Detecting and locating leaks in Underground Water Mains Using Thermography

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Abstract

Water systems all over the world experience water losses. Leakage is the most common reason of water loss. Problems associated with water main leaks are a growing concern around the globe. These problems include water and energy loss, in addition to considerable properties damage. In current practice, not all water leaks can be detected due to intensive time and expensive cost associated with the leak detection process; consequently, some leaks are still occurring and lead to problems mentioned above. Management of water leaks can be improved if leaks can be detected effectively then rectified efficiently. This paper presents a study conducted for detection of water leaks, and identification of their respective locations in underground pipelines using Thermography IR camera. The paper describes the field work and the experimental protocol, which were carried out over two years in three different locations in greater Montréal (Canada) area in order to investigate factors that affect the applicability and limitations of the IR technology used in this study.

Keywords: Water pipelines; Thermography; Water Leak detection; Failure investigations

Introduction

Thermography (IR) camera measures and images the emitted infrared radiation from an object. It can detect thermal contrasts on pavement surface due to water leaks. In addition, it enables relatively large areas to be investigated effectively in less time and consequently less cost comparing to currently leak detection methods. It is also independent of pipe type and size. Also, it can be used in day or night time. These advantages make using IR camera overcomes limitations associated with currently leak detection methods. This paper presents a study conducted to investigate the factors that affect the use of IR camera in detecting and locating water leaks in underground water mains such as weather conditions, soil and pavement surface conditions, ground water level and distance of sensor (i.e. IR camera) from source. The study also focuses on the impact of camera setting and vehicle speed on which the camera is mounted on the accuracy of the results obtained. Case example is presented to illustrate the use of the proposed methodology.

Proposed Methodology

The methodology presented in this study is based on intensive literature review, meeting with experts, and on the analysis of actual data collected from three municipalities in greater Montreal area; Pierrefonds, southwest, and downtown Montreal (Canada). The development of the methodology involves five major steps: I) identification of factors that affect thermal contrast at pavement surface; II) field investigation and on site experimental work; III) analysis of the data obtained in order to determine the most suitable conditions of using IR camera for the detecting and locating water leaks, IV) establish the relationship between the detected leakage area at pavement surface and the location of leak in the water main being tested; V) validation of the proposed methodology by comparing leak locations detected by the proposed system and by acoustic-based methods. Figure 1 shows the proposed methodology.

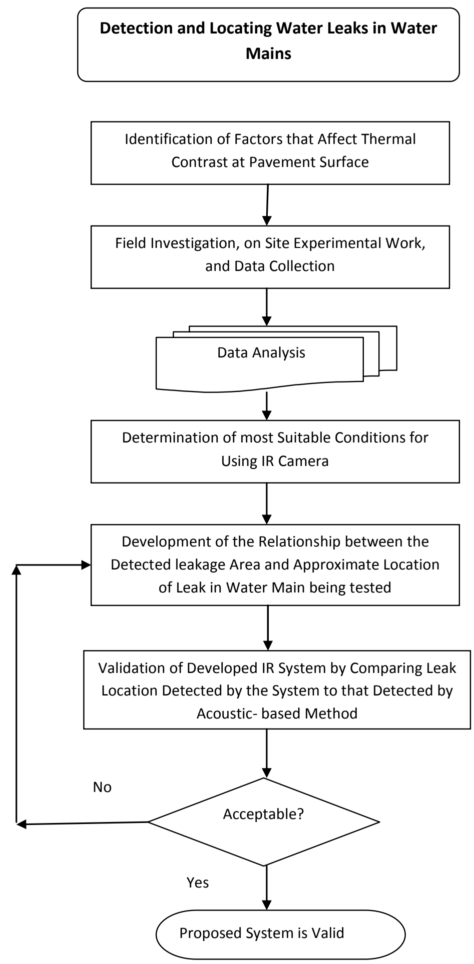

Figure 1: Proposed Methodology

Thermography (IR) Camera System

The ThermaCAM S 60 infrared condition monitoring system was used in conducting a set of field experiments. The system consists of an infrared camera with a built in 24o lens, a visual color camera, a laser pointer, and infrared communications link (FLIR SYSTEMS 2004). This system provides real time high resolution color images in both infrared and visual modes. The visual mode was used to check the existence of any foreign bodies on the pavement surface, which might affect thermal contrast. To document the thermal variation on pavement surface due to water leaks of pipes below ground it is possible to capture and store images on a removable flash card. The captured images that have sequential numbers can then be analyzed in the field using the developed methodology to determine approximate locations of leaks. Figure 2 shows the thermal contrast between areas with lower temperature (dark areas) that represent pavement surface temperature in its natural state (i.e. without leaks) and the bright areas that indicate water leak.

I. Factors That Affect Thermal Contrast at Pavement Surface

Based on a comprehensive literature review, seven interviews with experts, and preliminary field investigation it became clear that the following two major factors affect the thermal contrast at pavement surface.

1. Heat Balance at Pavement Surface

At the top of the pavement surface, four modes of heat transfer are considered: conduction into the pavement layer, convection, solar absorption, and grey-body irradiation to the surrounding (ASHRAE 1981; Hutcheon and Handegord 1983; Bentz 2000, Schlangen 2000). For irradiative heat transfer at the top pavement surface, two contributions are considered the first is radiation absorbed from the incoming sunlight. The second is the emission of radiation from the pavement to the sky (McCullough et al. 1999, Loomans et al. 2003).

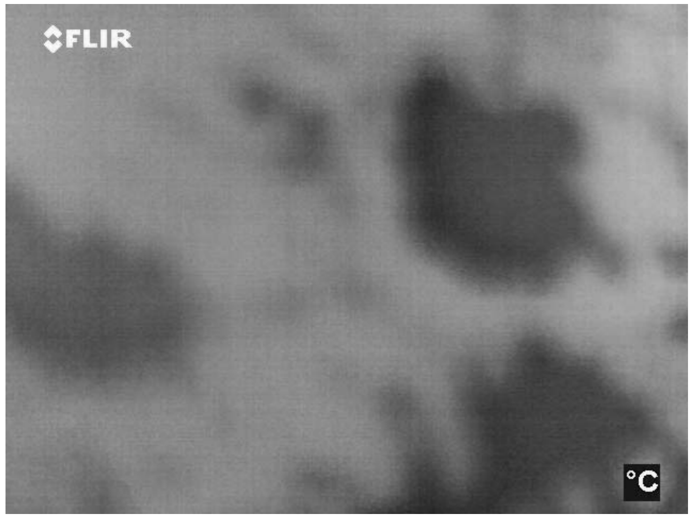

Figure 2: Thermal Contrast at Pavement Surface due to Water Leak

2. Heat and Moisture Transfer in Soil

Migration of heat and moisture in soil is a coupled energy and mass transport process, which is affected by the field distribution of temperature, pressure, and velocity (Liu et al. 2005). Soil heat transfer in the unsaturated zone of the soil is the sum of fluxes due to heat conduction and convection (Sung et al. 2002).

II. Field Investigation and on Site Experimental Work

Field investigation was conducted using thermography IR camera and the results obtained were compared to the results obtained using acoustic-based system, which will be referred to in this paper as "leak finder". Leak finder locates water leaks by detecting the sound or vibration induced by water leaking from pressurized pipes (Hunaidi et al. 2004).

Preliminary field experiments showed that the moisture level near the pavement surface affects the pavement surface temperature because of its major influence on the thermal properties of the soil. Furthermore, it was found that the thermal contrast detected by IR camera was close to the exact location of the leak detected by the acoustic-base leak finder device. Following the preliminary survey, detailed field investigation and experimental work was conducted in order to determine the thermal performance of water leaks in underground pipelines, and establish relationship between the detected leaking areas and the accurate location of the leaks.

In order to attain these objectives 42 water pipelines were scanned using IR camera. The diameter of these pipes ranged from 150 to 200 mm and their length ranged from 48m to 300 m. The field tests were conducted in down-town Montreal, South-West Montreal, and the Pierrefonds municipalities in Canada. The study presented in this research was carried out over 24-month period from July 2005 to August 2007, and the timing of the fieldwork was selected to represent a wide range of weather conditions in terms of prevailing light, and ambient air temperature. The inspection was also executed throughout a range of cloud cover from clear sky to overcast. This allowed testing the effectiveness of energy transfer between the sky and the investigated pavements. It should be noted that, the measured temperatures using IR camera were compared to those measured using thermocouple device. The average difference in measured temperature was (+/- 2 ^{0}C).

In order to obtain obvious color contrast in acquired images, IR camera set up was adjusted based on number of trials. The distance from the pavement surface to the camera ranged from 1.20 m to 12.0 m. Combinations of various ranges of vehicle speed, on which the camera was mounted, and time intervals of image capturing were carried out. The vehicle speed ranged from 5 km/hr to 20 km/hr and the rate of capturing images ranged from image/2 sec to image/10 sec.

III. Analysis of Data Obtained

Figures 3 shows the relationship found between pipe temperature, average ambient air temperature and average pavement temperature in fall season. As shown in Figures 2 the warmer pipe temperature indicates high possibility in detecting water leaks using IR camera according to Equation 1 (ASHRAE 1981; Hutcheon and Handegord 1983; Bentz 2000)

$$Q_{cond} = K_{cond} * (T_p - T_s) / L \quad (W/m2) \tag{1}$$

Where K cond is the average thermal conductivity of the soil and pavement in (w/m. K), Tp and Ts are the pipe temperature and surface temperature respectively and L is the length of the flow path (i.e. burial depth).

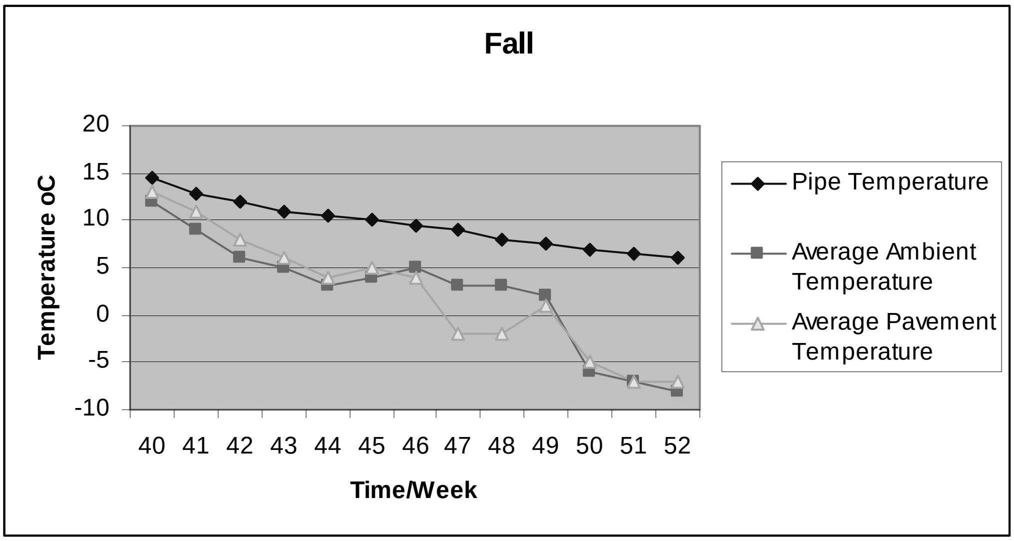

Figure 3: Comparison between Temperatures in Fall Season

Cloud Cover and Prevailing Light

Data collected in this research showed that pavement temperatures under clear sky and/or during day time were consistently warmer than pavement under cloudy condition and/or at night and early morning. As a result, detection of leaks will be more accurate under overcast condition between 11 pm and 6 am.

Change in Thermal Characteristics of Soil and Pavement Surface

Soils close to water leaks experience increase in moisture content and may become saturated. Such change in moisture content changes the thermal characteristics of the soil and makes it more conductive to heat relative to dry soil away from the leak. The soil temperature variation observed in this research through the four seasons indicates that the soil temperature presents higher variation in shallow than in deeper depth. During winter, the average soil temperature of deeper layers is higher than that at the shallow soil depths. It means that, during winter the heat is transferred from the deeper soil depths to surface, while during the summer months it changes direction. This is in agreement with the recent study conducted by Antonopoulos (2006). Also during the winter period, the rate of change in soil temperature under snow cover was less due to low thermal diffusivity and high albedo of the snow. It was found that areas detected that have a thermal contrast on pavement surface decreased with soil surface evaporation during daytime and slightly increases during nighttime.

Infiltration into Adjacent Sewer Pipes

The field investigation and experimental work carried out in this research revealed that more than 40% of the water leaks detected were infiltrated into adjacent sewer pipes, that prevent the moisture movement from reaching pavement surface, consequently, that type of leaks could not be detected using IR camera.

Ground Water Table

The ground water table has a great influence on the use of IR camera; experimental work conducted in the vicinity of Saint Laurence River in Montreal showed that the ground water table was higher than the pipe level. The IR images captured to the pavement surface at this area showed no variation in the thermal properties of the pavement surface.

Distance of Sensor from Source

The impact of the distance from the pavement surface to the camera was studied. Tests were conducted over a range from 1.20 m to 12.0 m. The experimental works revealed that the more the distance between sensor (IR camera) and pavement increases the more the thermal contrast enhances and vice versa. Therefore, more distinction of leakage area was obtained from a distance of 12.0 m from the pavement surface.

Vehicle Speed and Rate of Capturing Images

Combinations of twelve sets represent various ranges of vehicle speed and periodic capturing of images was carried out. The vehicle speed ranged from 5 km/hr to 20 km/hr and the rate of capturing images ranged from image/2 sec to image/10 sec. the best results obtained in terms of distinguishing thermal contrast and accuracy when the vehicle speed was set at 5 km/hr and the rate of capturing images was set at image/2 sec.

Effect of IR Camera Setup

In order to obtain obvious color contrast in acquired images, camera set up was adjusted based on sets of thirty six trials, it was found that the emissivity, palette type, and noise reduction function that reduce clutters, were the most effective parameters. The final selection of these parameters was as following: emissivity was selected based on pavement status ranged from 0.85 for snow cover, 0.90 for dry pavement surface and 0.94 for wet pavement surface. Palette iron was selected, which provides finest contrast and color degradation ranged from blue (i.e. represents lowest temperature) to white (i.e. represents highest temperature). Noise reduction function was activated.

IV. Modeling

The approximate locations of water leaks carried out in this research are based on two major steps:

1. Determination of areas that indicating thermal change at pavement surface (i.e. water leaks)
2. Establish the relationship between detected leaking area and pipe burial depth

1- Determination of Areas Indicating Water Leaks

Twenty five pipelines experienced water leaks were tested using IR camera in order to develop Equation number 2. Applying Equation number 2 the approximate location of leak can be found. Then, the user has to move to that location to determine the entire area that experience thermal contrast.

$$\mathbf{X} = \frac{\mathbf{(N-1) \times 0.28\, S}}{\mathbf{R}} \qquad \mathbf{(2)}$$

Where:

X: approximate location of water leak from the origin point (m)

N: chronological image number

S: average vehicle speed (Km/h)

R: rate of capturing IR image (image/sec)

2- Establish the relationship between detected leaking area and pipe burial depth

Field observations conducted in this research revealed that the detected thermal contrast due to water leak on pavement surface approximately represents a circular base of a cone, which its head represents the location of the leak in the pipe being tested.

V. Validation of Proposed Methodology

The leak locations detected using IR camera for twenty five water leaks were compared to those detected using the acoustic-based leak finder method. The results are shown in Figure 4. As shown in Figure 4 the difference ranged from 1.01m to 2.30m

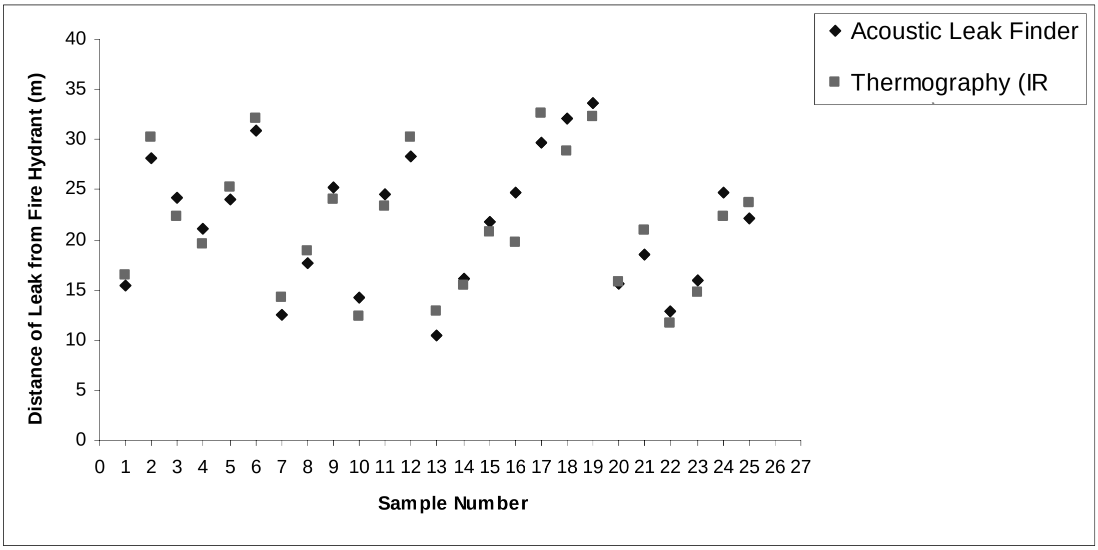

Figure 4: Leak Locations (m) using Acoustic Leak Finder Verses IR camera

Case Example

In this example we consider a 6" diameter CI water main segment, 48.7 m length (i.e. the distance between two fire hydrants), located 1.80 m below the ground in a residential area of the city. The municipality asks for performing a condition assessment work on that pipeline using thermography method (IR camera) and verifying the results by using the acoustic-based leak finder. The inspection team utilized a vehicle with speed 6km/hr and the rate of capturing images was 0.5 image/sec.

Applying the methodology described above the user found that

1- image number 6 showed thermal change as shown in Figure 5
2- The user moved to the location represents image number 6 and perform further investigation.

Appling Eq. 2

$$X = \frac{(N-1) \times 0.28\ S}{R} = \frac{(6-1) \times 0.28 \times 6}{0.50} = 16.80\ \text{m}$$

The results obtained is shown in Figure 5

Summary and Conclusion Remearks

This paper presented a study on the use of Thermography IR camera for detecting and locating leaks of water mains. The study encompassed field investigation and testing as well as modeling development. The field work was conducted on water mains in 3 locations in the greater Montreal area. The IR camera detected successfully number of leaks as a thermal contrast at pavement surface that occurred in fall and spring seasons, while it failed in detecting leaks occurred in summer and winter due to high pavement temperature and the snow coverage, respectively. The thermal contrasts due to water leaks take a shape of near circular cone base. The head of the cone represents the approximate location of leak. However, using IR camera in vicinity of sewer pipe was not reliable. The near optimum diurnal time of using the camera was between 6-8 am. The leaks detected using IR camera was compared to those detected using acoustic- based leak finder method. A case example is presented to demonstrate the use and accuracy of the developed methodology.

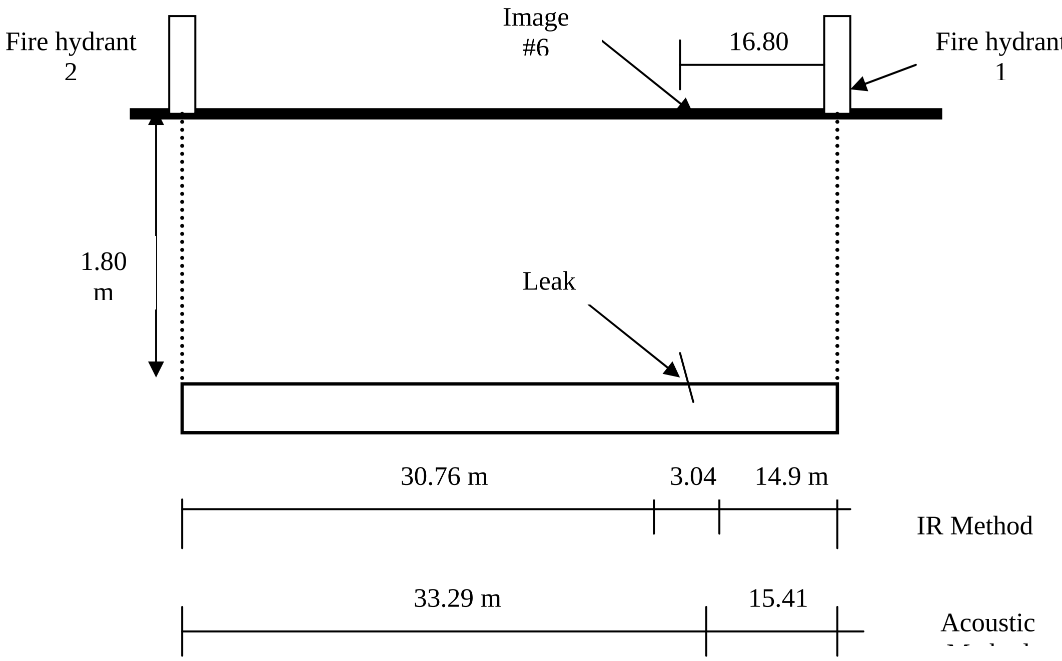

Figure 5: Case Example

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