Sonic characterisation of sewer change

Caractérisation sonique de l’évolution des égouts


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RESUME

Cet article présente un instrument de mesure à coût réduits, qui peut être utilisé pour découvrir des obstructions ou pour identifier des défauts structurels dans les conduites d’égouts. Le coût de production du senseur est d’un ordre de magnitude moins élevé que celui de techniques plus standardisées. La technologie emploie un modèle acoustique à décomposition normale ; les algorithmes de traitement prédissent la géométrie de la déformation du conduit ainsi que son étendue. Le senseur émet des signaux acoustiques encodés de courte durée, qui sont à leur tour reflétés par tout défaut présent sur la surface du conduit. Les signaux comportent des pulsations Gaussiennes et des balayages sinusoïdaux. Les contributions du niveau d’eau sur la fréquence du mode fondamental des ondes sonores sont aussi étudiées.

ABSTRACT

This paper reports on the development of a low-cost, rapidly deployable sensor for surveying live sewers for blockages and structural failures. The anticipated cost is an order of magnitude lower than current techniques. The technology is based on acoustic normal model decomposition, the processing algorithms predicting the extent and geometry of the pipe deformation. The instrument emits short coded acoustic signals which are reflected from any sewer wall defect. The signals include Gaussian pulses, sinusoidal sweeps and pseudo-random waveforms.

The effect of the water level on the frequency of the fundamental mode has also been investigated. It has been shown that the technique can be adapted to work reliably both in small section (75mm) pipe and in relatively large (600mm) sewer pipes.

KEYWORDS

Acoustic, blockage, condition, detection, sewer.
INTRODUCTION

In the UK the underground sewer system totals some 300,000 km in length with a replacement value of £104 billion. In England and Wales, the economic regulator OFWAT imposes a duty on the privatised water companies to maintain the condition and serviceability of this asset. Current visual technologies are limited by cost and time – new technology is needed that will work quickly and economically to permit ongoing programmes of pro-active maintenance to be carried out cost-effectively across the whole of the asset base.

Traditional CCTV techniques are not the ideal means of regularly checking for progressive operational deterioration, being relatively slow, expensive and the analysis of the images subjective. Analysis of repeated CCTV surveys of the same sewer systems has shown that up to 20% of defects can “disappear” with time, even though there has been no interventions (Korving and van Noortwijk, 2006). A better alternative is required to provide objective measure of current operational condition which will allow the operator to show that condition is stable and whether a change in the on-going level of service is needed. Image analysis systems for CCTV systems are now being developed to try and remove the subjectivity in the analysis of the images, however these systems still require the CCTV camera to travel through each sewer pipe (Fischer et al. 2006).

The structural condition and rate of deterioration is important because there is increasing pressure for water companies in the UK to improve their knowledge of sewer condition, asset lives and failure modes. The National Audit (NAO, 2004) concluded that “Companies should develop a clearer understanding of the rate of deterioration of their sewerage network assets”. In May 2004 The Public Accounts Committee of the House of Commons concluded that the way in which Ofwat and the water companies manage the structural condition of sewers should be improved [2]. Two key recommendations were: (i) “Ofwat should require companies to include the same sewers in its regular five year asset inventory assessments”, and (ii) “Ofwat should develop measures which provide an indication of the future condition and performance of sewer networks”: In MD161 [3], Ofwat said that “Each company needs to demonstrate how the flow of services to customers can be maintained at least cost in terms of both capital maintenance and operating expenditure, recognising the trade off between cost and risk”.

The current technology is insufficiently sensitive to determine the small changes that, over time, lead to decay and eventual failure. In this respect, it should be noted that the deterioration of condition and deterioration of serviceability do not occur at the same rate. Figure 1 illustrates how it is often the case that a sewer may be serviceable even when its condition has seriously decayed. The problem is that if attention is focussed on the sewer only when its serviceability has substantially decayed it is probably too late to rehabilitate the sewer. Expensive and disruptive renewal is then the only solution. This paper reports on a system that can measure the progress of the sewer along the condition curve so that rehabilitation can be carried out in the right place at the right time in order to ensure that whole-life costs are minimised.
SENSOR CONCEPT AND INITIAL TESTING

The measurement technique is based on the analysis of reflected acoustic signals, as these reflections carry sufficient information to identify structural defects and sediment blockages. The sound propagation in a pipe is a relatively straightforward problem if the diameter is much smaller than the acoustic wavelength (d≪λ) and the acoustic impedance of the fluid (e.g. air) within the pipe is much less than that of the pipe wall (e.g. concrete). Realistic sewer pipes are commonly filled with layers of porous sediment and their diameter is often comparable to the wavelength at audio frequencies. If the cross-section of the sewer pipe is large in comparison with the acoustic wavelength, then sound waves can travel in different directions and such a pipe represents a waveguide which supports a set of so-called normal modes.

The signal analysis technique used in this study is based on the acoustic normal modal decomposition in which the reflected strength of individual cross-sectional acoustic modes in the sewer pipe is analysed to detect the position and extent of a blockage or structural damage. A theory for modal propagation has been used to develop an instrument prototype which can be deployed rapidly in a live sewer. The prototype consists of a microphone, a speaker and electronic circuits to interface with a computer for digital signal processing (DSP) (fig. 2). This instrument emits short coded acoustic signals (e.g. Gaussian pulses, sinusoidal sweeps or other special waveforms) which are reflected from any defects of the sewer wall and recorded for future processing. The processing algorithms are based on the temporal windowing and Fourier analysis so that the temporal and frequency response can be linked directly to the extent and geometry of the sewer pipe deformation.
Many experiments have been carried out first in a 75 mm diameter, 3.75 m long plastic pipe in the laboratory to study the feasibility of the sensor concept. Due to the impedance mismatch between the end of the pipe and the open space a considerable amount of the transmitted signal is reflected back and so can precisely define the length of the pipe. This type of measurement can also find the location of an object placed inside the pipe. The prototype sensor has also been placed in a sloping 600mm diameter, 20m long jointed concrete sewer pipe located in the laboratory. It is shown that the reflected acoustic signature of this length of sewer pipe can be collected under a minute. The collected data can then be used to detect the location and extent of a minor change in the sewer cross-section which results from sediment built-up, sewer structural deformation and water level fluctuations. Given that the sensor concept was shown to work, further more systematic testing was carried out to investigate the effects of the water level and any blockage and its extent on the accuracy of the method. It will be shown that the technique can be adapted to work reliably both in small section (e.g. 75mm) and in relatively large (e.g. 600mm) sewer pipes.

2 EXPERIMENT DESCRIPTION

2.1 Hydraulic setup

Different hydraulic conditions are simulated in the 600 mm diameter, 20 m long jointed concrete pipe. Figure 3 shows a schematic diagram of the pipe system used for acoustic measurement. The discharge rate in the pipe is controlled by a butterfly valve attached to the upstream end of the pipe. There is a gate at the downstream end of the pipe which is used to adjust the water slope for different discharges. The slope of water level can be monitored by a multi-port manometer which has tapping points every 2m along the pipe.

2.2 Detection of section joints and blockage

The sensor concept has been implemented in the concrete pipe as shown in figure 3 by placing the sensor at the end and on the top of the concrete pipe. Different types of signals were sent through the pipe and the reflected signals were measured and
analysed through a pc interfaced with the sensor. The measurements have been taken for empty pipes, and when the pipe contained spherical blockages, of varying diameters (150-300 mm), positioned at different places along the pipe. Data from the reflections was used later to identify the location of the joints of the pipe and the spherical blockages.

2.3 Detection of water level

To vary the water level in the concrete pipe the inflow system contains a butterfly valve. By controlling the butterfly valve and the downstream gate different water levels have been achieved and acoustic sensor has been used to measure the reflected signal for each water level.

3 RESULTS

3.1 Object detection in a 75mm diameter pipe

A Gaussian pulse with a centre frequency of 2KHz and 20% bandwidth was used to excite the speaker placed at the end of the pipe. A 20mm×40mm×60mm wooden block was placed approximately 3m along the pipe.

Figure 4 shows the microphone response from the initial pulse at 30ms, and from the object at 50ms. The excitation pulse is below the fundamental frequency of the pulse and results in a well defined echo from the object.

![Figure 4 Acoustic response from an object within a 75mm diameter pipe](image)

Figure 5 shows this response as a spectrogram, where the frequencies are shown on the ordinate axis with the time shown on the abscissa. It provides a visualisation of the power content of different frequency packets. A red colour indicates areas of frequencies of high energy content, whilst blue indicate frequencies with low energy content.

The figure shows that although there is some banding at the start and end of the initial signal, it is compact in both frequency and time. The echo signal appears to have reduced frequency content below 2kHz but does not show any signs of dispersion.
Above the fundamental frequency, the phase velocity varies with frequency (Morse 1986). Also the phase velocity of a wave with a single frequency can vary depending on which mode the pure tone is travelling.

The object position can simply be determined from the temporal position of the echo. The distance from the speaker to the object and back to the microphone is the temporal position, with respect to the emitted signal, multiplied by the speed of sound for that mode. The speed of acoustic waves in air for frequencies below the fundamental resonance is approximately 340 m/s. In general, larger objects will produce larger responses, although the size and frequency spectrum of the response also depends on the object material characteristics. The fundamental frequency of the empty sewer pipe is approximately 8 times lower than that of the 75mm pipe. However the fundamental frequency varies with water depth.

3.2 Water level prediction within a large concrete sewer pipe

The 600mm diameter sewer pipe was filled with different depths of water. The speaker was excited with a chirp signal and the acoustic response of the pipe was recorded using a standard microphone. The frequency spectrum of the response when the pipe is filled to approximately 40% of its diameter is shown in figure 6. The acoustic response for seventeen different water levels was taken in steps of 20mm.
The resonance between 100Hz and 350Hz is caused by the speaker system. The fundamental mode resonance of the pipe is seen at approximately 600Hz. The fundamental frequency can be verified using finite element modelling (Yin 2003). However, the spectrum is complicated by additional resonances, caused by the inlet and outlet boxes at the ends of the pipe. To reduce the effect of the external influences the spectrum is smoothed by low pass filtering with a cut-off frequency of 4kHz. The result of this processing is shown in figure 7.

The peak frequency is read from this smoothed spectrum and is plotted in figure 8 for various water levels in partially filled pipes.
It can be seen that the central frequency of the fundamental mode rises linearly with water depth. The results are repeatable. This demonstrates that the data from the reflected acoustic signal can be used to measure water depth remotely.

4 CONCLUSIONS

There is a clear need for a cheap, robust system to detect sewer blockages and sewer condition. Acoustic sensing is one way to achieve this. By combining a simple audio system with processing based on the modal analysis of the system geometry, it is possible to detect objects in pipes. It has been shown that the technology works on both small 75mm diameter plastic drain pipes, and large 600mm diameter concrete sewer pipes. It has also been shown that it is possible to determine water level within the pipe by analysing just the fundamental modal resonance of the system.

5 LIST OF REFERENCES