AUTOMATED ASSESSMENT TECHNOLOGIES FOR RENEWAL OF UNDERGROUND PIPELINE INFRASTRUCTURE

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Abstract: As our drinking water and waste water infrastructure age, it is important to increase the knowledge about the actual status of the infrastructure. Assessment of pipeline condition is becoming a priority with municipal authorities worldwide. CCTV based assessment is the norm, however accurate assessment is difficult to achieve in practice as subtle defects are hard to discern. CCTV technique is also highly subjective due to its reliance on the skill and concentration of the field operator. In recent years research efforts have concentrated on developing systems that can not only collect accurate relevant data, but also use this data to make intelligent, cost effective decisions regarding the rehabilitation, operation, and maintenance of the network. This paper presents two state-of-the art technologies for automated assessment and robotic repairs of underground pipelines.

Keywords: pipeline assessment, SSET, hydroscope, robotic repair

1. INTRODUCTION

The 54,000 drinking water systems and 16,000 wastewater systems in the U.S. face staggering infrastructure funding needs of nearly US$1 trillion over the next 20 years [1]. In 2000, over US$15 billion will be spent on sewer and water construction projects (Fig. 1), which is only a third of what has been estimated by experts to be the minimum annual expenditure to replace aging facilities and comply with existing federal regulations. Historically, infrastructure rehabilitation has been driven primarily by repairing failures rather than preventing them [2,3]. Due to their lack of visibility, rehabilitation of underground pipelines is frequently neglected until a catastrophic failure occurs, resulting in difficult and costly replacement [4,5].

Traditionally the methods used to assess and interpret condition of underground water/sewer systems have consisted of a TV camera carried by a remotely controlled vehicle. While CCTV technology has advanced, the basic processes and results have remained unchanged. The technician has

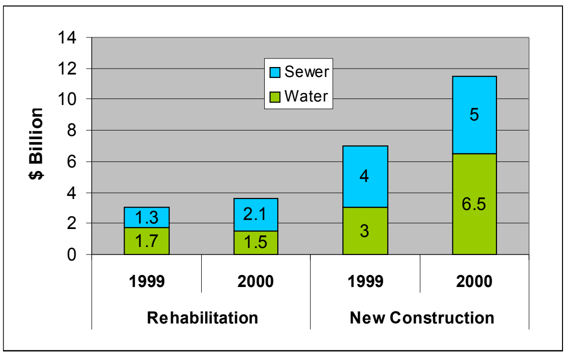


Figure 1. Construction Spending Projections

to identify pipe defects on a TV monitor located in a control vehicle at the jobsite (Fig. 2). Typically, the field technician identifies and classifies each defect (i.e., corrosion, cracks, misaligned joints, root intrusion, etc.), and then submits these records to the responsible engineer, for evaluation and a recommendation regarding rehabilitation. The data acquired in the field consists of videotape, photographs of specific defects, and record produced by the technician. The technician records can be produced manually or they can be automated.

Figure 2. CCTV Truck at Job Site

However, with either method, the quality of the data is dependent on the experience and skill of the technician.

The weak link in the whole process is the judgment that the technician must exercise when identifying and classifying pipe defects in the field (Fig. 3). Many factors, such as experience, mental awareness, equipment capability, field distractions and interruptions, environment, etc., impact the judgment. Nevertheless, major decisions regarding rehabilitation methods hinge on this judgment.

Figure 3. Pipe Defects – Protruding Lateral, Root Intrusion, Cracked Pipe and Offset Joint (clockwise)

Another characteristic of the traditional CCTV technology is the difficulty in estimating field production. The time it takes to internally inspect a pipe is dependent on the number and the degree of deterioration of the defects. At each defect, the operator must stop, assess, and record the condition. Therefore, it is very difficult to estimate the time and cost to perform the CCTV work. Pressure to maximize the daily production can result in poor quality data being provided to the office engineer for decision-making, in which case the engineer will most often base his/her decision on a “worst case scenario.” This can often result in costly and unnecessary fixes.

2. STATE-OF-THE ART ASSESSMENT SYSTEMS

CCTV based assessment can be error prone and subjective resulting in handicapped financial justification of rehabilitation work, except for gross defects. [6]. The need for adding tools to complement the current control environment is apparent. These tools will enable up-to-date evaluation and the development of maintenance plans. Research and development activities in this context have intensified. A large number of automated data collection technologies such as photographic and video imaging, laser, radar and infrared thermography have made it possible to collect data in shorter time for the analysis of infrastructure performance [7]. However, the accuracy and precision of these technologies are not well understood as most are still in the “prototype” stage of development. However, some of these technologies clearly hold a great deal of promise and are therefore the focus of this paper.

2.1 PIRAT - A system for quantitative sewer assessment

PIRAT (which stands for Pipe Inspection Real-time Assessment Technique), is the product of a five-year collaboration between CSIRO and Melbourne Water, Australia. The first experimental prototype for assessing operational sewers was developed by in 1995, at a cost of US $3 million. The PIRAT system comprises two semi-independent systems. The instrument system collects geometry data, and the interpretation system analyses this data to detect, identify, and rate defects.

2.1.1 System Characteristics

The PIRAT system consists of a silver robot riding on six tilted wheels equipped with laser and sonar scanners (Fig. 4). The robot inches its way through the pipe while the scanners search the surrounding walls for structural defects and weaknesses. As in a CCTV operation, a mobile control room is provided to house the operator and the control equipment, which performs real time data analysis.

Figure 4. PIRAT Sewer Assessment Robot

Figure 5 shows a typical on-site setup. A Sun SPARC station provides a windows-based interface for operator controls and manages storage of data. A CCTV color monitor equipped with a joystick is used for manual operation of the inspection vehicle during deployment and for obstruction avoidance. For all other times the system is controlled by the computer. A laser scanner is used in drained pipes and a sonar scanner is used in live pipes.

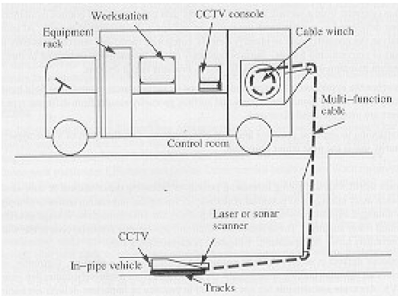


Figure 5. PIRAT Field Setup

The laser is mounted on the in-pipe vehicle. It projects a radial beam of light on the pipe wall. The beam is rotated to produce a disc of laser light and the reflected light is viewed by a video camera to determine the radius of the pipe. The video camera sensor has an array of independent light-sensitive sites called as pixels. These represent a radius resolution of approximately 1.5 mm. The speed of rotation of the beam is synchronized with the scan of the camera sensor. A 20 mw infrared laser is utilized in the prototype to maximize optical performance.

The sonar scanner has a rotating transducer, which outputs bursts of 2.2 MHz “pings”. The head listens for an echo from the pipe wall before rotating to the next position. The pipe radius is determined from the travel time of the ping and the sonic velocity in water. The return sound received at the transducer is a composite of the echoes from all features in this zone.

2.1.2 Interpretation System

The interpretation system implements Artificial Intelligence (AI) techniques to automatically identify, classify and rate pipe defects. The software is designed to process the radius data (up to 30,000 readings per foot or 100,000 per meter) to produce a condition assessment report. The software also implements a Management Information System (MIS), which allows further analysis of the results and access to the program controls via a graphical user interface (GUI). The task performed by the interpretation system is complex because the pipe defects overlap and have complex surface geometry. The automatic defect recognition is performed in five stages involving image processing and segmentation, neural network classification, knowledge based interpretation and report generation. The software hierarchy is illustrated in Figure 6.

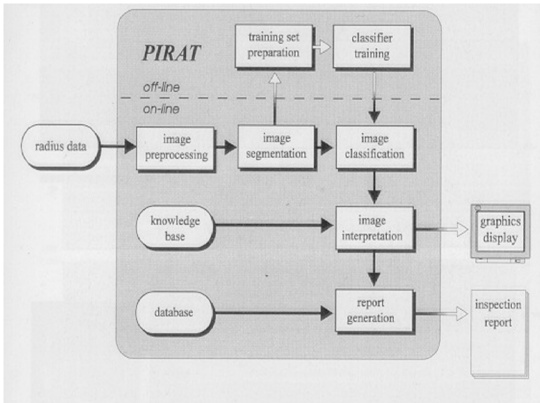


Figure 6. PIRAT Software Hierarchy

The image processing involves correction, grinding, and removal of missing values from the raw data. Correction reduces the effect of in-pipe vehicle motion. Grinding interpolates radius values from uniform circumferential and axial grid. Image segmentation clusters raw data into potential defect regions and characteristic geometric features. Classification of the regions is performed by a feed-forward neural network classifier, which has been trained off-line using selected training test data. The condition assessment report is generated automatically. A sample report is shown in Figure 7.

2.1.3 System Performance

The PIRAT system has been tested in over 4 km of live sewer for the city of Melbourne. The classification accuracy of the interpretation system was in excess of 97% on simulated pipe intersections, holes and voids, corrosion, deformation, joint displacement, cracks, and tree roots (Fig. 7).

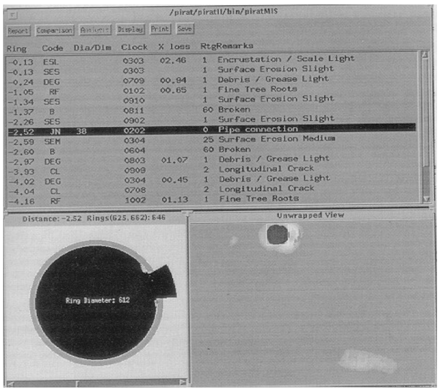


Figure 7. Condition Assessment Report – PIRAT

The PIRAT system was primarily designed for pipe diameters 600 mm and greater. For concrete and vitrified clay pipes the classification performance is much superior to CCTV. The classification performance for brick pipes was poor due to the low quality of data obtained and the deviation of the older brick sewers from the pipe geometry. Sonar data was determined to be significantly inferior to laser data and only gross defects and features are able to be detected using sonar. As a result the system is not effective in active sewers. Research is continuing to improve accuracy of the PIRAT system.

3. SEWER SCANNER AND EVALUATION TECHNOLOGY (SSET)

SSET is a pipeline inspection technology that incorporates state-of-the-art scanner and gyroscopic innovations to produce a detailed digital image. A color-coded computer printout shows the interior profile of the pipe, which includes written descriptions of each defect and is illustrated by designated color codes. The Sewer Scanner and Evaluation Technology (SSET) was developed by CORE Corp., and the Tokyo Metropolitan Government's Sewer Service (TGS) Company, Japan. This technology is the result of a two-year development process that began in early 1995 [8].

3.1 System Description

The Sewer Scanner and Evaluation Technology (SSET) is a flexible non-destructive evaluation data acquisition tool. The SSET removes the deficiencies of the CCTV to provide the engineer with more and higher quality information to make those critical decisions. This is accomplished by utilizing scanner and gyroscope technology. The information produced provides the engineer the ability to see the total surface of the pipe from one end to the other. The scanned image is then digitized so that a color-coded computer image can be printed out. Defects are illustrated by a designated color code. A written description of each defect is produced at the appropriate location along the pipeline. Figure 8 shows a plot of part of the distressed section of a sewer pipe. Horizontal and vertical deflections of the entire length of the line are also printed out.

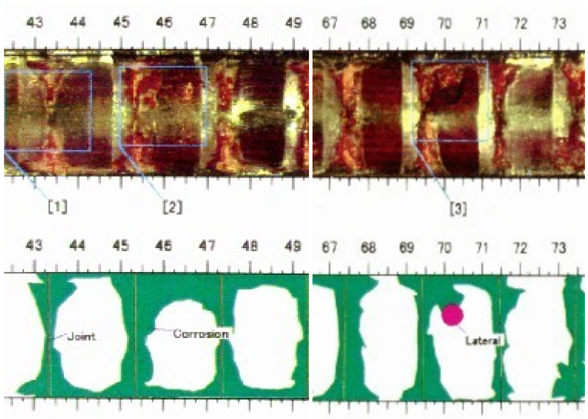
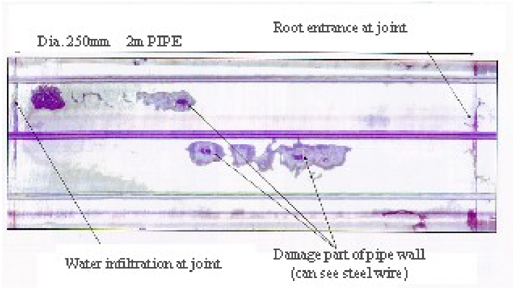


Figure 8. Sample Image of Sewer Pipe – SSET



The survey robot vehicle houses three major components: (i) the scanner, (ii) the CCTV; and (iii) a three axis mechanical gyroscope. The prototype system was introduced in 1997 and had a diameter of 130 mm and a length of 850 mm and weighs 25 kg. The prototype uses three skids, and the body of the robot was rigid, causing operational difficulty around sharp bends. The current version of the system utilizes two major components, a fish-eye optical scanner and a three-axis fiber optic gyroscope (Fig. 9). The machine has a diameter of 110 mm and a length of 850 mm and mass of 15 kg. The system can travel through pipe at a uniform speed and capable of

production rates of up to 1,500 m per day. Other components of the system consist of the necessary cable, control box, and monitors for forward looking and unfolded scanned view. The control box collects all data that will be transferred to a central data processing location where it is processed, checked, printed and developed into a professional report. The machine body has two articulating joints to facilitate obstruction avoidance and traveling through bends.

Figure 9. SSET Robot and Data Interpretation System

The mechanics of placing the SSET in the pipeline are similar to the CCTV inspection. The SSET is designed to function with external winches to propel the machine through the pipe. Since the SSET utilizes state-of-the-art scanner technology, it can travel through the pipe at a uniform rate of speed. The difference between the SSET and other assessment systems is that the scanner does not have to stop to allow the technician to assess each defect. All assessment is automated and not operator dependent. The operator is only responsible for proper equipment operation and acquiring the data, not interpreting the data. This is one of the strengths of the SSET system.

3.2 Benefits of SSET System

The major benefits of the SSET system over the current CCTV technology are:

- The engineer will have higher quality data to make critical rehabilitation decisions. This will expedite the evaluation process and permit a more thorough comparative analysis.
- Defects can be magnified to provide a clearer view.
- Better documentation of the condition of the pipe is provided.
- Horizontal and vertical pipe deflections are measured and illustrated graphically.
- Fieldwork is expedited because the technician is not required to assess the defects.
- The defects are color coded for better illustration and analysis.
- Statistical data can be generated on the defects (e.g., the total area of pipe surface corroded as a percentage of the total wall surface, etc.).
- The cost of the SSET system will be comparable to that of the CCTV technology (US$6per meter).

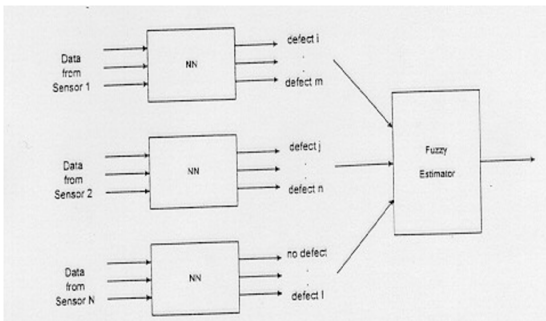
3.3 Interpretation System

Currently, the interpretation of the results of the scanned and videotaped images is done manually. Research is underway to automate the interpretation of the multi-sensory data. The interpretation system implements Artificial Intelligence techniques to automatically identify, classify and rate pipe defects.

In addition to scanned and videotaped images, and data collected by the gyroscope, the following information is also to be used in the assessment:

a) pre-diagnosis information such as intrinsic characteristics (age, sewer type, dimensions, depth),
b) working conditions (sewage nature, hydraulic regime),
c) environmental characteristics, including surface environment (traffic, works), soil environment (geology, hydro-geology)
d) history: construction mode (in trenches, trenchless),
e) difficulties during the construction.

The approach that is being used for automated interpretation of sensed data is the use of fuzzy Kohonen self-organizing maps (SOM) that read in data from sensors and create membership functions that indicate the condition of the utility (Figure 10). The set membership functions are appropriately weighted using an estimator to obtain a final assessment of the condition. A Kohonen SOM consists of a one-or-two dimensional array of neurons [9, 10]. Associated with each neuron is a feature vector whose elements are the synaptic weights between the neuron and the input nodes where the components of the sensor data to be classified are presented. Initially, the feature vectors are set randomly, but are adjusted during training in such a way that neighboring neurons on the feature map have similar feature vectors. When an unknown sensor data is presented to a trained network, it is recognized as belonging to a particular data cluster if it activates a neuron in the region labeled as corresponding to that cluster. Since it features self-learning and adaptive capabilities, the tool will get smarter and more



accurate with use.

Figure 10. Fuzzy Kohonen Self-Organizing Map

3.3 Evaluation Process for the SSET

In January 1996, the American Society of Civil Engineers (ASCE)/Civil Engineering Research Foundation (CERF) established CEITEC (Civil Engineering Innovative Technology Evaluation Center) to assist both the owners of new technology and the potential users of the technology to provide a cooperative mechanism for the evaluation of innovative technologies. The SSET system was the first technology to be evaluated by the ASCE-CERF/CEITEC process.

As part of the CEITEC process, CERF developed a proposal that was sent to over 100 municipalities inviting them to participate in a nationwide, comprehensive new technology evaluation program. Thirteen Departments of Public Works agencies across the U.S. and Canada agreed to participate at a cost of US$20,000 each. Approximately 3,300 m of sewer pipelines were inspected during the 1998-99 period for each of the participating agency using the SSET technology. The evaluation report providing a technical and functional analysis of the SSET performance was provided to each agency. The overall evaluation as to effectiveness of SSET to assess sewer lines for defects is under preparation by a task force consisting of industry experts and will become available in May of 2000.

This formal, non-biased, third party evaluation process will aid and expedite the introduction of this new and innovative technology. It will eliminate the need for each municipality having to conduct their own evaluation of new technology.

4. CONCLUSIONS

Detection of interior defects is generally the first warning of problems that could occur within sewer lines. At present, the state-of-the-art inspection systems for sewer lines are dominated by CCTV technology. Diagnosis of failures or defects depends on the experience, the capability and the concentration of the operator, and the reliability of the TV picture.

SSET and PIRAT are two state-of-the-art technologies, that can provide quality data on sewer condition including: pipe geometry, vertical and horizontal deflection, structural deficiencies, location and extent of defects (both gross and minor), and an automated analysis and rating of the overall integrity of the sewer line. This information will assist engineers and asset managers in making a more reliable and cost effective determination of the repair and rehabilitation needs for the scanned pipeline.

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