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Non-Destructive Visual-Statistical Approach to Detect Leaks in Water Mains

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***Abstract*—**In this paper, an effective non-destructive, non-invasive approach for leak detection was proposed. The process relies on analyzing thermal images collected by an IR viewer device that captures thermo-grams. In this study a statistical analysis of the collected thermal images of the ground surface along the expected leak location followed by a visual inspection of the thermo-grams was performed in order to locate the leak. In order to verify the applicability of the proposed approach the predicted leak location from the developed approach was compared with the real leak location. The results showed that the expected leak location was successfully identified with an accuracy of more than 95%.

***Keywords*—**Thermography, Leakage, Water pipelines, Thermograms.

I. Introduction

WATER distribution networks (WDN) contributes highly in any development of municipal infrastructure systems since they are considered to be the most crucial and valuable assets. They constitute the key element in the development of public health, safety and urban population growth [1]. Nevertheless, according to a 2006 world bank paper: 45 million cubic meters of water are reported to be lost through the WDN every day in developing countries and more than 32 billion cubic meters lost globally every year [2]. Water losses imposes direct costs to the government such as the loss of money spent into treating and transporting the damaged assets, also an indirect costs will be carried by the society and this might be crucial in case of having serious damages that will reduce the quality of the provided water and endanger the public health. As the population growth in Qatar increases, the amount of stress on the network increases and the risk of decreasing its lifetime and a potential leak has become high.

Water loss (leakage) in the WDN is an elementary sign for the pipe deficiency that may poses threats to the quality of water provided in which these deficiencies constitute a pathway for microorganisms' intrusion inside the pipeline endangering the public health [3].

Longevity of the WDN is associated with the network leak monitoring in order to reduce the likelihood of water loss and its related risks. Therefore, numerous approaches had been established to detect WDN leaks, however such techniques used to perturb the piping network physically by excavation at the pipe location and mechanically through shutting the flow down inside the network [4]. Previous approaches can be summarized into flow and pressure monitoring, noise monitoring, visual inspection, electromagnetic techniques and ultrasound techniques [4]; however, flow and pressure monitoring and noise monitoring are the most common approaches used to detect leaks in water networks [5].

Flow and pressure monitoring techniques provides accurate results but they require sets of data that represents the actual situation of the flow and pressure precisely which need monitoring over a long period of time (time consuming process). Therefore, such technique is not valid for an immediate leak detection [5].

Noise is generated from the abnormal behavior of the flow around the pipes cracks and propagates along the pipe to be captured at the ground surface. Acoustic technique converts the noise generated from a leak event to numbers through placing sensors at the pipe tip to measure the delay in the sound signal detection at each end; hence locating the exact leak location [6], [7]. However, large leaks result in high frequency undetectable waves that make the use of a noise monitoring techniques inapplicable. Moreover, noise monitoring techniques are slow in process and get affected by external noises close to the pipe location such as a moving truck [8].

In this paper a non-invasive, non-destructive approach has been implemented to predict leak locations through the use thermal images and statistical analysis of the thermal images. Thermography is the practice of detecting object radiation in the infrared range of the electromagnetic spectrum (roughly 9,000-14,000 nanometers or 9-14µm). Images produced of that radiation are called thermo-graphic images or thermo-grams. Any object in nature has the ability to emit energy (radiation) with different intensity depending on its temperature and emissivity according to the black body radiation law. Surfaces above a leak location is expected to experience a temperature variation due to the interference of water from the leak which would make it emit energy different than the energies emitted from dry locations. Therefore, a considerable temperature contrast may take place giving an indication of leak. Appropriate statistical analysis of thermo-grams was established in this paper that will assist in detecting leak locations in water mains through a non-destructive non-invasive technique.

II. Thermography Infrared (IR) Camera System

A VarioCAM hr head (Fig. 1) thermo-graphic system was used in this study. The system has a long wave infrared

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spectral range (LWIR) of 7.5 to 14 µm. The lens reflects the object scene onto a micro-bolometer array at a resolution of 384 x 288 pixels. A wide-angle lens was used to capture the IR radiation emitted by the object in the field of view (FOV) and to duplicate it onto the detector array with a focal length of 12.5mm and a minimum focus of 0.2m. Other properties and technical specifications of the VarioCAM hr system are stated in Table I.

Fig. 1 VarioCAM hr head

TABLE I
PROPERTIES OF IR CAMERA

spectral range	7.5 to 14 µm.
temperature measuring range	(-40 to 1,200) ^{o}C
emissivity	adjustable from 0.1 to 1.0 in increments of 0.01
recording, image format (pixels)	384 x 288
detector	uncooled micro-bolometer focal plane array
ir frame rate	50/60 hz
ifov(mrad)	1.4
fov(^{o})	30x23
humidity during operation and storage	relative humidity 5% to 95%, non-condensing
weight	approx. 1.3 kg

III. METHODOLOGY

The methodology presented in this paper is based on the assumption that the temperature of the pipe line in dry condition (no leak) will follow a uniform distribution (ideal case), since there is no interference that will cause temperature variation (leak), however, having a leak along the pipeline will impose variation of the uniformly distributed temperature values. The dry uniformly distributed temperature values will follow a normal distribution trend with a particular mean (µ) and standard deviation (σ). The temperature of the dry regions will lay at the middle of the distribution contributing 90% of all temperature values, and the rest 10% temperature values would be the expected leak (wet) locations. The 10% will be distributed between the two tails (5% each). During the experiments the temperature of the leaking water was almost 28C^{o} which was greater than the ambient temperature of 25^{o}C. Consequently, temperatures of the right tail of the normal distribution curve would represent the leak (T≥ Z (95%)) where T is the leak temperature and Z is the value associated with 95% probability as illustrated in Fig. 2. After finding the temperature range that corresponds to the leak, visual inspection was done through the VarioCAM software by readjusting the thermo images temperature scale so that regions that had temperature equal or greater than the estimated leak temperature were given a brown color in order to detect the leak location visually. A real leak location existed in Doha city was studied in collaboration with Qatar General Electricity and Water Corporation. Methodology is described in Fig. 3.

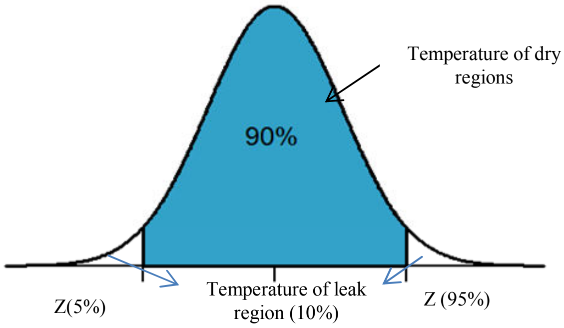

Fig. 2 Temperature distribution of a leak scenario

Six thermo-graphic images were captured along a 10 meter PVC pipe surrounded by crushed sand stone that experienced a real leak in Doha city (collaboration with Qatar general electricity and water corporation). The thermo-graphic images were captured using a VarioCAM infrared camera that has the ability to translate the thermo images into 384x288 pixels (temperature values) for each thermal image. A combination of these temperature values for the whole thermographic images was processed into a statistical analysis software (MINITAB17). Mean and standard deviation of the temperature values were estimated to be 26.0776^{o}C and 0.838464 respectively. According to the assumption that the captured temperature values were following a normal distribution X ~ N (µ=26.0776^{o}C, σ = 0.838464), temperature values that are associated with the leak were expected to appear with a probability less than the others, therefore, leakage temperature expected to have a probability of 5% or less to exist. According to the temperature of the leak water high temperature values would represent the leak. Consequently, temperatures of the right tail of the normal distribution were considered to be the leak temperatures (T ≥ Z (95%)). It was found that T≥ Z(95%) =27.5^{o}C which any value of temperature that equals or greater than (27.5^{o}C) will be considered as a leak sign (Fig. 4) on the infrared images to be inspected.

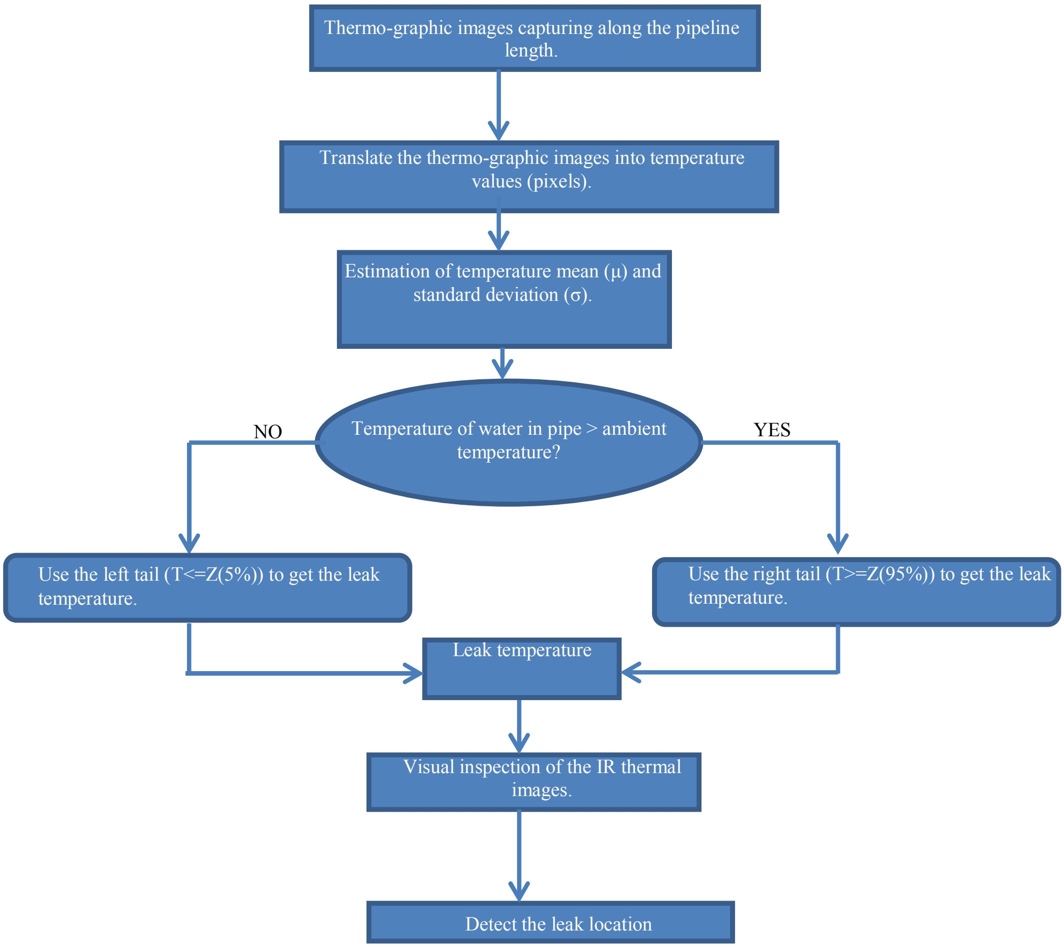

Fig. 3 Proposed methodology

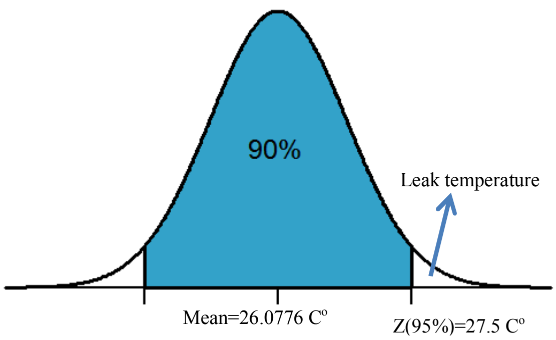

Fig. 4 Leak temperature illustration

IV. Results and Discussion

Visual inspection for the thermo-graphic images was done through the IR VarioCAM software, where the scale temperature was readjusted so that temperature values of (27.5°C) or higher was given a brown color. As shown in Fig. 5, thermo-graphic images along the pipe line length were examined and it showed that image (B) had a slightly brown color at its edge where it continued on in image (C) that was almost covered by the brown color; therefore, using the discussed approach it can be said that the water leak was found to be slightly on image (B) and intensively on image (C). Since the pipe length is 10 meters and 6 images were captured so each image represents about 1.67 meters, accordingly the leak was detected in the area between 3.34 m to 5.01 m (boundaries of image (C)) with a center of 4.175m from the pipe beginning.

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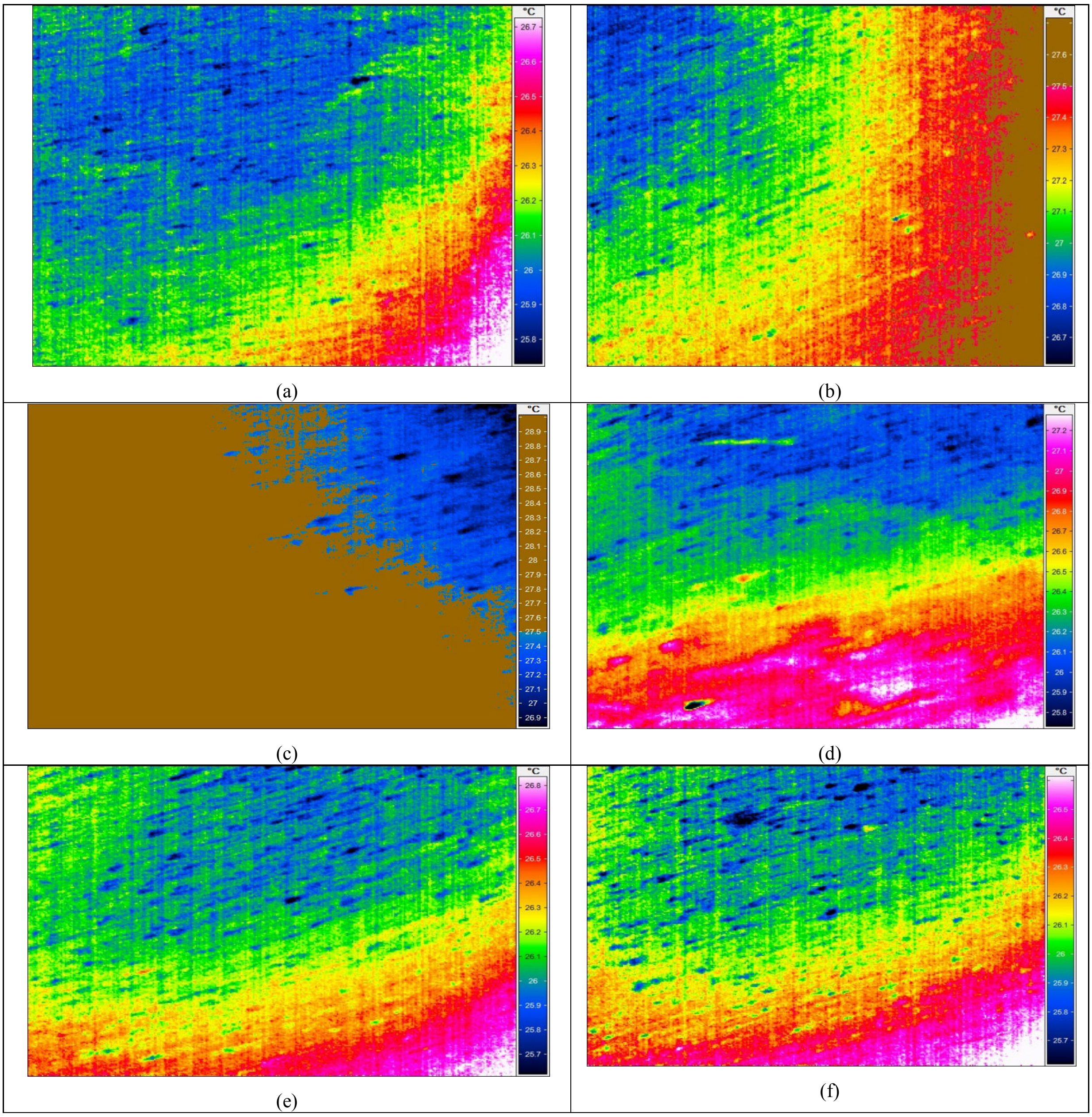

Fig. 5 Thermal images of 10 m PVC pipe experiencing a real leak (A, D, E, F) are dry (B, C) are wet)

V. Approach Verification

In order to verify the results of the proposed approach, manual leak detection was performed with the help of Qatar general electricity and water corporation. It was found that the actual leak existed at a distance of 4 m from the pipe beginning of the pipe, which is close to the estimated leak by the proposed approach. The error was calculated to be only 1.75%. Fig. 6 and Table II show a comparison between the actual and estimated leak.

TABLE II
Real and Estimated Leak Information

Estimated leak location	3.34m - 5.01m , image3
Real leak location	4 m
Error%	$\frac{\frac{3.34+5.01}{2}-4}{pipe.length=10}=1.75\%$

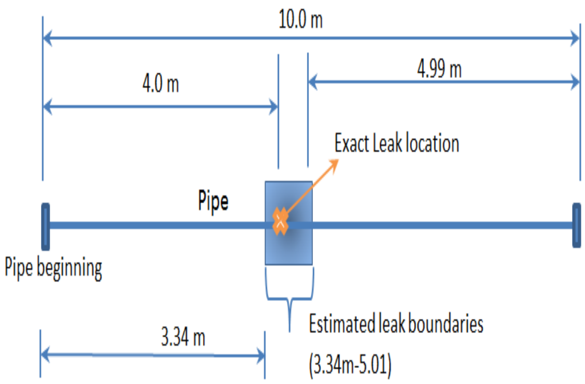

Fig. 6 Comparison between real and estimated leak locations

VI. Conclusion

An effective non-destructive, non-invasive approach for leak detection was proposed. The proposed approach depends on collected thermal images of the ground surface of an expected leak location. Statistical analysis of the collected thermal images followed by a visual inspection of the thermo-grams was performed in order to locate the leak. Temperatures associated with the leak would account for 5% of the entire temperature values of an IR image. Therefore, temperatures of the right tail of the normal distribution were considered to be the leak temperatures ($T \geq Z$ (95%)). It was found that the actual leak existed at a distance of 4 m from the beginning of the pipe, which is close to the estimated leak by the proposed approach of 4.175 m. The error was calculated to be only 1.75%.

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