Detection of Water Leakage in Buried Pipes Using Infrared Technology

A Comparative Study of Using High and Low Resolution Infrared Cameras For Evaluating Distant Remote Detection

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Abstract
Water is one of the most precious commodities around the world. However, significant amount of water is lost daily in many countries through broken and leaking pipes. This paper investigates the use of low and high resolution infrared systems to detect water leakage in relatively dry countries. The overall aim is to develop a non-contact and high speed system that could be used to detect leakage in pipes remotely via the effect of the change in humidity on the temperature of the ground due to evaporation. A small scale experimental test rig has been constructed to simulate water leakage in The Great Man-Made River Project in Libya, taking into consideration the dryness level of the desert sand and the scaled dimensions of the system. The results show that the infrared technology is an effective technology in detecting water leakage in pipes. The low resolution system has been found as valuable as the high resolution system in detecting water leakage. The results indicate the possibility of distant remote detection of leakage in water systems using infrared technologies which could be mobilised using drones, helium balloons, aeroplanes or other similar technologies.

Keywords: Water leakage detection, thermal images, infrared cameras, sensors, monitoring systems, remote detection, drones.

I. Introduction

No doubt, water resources are limited around the world and a high standard of water management is extremely required in most countries. Economically, leaks are costing where in addition to wasting water; it consumes significant power to treat water or to transfer it from one point to another [1]. Some global studies have shown that the losses are ranging from 10% to 40% around the world [2]. Early detection of leaks improves operational efficiency, lowers operational costs, reduces potential for contamination, extends the life of the facilities, reduces potential property damage and water system liability and reduces water outage events [3]. Several research projects have been presented in the literature to detect water leakage using different leakage detection techniques such as acoustic emission, pressure sensors and infrared [2, 4, 5]. Different sensors are found to have different capabilities, for example when water is pumped at relatively high pressure, it could be difficult to detect the pressure drop caused by a leakage; hence pressure sensors could fail to detect that. Also, some sensors could be expensive and would require distributed installation around the water system.

As the water leakage causes temperature differences in the area nearby, infrared thermal cameras can detect the leak by visualising the leakage points upon the change in temperature on the surface above the pipeline. This paper addresses the use of infrared technology in order to detected water leakage from buried pipes. The goal is to detect and locate the leakage in pipes effectively with low cost and low resolution technology [6]. This paper compares between a low resolution camera and a high resolution camera in respect to leakage and location detection with support of image processing techniques. This to assess the potential of using distant remote detection of leakage in water systems using infrared technologies which could be mobilised using drones, helium balloons and aeroplanes.

When solar radiation falls on any surface of material, part of this radiation will be reflected from the surface and the rest will be absorbed. The energy generated by the absorbed radiation will increase the temperature of the surface of the material. The difference in temperature between the surface and the material underneath will create heat flow from hot part to the cold part. The rate of heat flow will depend on the conductivity of the material and the amount of temperature difference. It is well known that heat transfers between bodies by conduction, convection and radiation. Heat is the energy that flows from the hotter body to the cooler one [7]. In our case of buried water pipe system, heat transfers from the surface above the pipe to the pipe and vice versa based on which is cold and which is hot. The pipeline system will work as heat exchanger whereas heat from the surface flows to the pipe.

In some cases, the temperature difference might not be detected using infrared technology as some of the thermography cameras have limited sensitivity within 0.2 °C [8] or because the levels of temperature of the pipeline and the surrounding areas are similar. To avoid this situation, it is proposed to use the technology in real life within a specific time of the day when the difference is maximised.

The pipeline system itself causes difference in temperature on the surface above it. However, leaks could significantly influence the difference in temperature more than what the pipeline can do. In this simulated experiment, the water in the pipe was at a lower temperature than the surrounding backfill material in order to simulate real scenarios, especially in summer times in hot areas, when the temperature of the water will be at significantly lower temperatures.

For the buried pipeline, the heat flows from the surface to the pipeline if the pipeline is cooler than surrounding areas even if there is no leak and vice versa if the pipeline is hotter. The direction of the heat transfer depends on the temperature of the fluid transported and some other factors such as the conductivity of the material of the pipe, diameter, and the thickness of the pipe wall, etc. However, when the leak happens, the nearby area will be cooler than the surrounding and this causes remarkable change in the surface temperature above it. In this project the used pipe material was plastic which known to be a less conductive material [9].

II. THE GREAT MAN-MADE RIVER PROJECT (GMRP)

The Great Man-Man Made River project is the largest water transfer scheme built on earth to date. The project is divided to five stages. The total length of the pipeline exceeds 6000 km of 4 m diameter pipes. For Example, just the first phase of the project (Sarir/Sirt Tazerbo/Benghazi System) requires approximately 250,000 pipes of 7.5 meter long and 4 meter diameter [10].

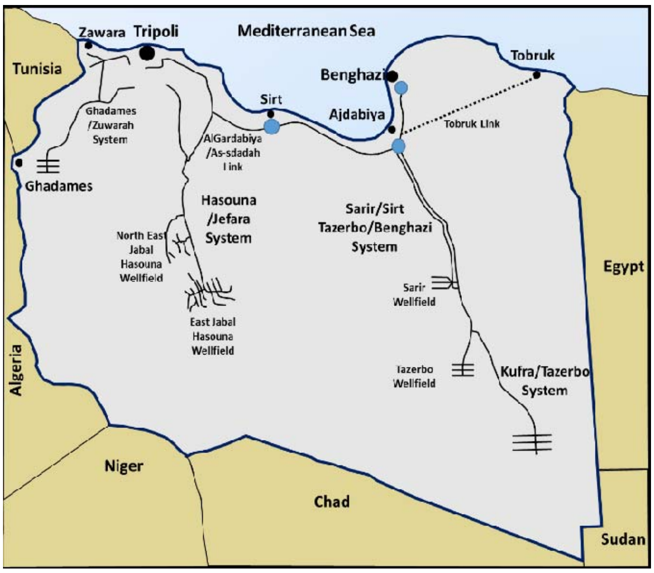

Fig. 1. The Great Man-Made River Project Map in Libya.

The GMRP transfers more than six Million Cubic Metres per Day (MCMD) from the south to the north of Libya. The initial design of first phase transfers 2.68 MCMD and will reach 3.68 MCMD [11]. The water is extracted from beneath the Sahara and either pumped, or allowed to flow by gravity, to the coastal side where the majority of the Libyans live. In addition to the 6000 km of pipeline, the project includes many water well-fields composes of a great net of pipelines and hundreds of wells of about 500 meters deep each. Many huge pump station complexes and many more huge water reservoirs of more than 50 million cubic meter of water storage capacity are also included.

As a water transfer system, the Great Man Made River Project will be definitely subjected to water leaks similar to any other water projects. The conveyance pipeline in is the most vulnerable section of the project than other sections such as the wells. It represents a major risk [10]. One of the project's high management priorities is to have a good early leakage detection system that can identify the leaks at their very first stages. Fig. 1 shows the map of the Great Man-Made River Project in Libya.

The sand temperature in the desert where the project has been constructed exceeds 50 °c in the day time [10]. The temperature of water is normally between 25-30 °c because it is pumped from deep water wells.

III. THE EXPERIMENTAL WORK:

A. The test rig

Fig. 2 shows the experimental test rig implemented to monitor the test section of the buried pipeline using two infrared cameras (the high and low resolution thermal cameras). The rig consists of a pipeline with inlet/outlet water tank, water pump and valves to control water flow. The test area consists of a box filled with soil in which part of the pipeline is passing through it to simulate actual buried pipeline. The test area is surrounded by polystyrene pieces to avert the heat effect of the surroundings in order to get clear thermal image for the tested area.

The pipeline is buried 110 mm deep under the surface. That is bigger than 5 times of the pipe diameter which is 20mm. The type of pipe material is plastic, which is known with less heat conductivity.

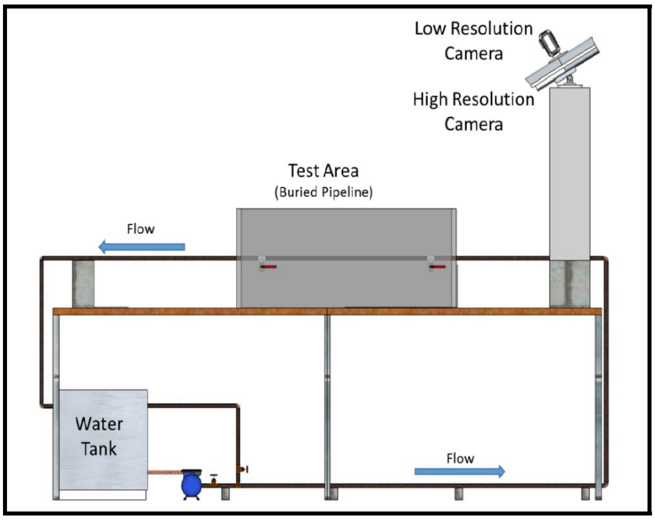

Fig. 2. The experimental test rig with the high and low-resolution cameras.

B. Thermal Imaging cameras utilised in this work

The thermal imaging is a non-destructive technique (NDT) for sensing infrared radiated from the surface of an object [12]. The thermal image of an object is the result of infrared radiation of the surface of the object, which can be sensed using the thermal infrared camera. The thermal image is a visible image from which tested objects can be assessed based on their heat emission [13]. The used cameras in this work are a low resolution camera (IRISYS) and the high resolution camera (Flir A310f).

Flir A310f is a relatively high cost, high resolution infrared camera with network connectivity. The camera is normally used in monitoring properties, process monitoring, quality control, fire detection in hazardous areas as well as a security camera.

The used IRISYS camera in this project is a low resolution and low cost infrared imager that can be easily used as a measuring device for measuring temperatures. Despite its low resolution and low cost, it is still beneficial in bringing the advantages of thermal imaging techniques. The IRISYS is producing a 16x16 low resolution image which can be enhanced using interpolation method to improve it visibility [6].

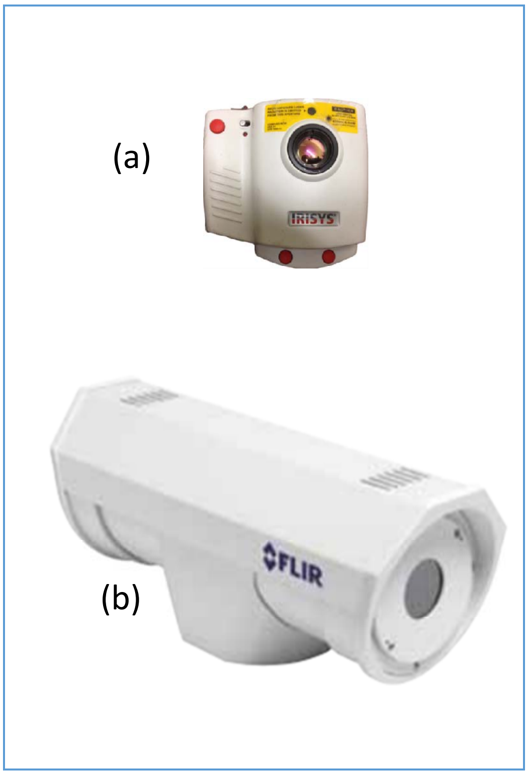

Fig. 3. The IRISYS system (a) and the Flir Camera (b) (images not to scale) .

The following figures (Fig. 4 and Fig. 5) show the original images and the processed imaged from both low resolution and high resolution cameras.

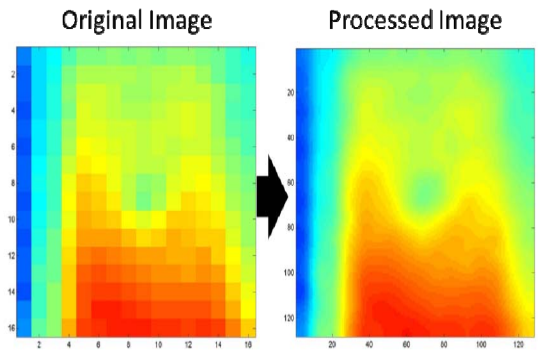

Fig. 4. A low resolution original image and the associated processed image.

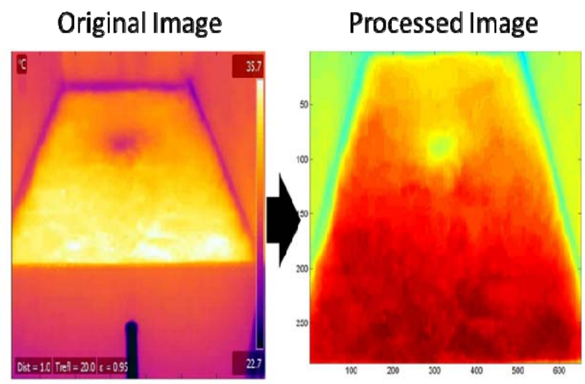

Fig. 5. A high resolution original image and the associated processed image.

IV. LEAKAGE DETECTION

A. Leak Detection comparison using both low and high resolution cameras:

Fig. 6 (A to F) is a series of processed images for both the low resolution camera (IRISYS) and the high resolution camera (Flir) taken simultaneously from the same experiment. The figures represent the progress of the leak detection throughout the experiment. The surface of the test area has been subjected to heating using infrared light to simulate surface heating during daytime by the sun. The leak is this case has started at the beginning of the experiment.

In Fig. 6, the leak is not detectable visually in the first images (A and B) while it becomes more detectable later during the day or early evening (D and E) where the leak is so evident and both cameras have given almost the same results.

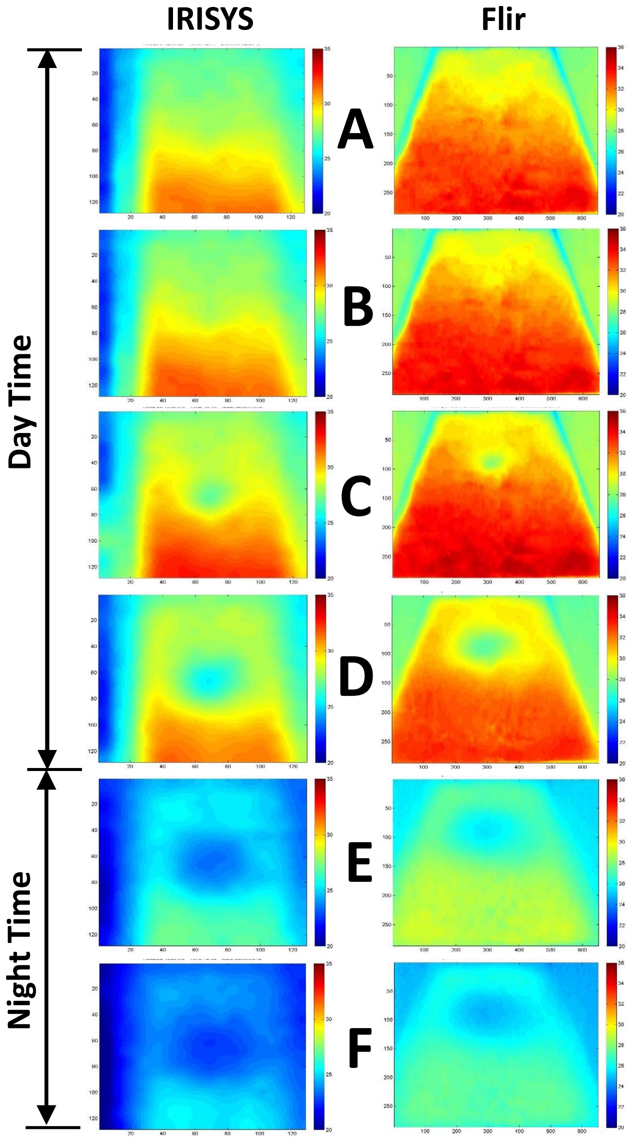

Fig. 6. Progress of leakage detection (A to H) for both Flir and IRISYS in daytime and night-time

B. Finding the leak location in both low and high resolution cameras:

Fig. 7 and Fig. 8 are selected images for both Flir and IRISYS cameras respectively. Analysis to the image is done via a chart using cross-section lines drawn on it along the pipeline direction or perpendicular to it.

In the chart, the cross section line which crosses the pipeline above the leak point outlines a different shape from the other two lines and will show the leak, as the temperature in the suspected leak point was clearly less than the preceding and succeeding points. Both cameras, the high resolution and the low resolution, have shown the leak with similar capabilities.

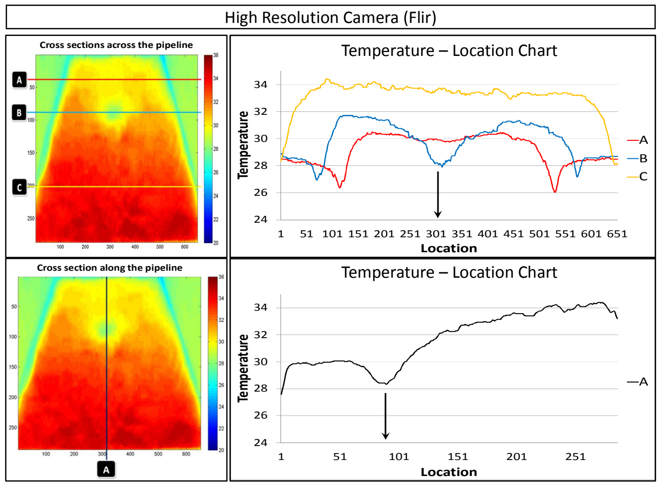

Fig. 7. A high resolution infrared image and the assciated temperature profiles.

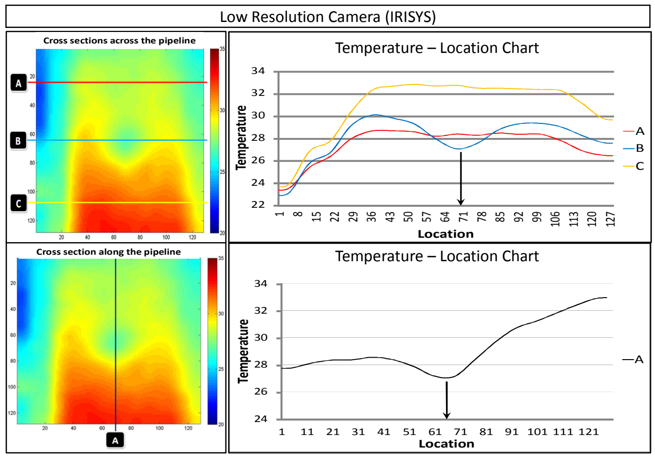

Fig. 8. A low resolution infarred image and the assciated temperature profiles.

C. Differentiation between leak and no-leak condition using 3D image.

The thermal image shows the leak as a spot on the suspected leak point while it shows the path of the pipeline in case there is no leak. The 3D mesh image as in Fig. 9 shows the leak as a 'sinkhole' in the middle of the suspected area while it shows the path of the pipeline as a trench along the pipeline length.

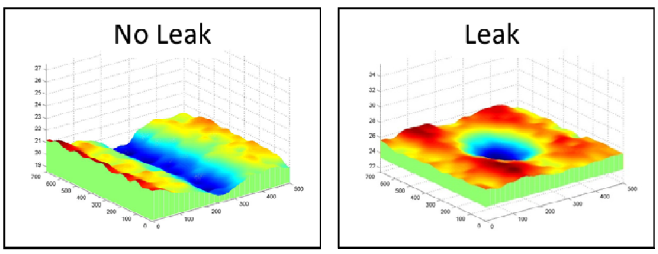

Fig. 9. Examples of 3D images showing the difference in detecting leakage and detecting the pipe path itself.

D. Differentiation between leak and no-leak condition using the temperature profile:

A chart for three selected cross-section lines across the image can clearly show how the pipeline is affecting the surface temperature above it.

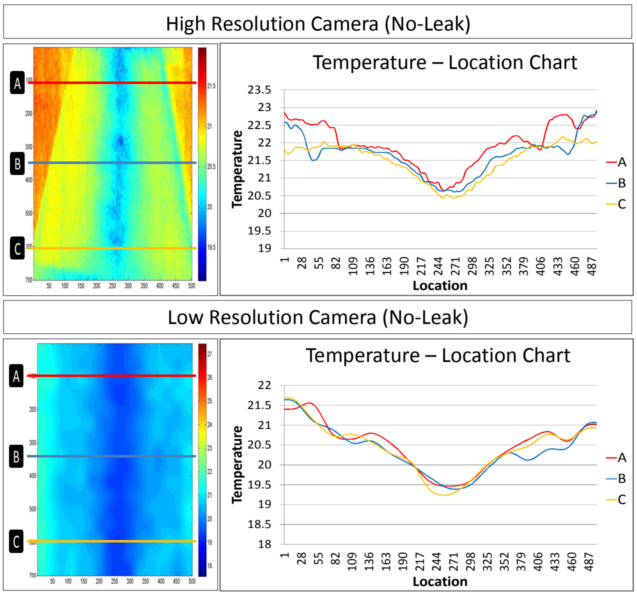

Fig. 10. No-leak condition for both Flir and IRISYS cameras.

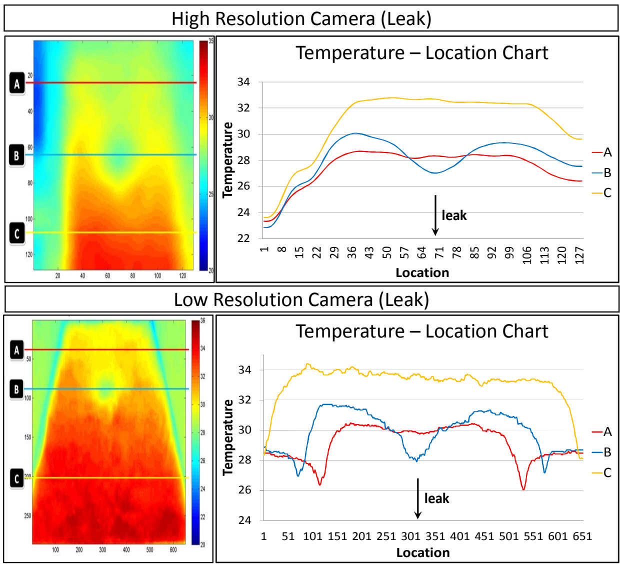

Fig. 11. Water leakage condition for both Flir and IRISYS cameras.

The lines will have a lower (or higher based on the temperature of the water) temperature on the area above the pipeline than the two other sides. In case of the no-leak condition, the three lines drawn for the three selected cross sections have shown a lower temperature at the middle point. While, in the leak condition only the line located above the leak point have shown a lower values in the middle than the other two cross section lines, see Fig. 10 and Fig. 11

E. Proposal for the use of the thermal cameras for pipeline inspection:

The thermal cameras could be fixed in certain point for continuous monitoring especially for critical points of the pipeline where leaks are most expected. It also can be used as a mobile camera in routine inspection for the pipeline especially in large projects such GMRA or where it cannot be fitted in open areas. It is suggested that the camera would be better used as a part of a sensor fusion system to confirm whether the leak exists or not.

The use of mobile cameras can be done using several techniques. In this paper it is suggested that the camera can be fitted with either quadcopter drone or a helium balloon so the images can be taken from higher and better point of sight. This might require to be jointed with GPS system in order to record the location of the image taken, see Fig. 13 and Fig. 14.

1) The thermal camera with a helium balloon:

For larger projects with longer distances pipeline in open areas the camera can be fitted to a helium balloon. The balloon could be secured to a vehicle as shown in Fig. 12.

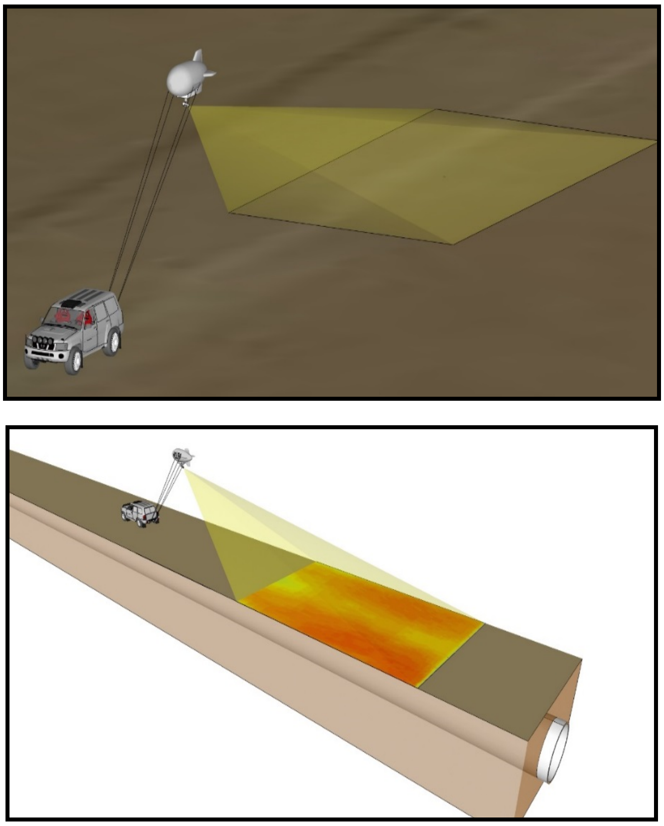

Fig. 12. An infared camera and a GPS system can be attached to a helium balloon to be used for pipeline inspection for long distances.

2) The thermal camera with quadcopter drone:

For shorter distances pipeline, the quadcopter drone can be used to hold the camera and fly over the pipeline or the suspected area of leak for inspection, see Fig. 13.

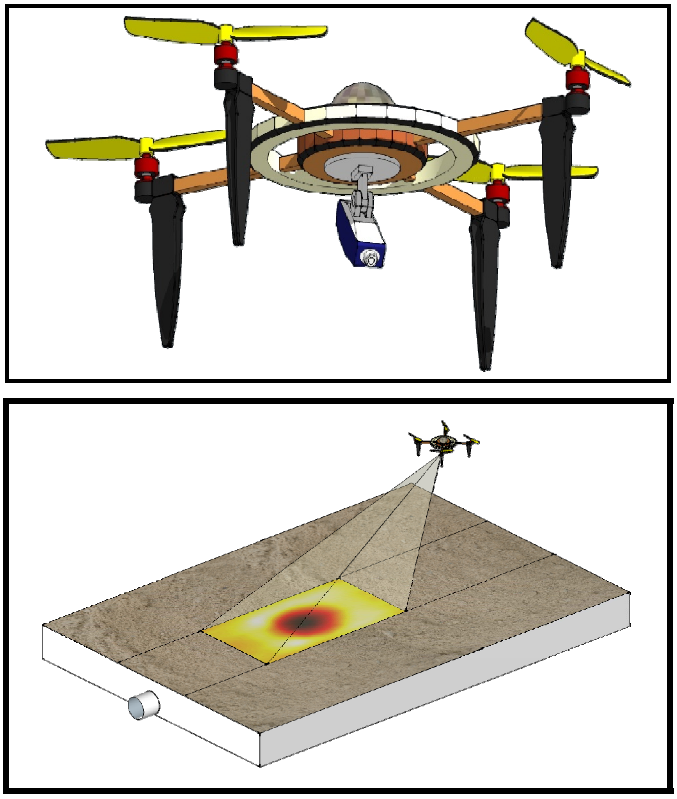

Figure 13: An artistic impression of the quadcopter drone with infarred camera and a GPS system.

CONCLUSION

Detection of water leakage in pipes is becoming extremely important to save water and energy. This paper has suggested the use of low and high resolution cameras to test the detection of water leakage using a small scale simulator. It has been found that when leakage occurs, a specific thermal profile will be generated that could be easily detected by both types of cameras (particularly late afternoon or early evening). The cameras are able to visualise the leak despite the leak itself is not being evident on the surface by visual inspection. The difference in the temperature generated on the surface has clearly been detected by both, the high resolution thermal camera (Flir A310f) and the low resolution thermal camera (IRISYS). However, the resulted images from both cameras have needed additional processing to confirm the leakage and its location.

The low resolution camera is found as successful as the high resolution camera in detecting and locating the leakage. As the cost of producing water leakage detection system using thermal cameras is an important factor, the result of this research will assist in the design of a low cost water leakage detection system. The produced systems could be mobile or use fixed cameras, depending on the importance of the inspected point. One other important outcome of the findings, is that the high resolution camera could be used to detect leakage in large areas from high altitudes since the pixel density of the images will still be effective as evident from test conducted using the low resolution infrared camera.

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