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Detection of Leak Holes in Underground Drinking Water Pipelines using Acoustic and Proximity Sensing Systems

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Abstract

Unwanted water leakage due to leaky pipelines is almost always pertaining in drinking water supply networks. Since the supply networks are usually underground this problem becomes more challenging. To help resolve such problem, this paper studies the possibilities of remote monitoring and detection of unwanted leaks in the underground drinking water pipelines from surface using an acoustic and proximity sensor systems. The acoustic and proximity sensing uses audio and vibration noises produced during burst of water from the leak in the pipeline. A modeled water distribution system with known leaks is first used to test the performance of these sensor systems and then applied in some pilot areas of the public water supplying pipeline system of Kathmandu, popularly known as Kathmandu Upatayaka Khanepani Limited (KUKL). Results from both modeled and the real distribution systems confirm the performance of sensor system to identify a numbers of the underground leak hole remotely from surface, which are later confirmed by digging with KUKL authority. The paper presents the result of one of those studies which provides a proof of remote tracking of underground water supply leaks. Moreover, the research indicates that if a distributed network of such sensor system and a point-to-point dedicated communication networking is considered, a real-time automated remote monitoring of a water distribution networks over a large area can be possible to track any unseen leaks in underground pipelines.

Keywords: Water leak detection and localization, acoustic and proximity sensor system, Fast Fourier Transform.

Introduction

Drinking water scarcity problem exists almost everywhere in these days. The reasons behind it are basically the lack of water resources and the lacks in proper management of the available water supply system by the concerned authorities. Also, significant amount of water is lost due to leakage pertaining in the system. For example, in the context of Nepal, approximately 40 % of drinking water is lost due to leakage, indicating a poor distribution system in the Kathmandu[1]. Proper management of available water supply with automated monitoring system is therefore highly desirable to address the crux of drinking water scarcity problem. Recently, information and communication technology (ICT) has gained interest in the field of drinking water management also for the automated monitoring. Various researches are undergoing starting from designing of sensor systems, systems for data logging and processing and flow control systems[2-8].

In the context of Nepal, the existing water flow monitoring system is an age-old manual technology. This research, therefore, aims to explore an automated system for remote sensing of underground pipelines that help monitoring water flow and detect possible water leaks. Specifically, the study examines the performance of an electromagnetic sensing system, namely an acoustic and proximity sensors, for surface monitoring and detection of possible leaks in the underground drinking water pipelines. The basic principles behind it is that the acoustic and proximity sensing uses audio and vibration noises produced during burst of water from the leak in the pipeline[4-6].

To test the performance of these sensor systems, a modeled water distribution system with known- leaks is first considered. Then a number of surveys were conducted over some pilot areas of public water supplying pipeline system of Kathmandu, popularly known as Kathmandu Upatayaka Khanepani Limited (KUKL), as case studies.

Methodology

The research plan starts with the study and implication of various sensor systems, data logging communication and processing systems for water flow monitoring and leak detection. First, the study considers a prototype of sensor systems, namely the acoustic and proximity sensing, conducts their performances with a modeled water distribution system (as shown in figure-1) in the campus area of the Institute of Engineering (IOE), Pulchowk Campus[6] and then the modeled system is tested in some pilot area of the public water supplying pipeline networks of the KUKL. Overall, the research is divided into the study of the sensor system networking, its prototyping, modeling, testing and verifications through field observations.

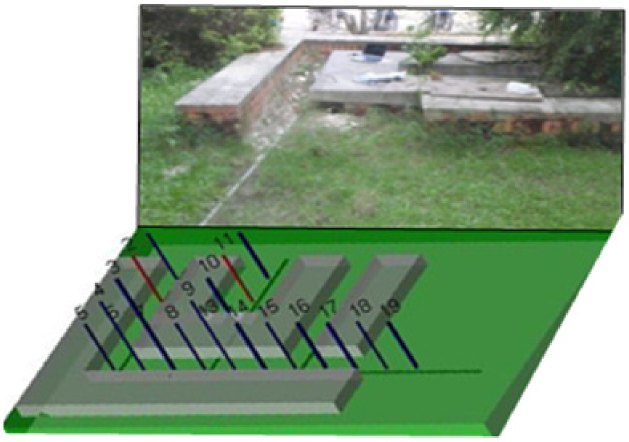

Figure-1
Conceptual illustration of the modeled water pipelines (bottom) and implemented ground surface (top). Points 1 to 19 are the test points (TP), where TP2 and TP11 are artificial leak holes

Instrumentations: Among various techniques to detect the underground water leaks, acoustic sensing equipments are simple and sensitive enough to record the stress waves created by leakage in high pressure pipes. Knowing how these waves vibrate pipe is then very important in leak source localization, where two listening devices installed at two different points are used to identify the leak location[4-6].

Acoustic Sensing: The core of the leak detection unit used here is of Adler Technology (Model: ADL-III), which consists a ground sensor, a processing/controls box and a headphone. The sensor is placed above the pipeline on the ground to pick up acoustic noise created by underground leakages. The output of the sensor can be listened via the headphone. Parallel recording of the sound levels are fed and analyzed by a computer system via its audio port. Data are sampled at highest sampling frequency possible in the computer i.e., the sampling frequency for Fast Fourier Transform (FFT) is of 44.1 KHz. Since the same sensor has to be used for all the locations, the data is recorded in a time window. Different timing windows are tested. The timing window of 1 second is long enough to record all the important variations and yet short enough to take the readings quickly[6].

Since the leak points generate acoustic signals of higher amplitude, the average amplitude and the energy of the signal at leak points must also be high. However, the acoustic signal does not have any dc component and hence the average of the amplitude is always zero. The solution is the average of the absolute value of the signal intensity. Further, since the average intensity of the signal is zero, the energy of the signal is equal to the variance. With these defined parameters, the leak location is the point which has both intensity and energy distinctly higher than its neighbors. The acoustic data are recorded in relative scale and same relative scale is used throughout the analysis[6]. The measurement set up of this sensor system is illustrated in figure 2.

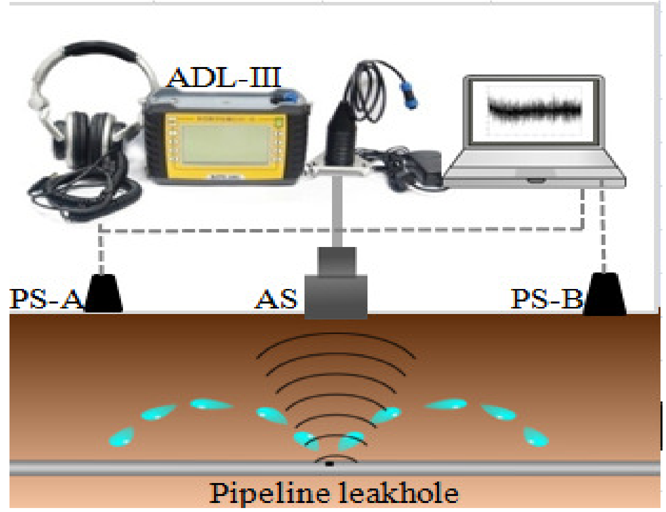

Figure-2
Conceptual illustration to show a leak detection using an acoustic sensor (AS) of ADL-III and the leak localization using two proximity sensors (PS-A and PS-B) along an underground drinking water pipeline system

Proximity Sensing: There are various methods for localizing leaks. These devices can include pinpoint listening devices directly on the ground. Once a leak occurs in a pipeline, water rushes outside through the leak creating a pressure wave with frequency in audio range. Energy generated from the leak is transmitted within the pipeline through the water, which in turn produces mechanical vibration in the surface of pipeline. An underground acoustic sensor attached on the outer surface of the pipeline can be used to pick up these vibrations. Correlating devices like pickup accelerometers listen at two different points to identify the leak location. An underground acoustic sensor attached on the outer surface of the pipeline can be used to pick up these vibrations.

A leak in a section of a pipe can be localized by using two pickup sensors placed at the opposite ends, as shown in figure-2, to record the time difference of the signal. If L is the length (in meters) of the section, v is the velocity of sound in the pipe (in meters per millisecond) and T_d is the time delay (in milliseconds), then leak position, x (in meters) can be derived as, $x = (L-vT_d)/2$. The signal received from the sensor is squared and made smooth using a low pass filter to obtained signal energy function. Then, a correlation function is calculated using the two energy signals. The value of time at which the value of correlation function is largest gives the time delay.

Results and Discussion

Test measurements are performed first with the modeled pipelines to confirm the performance of the sensor systems. The field study is then performed around some pilot areas of KUKL's water distributing pipeline networks. The recorded raw data of the seeping water though the leak are sampled and converted from analog to digital form.

The signal intensity is determined by averaging the absolute value of the recorded signal with individual sample of 44.1 KHz along 1 second sampling window. Since the signal does not have any dc component the average intensity is zero; and the energy of the signal is equal to the standard deviation. These parameters approximate the leak locations that correspond to both intensity and energy distinctly higher than its neighbors. The acoustic data were recorded in relative scale and same relative scale is used throughout the analysis.

Figure 3 is an evidence of the model test of leak location using acoustic sensor. For leak detection, different test points (TP) are marked along the pipelines with different spacing. The sample spacing is taken to be 12 inches. Nineteen tests points are selected and they are numbered from 1 to 19 as shown in the figure1. TP 2 and TP11 are the actual leakage points in the setup, with leak in point 11 (diameter = 5 mm) larger than that in point 2 (diameter = 3 mm). As it is evident from figure 3 the highest value of both intensity and energy at a test points corresponds to a leak point as modeled.

For the localization of the leaks a proximity sensing is applied in the same system. Sample signals taken from two proximity sensors are shown in figures 4a and 4b from two test points. The recorded signals are further analyzed in terms of energy function and correlation functions, where the maximum correlation is found at 0.262 ms. The results are indicatives to approximate the local leak location. This approximation, however, is not very exact to pinpoint the leak. It is because the measurements are highly affected by background noise and usually distorted. Since he background noise in the field observation are almost always very high are limited our proximity analysis only to the modeled pipelines.

One of the results obtained real underground water distribution system around Pulchowk Campus area is shown in figure 5, where the surveyed route and the detected leak point are displayed. For acquiring the exact surveyed geographical locations a Garmin e Trex Global Positioning System (GPS) module is used. This GPS module has easy interface and can store up to 500 waypoints. The exact location and the altitude of the points are noted and then are plotted over the geographical map.

The intensity and energy readings of the sampled test points are shown in Figure 6(d). Samplings are done at twelve points. Out of the twelve test points, the eleventh test point (TP11) shows the maximum signal intensity and maximum signal energy. Thus, it is confirmed that the leak must have occurred around TP11.

The data are further examined with Fast Fourier Transform (FFT) analysis in the frequency range 70 Hz to 1800 Hz as shown by figures 6(a), 6(b) and 6(d) for TP10, TP11 and TP12, respectively. This frequency range is chosen because it is the working frequency range of the acoustic sensor. The result evidences strong frequency components lying in the frequency range from 70 Hz to about 400 Hz. As the sensor moves away from the site of leak (TP11), the frequency components get weaker meaning to away from leaking noises. From Figure 6, it can be seen that TP1 is far most from the leakage area, and TP11 is right above the leakage area. However, by visualizing the signal intensity at the various leak points it can be seen that there are dips in signal intensity like at TP6, TP8 and TP10 even though these points are closer to the actual leak point. A possible explanation for the occurrence of this anomaly is that a noisy environment surrounded our sensor. Our sensor was picking up people's footsteps, and the tremor of vehicles running nearby thereby degrading the signal-to-noise ratio of the input.

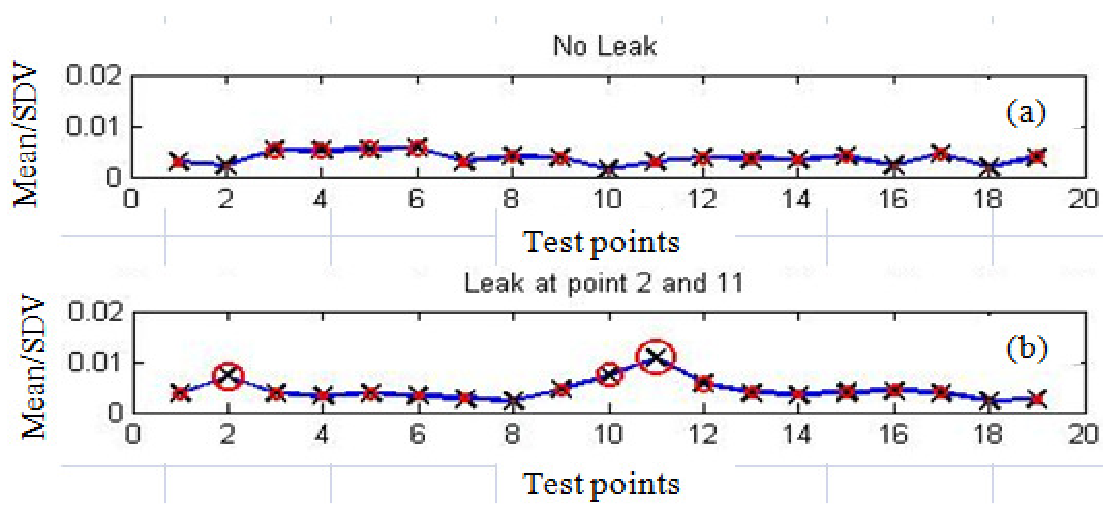

Figure-3

Normalized mean (solid line) and standard deviation (circle) measured by acoustic sensor along the modeled test points. (a) Case of no leak, and (b) During leaks at points 2 and 11.

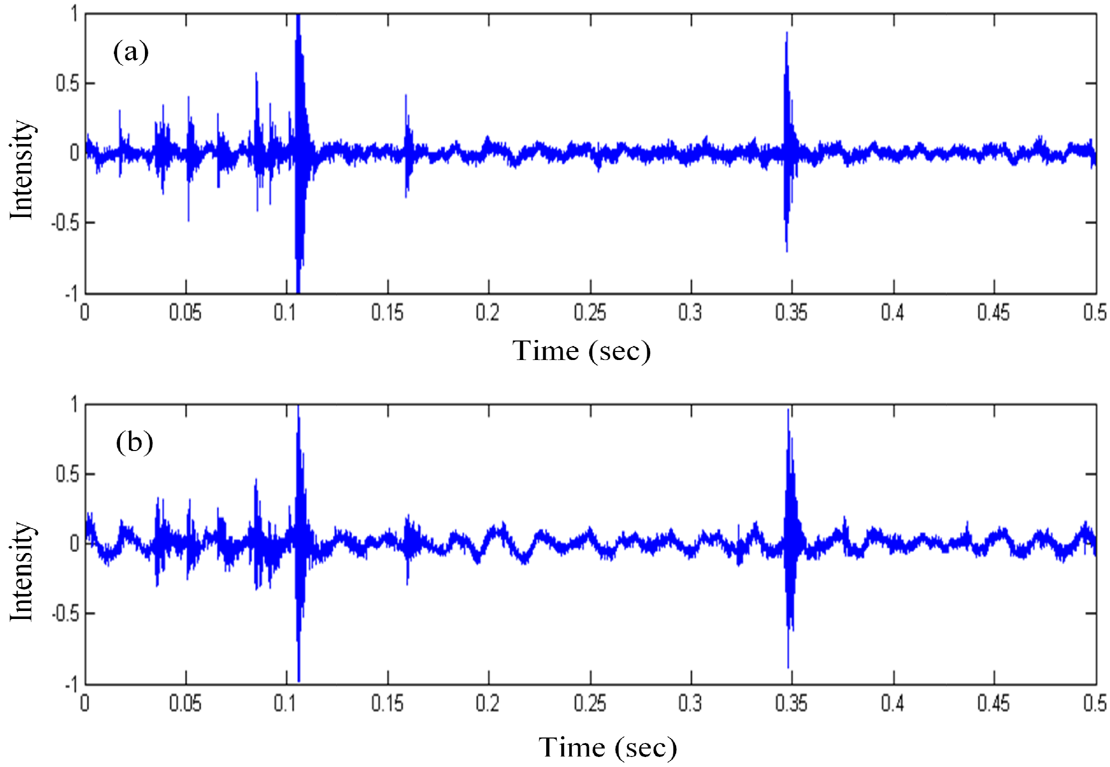

Figure-4
Recorded raw signals obtained from proximity sensors (a) from PS-A and (b) from PS-B

Figure-5
(left) Map showing the surveyed domain and the test points (TP). (right) Detected underground leak hole at TP11

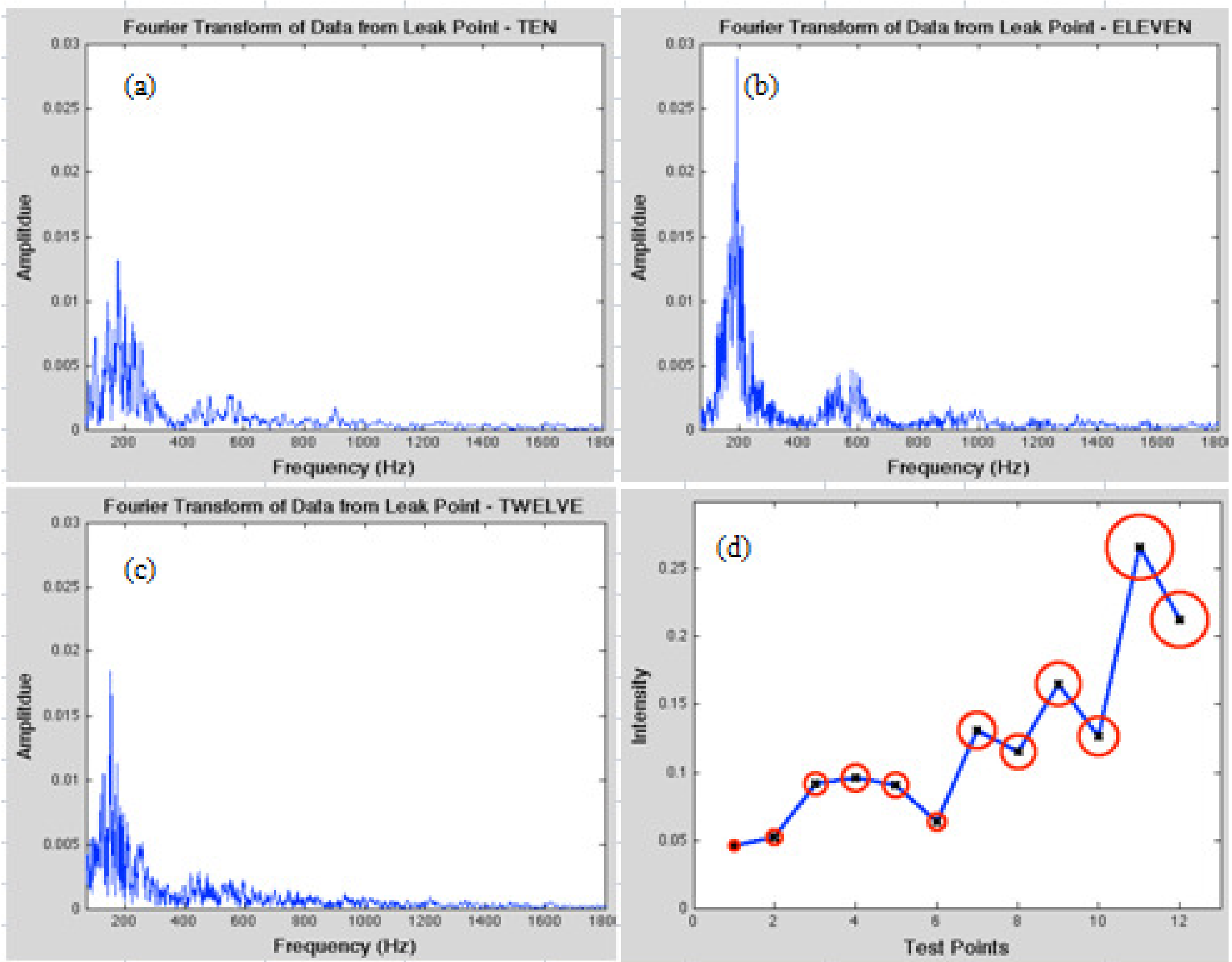

Figure-6

FFT of the recorded data at different test points of (a) TP10, (b) TP11 and (c) TP12. (d) Intensity (solid line) and energy (circle) of the recorded caustic signal at TP1 to TP12

Conclusion

Water distribution systems almost always suffer due to leakages. As the water supply networks are usually underground this problem becomes more challenging. To help mitigate the leakage problem, this study examines and explores the performance of an acoustic leak listening device and proximity sensors. The test measurements are performed first with the modeled pipelines, which confirm the performance of the sensor systems. The field study is then performed around some pilot areas of KUKL's water distributing pipeline networks. Results from the real distribution systems also evidence the performance of sensor system to identify the underground leak hole remotely from surface, which are later confirmed in the field by digging with KUKL authority. The results presented here indicate that if a distributed network of such sensor system and a point-to-point dedicated communication networking is considered, a real-time automated remote monitoring of a water distribution networks over a large area can be possible to track any underground leaks.

Acknowledgements

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