 1 GHz and 250 MHz center frequency, thus obtaining both high resolution near surface data and deep penetration data in order to locate footings, columns and targets in the 1m to 5 m depth range. The 1 GHz antennae are ideally suited for mapping wall thickness, rebar cover, corrosion and any cracks and voids within and outside the pipe wall. Preliminary PPR results were not available at the paper submission deadline.

CASE STUDY #2: TOLO HARBOR, HONG KONG

The 7 km long Tolo Harbor sewer line is a 3.180 m diameter reinforced concrete tunnel that has been in service for 15 years. It has only two access points at Shatin Portal and at Diamond Hill (Figure 4).

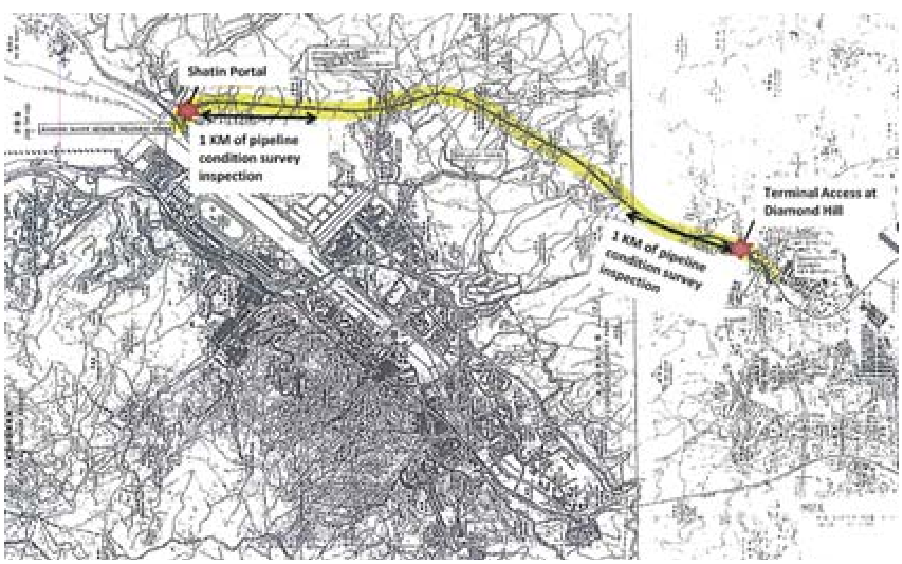

Figure 4. Location of the TEES tunnel in Hong Kong.

The owner of the pipe, the Department of Sewerage and Drainage (DSD) is concerned about the condition of the pipe. Since man entry was not an option due to safety issues, they commissioned a robotic multi-sensor inspection.

Figure 5. The multi-sensor inspection robot before deployment at Tolo Harbor, Hong Kong.

Due to the diameter of the pipe accurate dimensional information was critical for the condition assessment, since CCTV could only provide a supporting role. A modified multi-sensor robotic platform was used for the inspection. The long-range MPIS combines state of the art data collection and analysis with proprietary processing and reporting software. The tracked robotic inspection platform is outfitted with high definition CCTV and LIDAR sensors and has a 2000 m maximum deployment capability. LIDAR measurements determine the exact size and shape of the pipe and provide quantitative assessment of deformation and corrosion. The system is customizable and can be deployed through an 400 mm manhole and can be used to inspect any pipe size over 400 mm in diameter. Bypass pumping is not required as long as the camera is above the flow. Inspection reports provide integrated and quantitative corrosion and debris measurements, 180 degree virtual pan/tilt/zoom function, video, laser and sonar flats.

Demanding access conditions created added challenges and were overcome by a cooperative local subcontractor and detailed advanced project planning. Equipment and crew was mobilized from Vancouver, Canada and the inspection, two runs of 1 km from each access locations was completed in a 24 hr time window.

The final report included the WRc coded video, a summary of service and structural defects, LiDAR cross sections at every 10 m interval, defects and observations from the CCTV and LiDAR and an interactive 4 in 1 viewer. Service and operational defects were mainly sediments (less than 5% cross sectional area), attached deposits, encrustations and other obstacles. The defect grades were 3 and 5 respectively. Structural defects were multiple cracks at joints (Grade 1), longitudinal fractures (Grade 3) and holes (Grade 4).

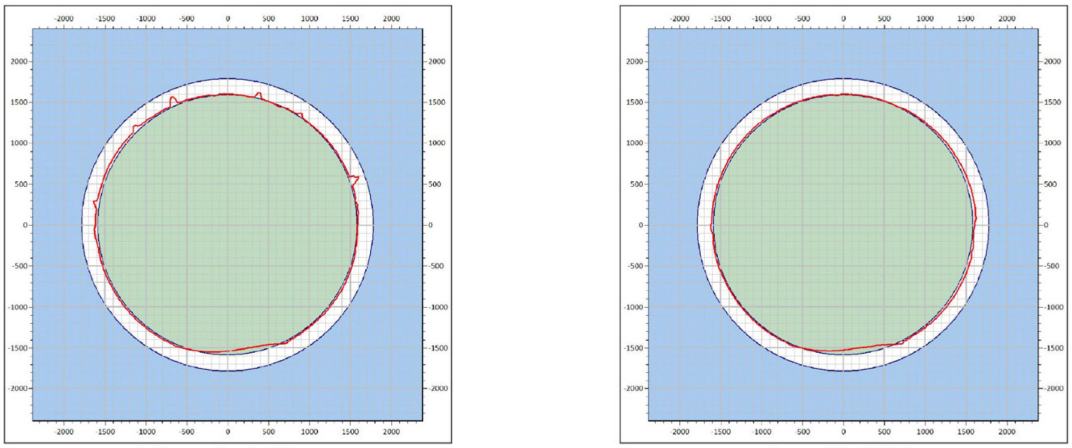

Figure 6. LiDAR Cross sections from the 3.180 m diameter Tolo Harbor, Hong Kong sewer tunnel.

SUMMARY AND CONCLUSIONS

With limited available funding and budget constraints becoming more prevalent, timing of rehabilitation and overall intelligent asset management are more critical than ever for municipalities and asset owners. Advanced pipe condition assessment technologies have demonstrated to be cost-effective, non-destructive methods that are able to help better refine structural condition and estimated remaining life of an interceptor, accurately determine overall severity of pipe degradation, as well as provide a basis for improved cost allocation and timing of rehabilitation efforts.

REFERENCES

Dettmer, A., Hall, A., Hegab, H., and Swanbom, M., 2005: Refining laser profiling method used for pipeline assessment. Proceedings of the North American Society for Trenchless Technology (NASTT) 2005 NoDig Show 2005. Orlando, FL, April 24-27 2005.

Dettmer, A., 2007: Position and orientation correction for pipe profiling robots. PhD thesis, Luisiana Tech University.

Salik, J. and Conow, O., 2012: Pipe Inspections: Robotic laser profiling demystified. Precast Solutions Fall 2012, pp 22-25.

Shelton, J. and Travis, J. P., 2012: Laser profiling – A case study in field accuracy. Proceedings of the North American Society for Trenchless Technology (NASTT) NASTT's NoDig Show 2012, Nashville, TN, March 11-15 2012. Pp B-5-03-1-5.