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Review

Multi-tier method using infrared photography and GPR to detect and locate water leaks

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ABSTRACT

This paper presents newly developed method for detecting and locating leaks in water distribution networks utilizing two detection techniques; ground penetrating radar (GPR) and infrared photography (IR). The experimental work and field investigation were carried out over 2 years in three locations in City of Doha, Qatar to capture 115 IR image frames and 23 GPR image frames. Firstly, GPR technology is utilized to accurately define location of buried pipes. After locating these pipes, IR images are collected for simulated and actual leaks. The developed algorithm segments each image into leakage and non-leakage areas and the centroid of each leakage is calculated using Green's theorem. Subsequently, GPR images are introduced as a second layer and overlaid with IR images to compare pipes location with leak location. The method was successfully applied to detect simulated and actual leaks in summer and winter seasons with small margin of error (2.9–5.6%) in estimating leakage areas. When examining the investigated four operating conditions, it was found that the developed method can predict leaks in a more reliable way if the camera height is 2 m and the speed is 1.65 m/s in both simulated and actual leaks. The newly developed method is robust and can aid operators and city engineers in detecting and locating water leaks with high accuracy.

Contents

1. Introduction

The control of water losses has been an activity associated with water distribution in the last decade to minimize service interruptions and damage to surrounding properties and infrastructure networks. Most of the leakage management related methods developed so far can be broadly classified as follows: 1) leakage assessment methods which are focusing on quantifying the amount of water lost; 2) leakage

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detection methods which are primarily concerned with the detection of leakage hotspots and 3) leakage control models which are focused on the effective control of current and future leakage level. This paper is focusing leakage detection and localization methods.

Roughly, these methods can be grouped into: 1) acoustic logging [1–4], 2) step testing [5,6], 3) ground motion sensors and ground penetrating radars [7–9], 4) infrared technologies (IR) [10,11] and 5) transient test based techniques (TTBT) [12–14]. However, these methods are considered to be expensive and time consuming as they are limited to certain pipe materials and/or affected by traffic and population densities except for TTBT [7,12]. Current state of the art for leakage detection focuses on two aspects; 1) exploring the use of thermal and acoustic methods to approximately estimate leakage location [7,15] and 2) conducting experimental studies in one or more weather seasons to determine the optimal operation conditions for data collection [15–18]. For IR technologies, previous research efforts didn't attempt at; 1) conducting experimental studies in extreme hot weather conditions to determine the optimal operation conditions for data collection, 2) clustering captured infrared images into leakage and non-leakage areas, 3) estimating area of each leakage from analyzed infrared images, and, 4) comparing estimated leakage areas with actual leakage areas. TTBT can be used on single pipelines only because transit waves may reflect from pipe's features not from the leak [12,13]. The technique also requires monitoring of the physical parameters (i.e. pressure) to be analyzed by a form of mathematical modeling [14].

The objective of this paper is to develop a method to circumvent the above stated limitations by; 1) utilizing a multi-tier detection technology; ground penetrating radar (GPR) to detect pipes location and infrared photography (IR) to detect leaks, 2) developing an image segmentation technique to estimate leakage area and estimate its centroid using Green's theorem and 3) test the developed method against simulated and actual cases. The novelty of this paper with respect to the above mentioned research efforts lies in: 1) exploring the use of multi-tier method to detect and locate water leaks, 2) developing and testing an automated algorithm to detect and locate water leaks based on captured IR and GPR images by utilizing image segmentation techniques rather than relying on experts' judgments and 3) studying the effect of four operating conditions on detecting and locating leaks in water pipelines using three case studies.

2. Background

As mentioned early, leakage detection and localization methods can be grouped into five groups; 1) acoustic logging technologies, 2) step testing technologies, 3) ground motion sensors and ground penetrating radars (GPR), 4) infrared technologies (IR) and 5) transient test based techniques (TTBT).

In acoustic logging (AL), vibration sensors and hydrophones are distributed along the pipe length and attached on the pipe fittings [3]. These hydrophones are used to collect measurements about the propagation of acoustic waves in the water pipe [1]. AL can detect the approximate location of water leaks but it is not suitable for pinpointing their exact location. The preferred time for collecting data using AL is at night times between 02:00 am and 04:00 am to minimize the effect of background noise on collected data [4]. AL can cover a wide area if operators have considerable experience in detecting water leaks using such technology [14]. However, AL is affected by background noise which can limit the ability of detecting and locating quiet leaks [14, 15]. Also, researchers have questioned the economic feasibility and reliability of AL techniques [4,14,15].

Step testing was considered as an effective technique for locating leaks by water utilities until 1990s when it was substituted by acoustic logging [5,6]. In step testing, the water distribution network is divided into subnetworks and each subnetwork is tested by the systematic closing of valves during the period of minimum night flow [6]. However, step testing suffers from the following shortcomings; 1) it may generate health and safety concerns because of backsiphonage (i.e. the risk of infiltration of ground water into water pipelines), 2) customers may suffer from water outages for a period of time as a result of closing water valves and 3) most likely water distribution networks are designed and constructed without taking into consideration the possibility of using step testing to locate future water leaks [2].

Ground penetrating radar (GPR) inspection is a geophysical imaging technique used for subsurface exploration and monitoring and it is widely used within the forensic, engineering, geological, mining and archeological communities [8]. In GPR, electromagnetic waves are transmitted from the antenna and subsequently reflected by the underground objects. The reflected waves will be received by the antenna and recorded to create a profile of the subsurface underneath. Water leaks can be detected by visually inspecting the generated GPR profiles. The generated GPR profiles will show irregularities in inspected pipelines due to underground voids created by leaking water [7,9]. This methodology is a suitable for detecting leaks in metallic pipes with large diameter [19]. Nevertheless, GPR is labeled as a time consuming methodology and cannot give reliable results because it doesn't pinpoint the exact location of the leak [8].

For IR technology, it measures the emitted IR radiation from an object and therefore it will detect any thermal contrasts at pavement surface due to leaks in water pipes [17]. When compared to the above discussed techniques, it is less time consuming and hence more cost effective for investigating large areas [20]. It is also independent of pipe material type and pipe size with no limitation on the required testing time (i.e. day or night time) [15]. The radiation measured by IR camera is affected by the object temperature, weather conditions, soil, and pavement surface conditions. Weil [21] utilized IR to detect leaks in sewer pipes by visually examining IR images of affected areas of the sewer pipe. In 2007, a study was carried out by the National Research Council (NRC) in collaboration with the American Water Works Association (AWWA) to detect water leaks using IR [7]. The study was limited to simulated leaks and was performed in the fall semester during nights to test the efficiency of IR at the NRC leak detection facility. Subsequently, Fahmy and Moselhi [17] investigated the efficiency of IR in detecting real leaks by considering factors beyond those considered in previous research efforts. The authors considered a wide range of weather and light conditions in three different locations with varied groundwater levels. They also considered the existence of adjacent sewer pipes, different IR camera setup, and vehicle speed, along with their impact on the accuracy of the results obtained. Hiasa et al. [19] presented an experimental study to determine the most suitable time window to collect data from an object by using an IR camera.

In transient test based techniques (TTBT), a transient wave is generated and the traveled transient wave along the pipeline is then reflected at the leak [11]. The measured pressure trace is utilized to identify the location of the leak. TTBT can be used to estimate the size of the detected leaks in both plastic and metallic pipes [13]. However, Puustet [2] pointed out that TTBT was deployed and tested on single pipelines as transit waves may reflect from pipe's features not from the leak [12,13]. The technique also requires monitoring of the physical parameters (i.e. pressure) to be analyzed by a form of mathematical modeling [14].

In general, the above sited research efforts for detecting water leaks using IR were limited to:

1) Simulated leaks: the majority of the above stated work was performed on simulated leaks except for Fahmy and Moselhi [17].
2) Detecting approximate location of leaks: the above sited research efforts didn't provide computational models for calculating area and centroid of each leakage using image segmentation techniques.
3) Cold weather conditions: the use of IR technology was not investigated in extreme hot conditions.