Pervasive Sensing for Buried Wastewater Collection and Drainage Networks

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Highlights

- Autonomous robotics has the potential to transform buried pipe infrastructure management.
- End users indicated four inspection method gaps: mapping, blockages, leakage and condition.
- Results show the potential for accurately mapping pipe locations and detecting blockages.

Introduction

Piped drainage networks are critical infrastructure systems in urban areas, however their local performance can degrade unexpectedly causing significant failure, e.g. urban flooding. Local asset condition is often unknown as currently in-system inspection is time consuming and expensive. Inspection predominantly relies on tethered CCTV crawlers, which require a multi-person team to operate. CCTV images are analysed for defects by an operator during collection, or analysed post-collection. Manual defect identification and characterisation has a tangible degree of subjectivity (Dirksen et al., 2013). More recently automated analysis of CCTV data has become possible (e.g. Myrans et al., 2018), eliminating human subjectivity but these methods have similar levels of uncertainty and provide little or no quantitative assessment. Current pipe inspection data is limited in quantity and tends to be biased towards pipes "expected" to be in poor condition, or whose failure would be expected to cause significant societal impact. This data bias inherently distorts and limits the deterioration modelling which feeds refurbishment and replacement plans. To deal with limited inspection data, solutions for more autonomous and robotic surveying are being developed. Some are advected by the flow (e.g. Smartball https://puretechltd.com/technology/smartball-leak-detection) and so can survey a defined section of the network, others are physically large (e.g. Kolvenbach et al., 2020), so cannot survey the majority of pipes in typical networks. The use of robotics has grown significantly in other application areas, inspection robots allow hazardous environments to be inspected safely (Yu et al., 2019), different sensors deployed on robots can produce data that is more reliable and repeatable. Recently, a multi-disciplinary team, containing computer scientists, physicists, control and mechanical engineers as well as water engineers have started to investigate the potential for using autonomous swarm robotic systems to survey buried sewer and water supply pipes (www.pipebots.ac.uk). This abstract focusses on urban drainage applications, presenting initial results in accurate system mapping and blockage detection.

Methodology

Automated robotic inspection can offer enhanced levels of system knowledge to that available using tethered CCTV based inspection systems. This enhanced level of knowledge could be in: (i) better quantification of asset defects and performance impacts; (ii) more comprehensive spatial system data; (iii) more frequent inspections can identify transient defects; and (iv) repeated inspections can obtain temporal data to assess asset deterioration.

An end user workshop identified and ranked key inspection challenges, given current and anticipated pressures (under a range of scenarios) for water supply, wastewater collection and drainage system operators (Pipebots, 2019). Six key challenges were identified, with delivery pathways and solution requirements. The six key challenges were (i) asset mapping, (ii) leakage, (iii) impacts on the environment, (iv) condition monitoring, (v) cost-benefit balance and (vi) eliminating disruption. Work to address these challenges has been structured into scientific themes to develop the knowledge that can address the specific challenges. In the Pipebots project these themes are: **Sensors:** Sensors are key to accurately understanding the condition of wastewater collection and drainage systems. Pipebots is investigating novel sensors, initially focussing on acoustic and ultrasonic devices because these have advantages over image-based systems in needing less power and requiring less computational overhead in terms of data volumes and processing. Robotic systems also need sensors to enable autonomy and navigation, but this theme is focussing on technology for condition and performance assessment. Two main issues studied so far (to link with the output from the end user workshop) are sensing blockages and pipe wall cracks. **Navigation:** Simultaneous localisation and mapping (SLAM), can provide the information needed for robots to navigate an unknown system. Such data can accurately record the location of defects and improve asset maps of networks. If the network can be mapped to a sufficient accuracy, repeated defect inspection is possible and also much greater application of trenchless technologies is enabled. **Autonomous Control:** Autonomy of the robotic systems is vital to reduce the costs of inspection. Robots able to inspect a limited portion of a network, before returning to the insertion point, or navigating to a separate retrieval point will transform the inspection cost. If robots are able to stay inside networks semi-permanently and work collaboratively then cost reductions would be even more significant (Parrott et al., 2020). **Communications:** The focus on communications is developing the capacity to communicate between robots and from robots to the outside world. Smaller diameter pipes, especially those that are partially water filled, can provide significant challenges for communication, both in terms of signal attenuation and the capacity of reliable data bandwidth. Robot to robot communication has various roles including to ensure system wide surveying and to transfer urgent data to a central hub. **Robotic Systems:** Robotic platforms physically and electronically integrate sensing, navigation, autonomy and communications. They also provide the mobility and environmental resistance to enable navigation and surveying of networks. A key target for this theme is to deliver platforms that are of a size to access the majority of any wastewater collection and drainage network, whilst carrying a useful sensor package.

Results and discussion

Results are presented from two aspects of robotic inspection systems that align with two of the identified end user challenges, firstly impact on the environment (blockage detection) using novel sensing packages and navigation using SLAM.

Detection of sewer blockages: The application of acoustic and ultrasonic sensing for the detection of sewer blockages has produced encouraging data. Figure 1 shows simulated results for reflection coefficients measured from blockages of varying sizes using a range of acoustic frequencies in a dry pipe. It can be seen that the size of the blockage has a clear influence on the reflection coefficient, allowing the data to be processed to return a blockage size. Additional work, not presented here, has shown that the reflection signature from joints and incoming laterals is distinct from that of a blockage, allowing clear discrimination of blockages. Yu et al., 2021 also numerically and theoretically investigated acoustic propagation in partially water filled sewage pipes, which will allow application in more realistic pipe environments.

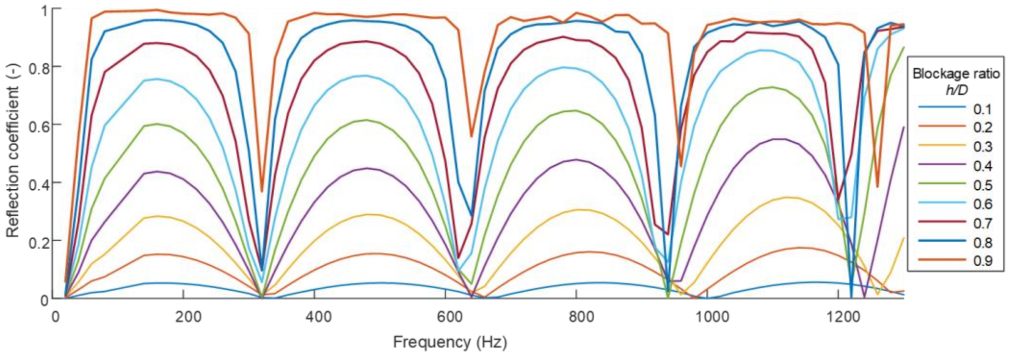

Figure 1: Simulated reflection coefficients for a range of blockage sizes and acoustic frequencies.

SLAM navigation: Scaled CCTV data from live sewers has been used to test visual SLAM (vSLAM) techniques. vSLAM requires loop closure (i.e. recognising that a robot has returned to a known location). However, the sparsity and repetitiveness of features in sewer pipes can result in place recognition errors. Figure 2 shows loop closure and vSLAM test results in live sewer pipes. There are two separate camera runs down the same pipe (frames 1-238 from run 1, frames 239 to 454 from run 2). Figure 2a uses FAB-MAP (Cummins and Newman, 2008), the semi-transparent grey dots along each row in the matrix indicate the maximum probability match between the current frame and those seen previously. The dark line of dots on the diagonal shows new frames being correctly identified as novel; from current frame (row) 239, the dark line moves off diagonal indicating loop closure, i.e. frames identified on run 2 that are very similar to frames in run 1. Figure 2b shows the loop closure frames identified by the magenta point in Figure 2a.

Figure 2: vSLAM loop closure. (a) Appearance-recognition result matrix. Most likely previous frame for each current frame is circled. (b) Example loop closure frames (magenta star in (a)). After Evans et al., 2021.

Conclusions and future work

Autonomous robotic inspection has the potential to transform the management of urban drainage systems. However, there are a number of scientific challenges that need to be addressed before this concept is viable. Engagement with end users indicated six key inspection challenges and we have presented some preliminary results to address system navigation and blockage detection. These demonstrate the feasibility of using novel sensors for blockage detection and for using visual data for SLAM. These technologies and others, described above are developing in order to realise autonomous swarm robotics.

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