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Identification of Buried Pipes Using Thermal Images and Data Mining

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Abstract

Knowledge of buried infrastructure is essential for management and decision-making in water utility companies. To pinpoint the benefits of thermography, a case study was conducted, namely, thermal images were taken under various conditions in a particular area containing a buried pipe. Thermal images were subsequently analysed, an image database supplemented with environmental data generated, and a data mining method applied. The results generated this way complement the raw images and reveal additional relationships regarding the visibility of the infrastructure, and the possibility of making promising improvements in infrastructure identification, which can be applied in subsequent work in other applications.

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Keywords: Thermographic Imaging; Temperature; Cost Lowering; Pipes; Water Distribution Systems.

1. Introduction

Thermography has shown to provide significant applications in various fields, such as medicine, engineering, industry and so on. Thermal cameras enable relatively large areas to be investigated effectively in less time [1] and, consequently, at lower cost, when compared with other current non-destructive methods. Trying to identify buried infrastructure by the use of non-invasive methods is a challenging task for utility companies, such as water supply and wastewater collection systems, energy, and telecommunications among others.

Termographic images may produce rich information, which, unfortunately, is not always apparent. There are several factors that affect visualization, which can, in fact, improve suitable contrasts in infrared images.

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Fig. 1 provides simple evidence that something buried is identified from a thermographic image, while a conventional snapshot does not show that information. However, sometimes it may happen that the image is not clear at all, as shown in Fig. 2. Also, if the eye is not trained enough, it may be difficult to ensure whether something lies or not under the ground. In fact, the important point is that we can obtain more information from the images than it is obvious at plain sight.

To develop powerful methods to treat images and get better visualizations is thus of great importance. In this contribution we discuss the possibility of considering data from the site observed at various times of the day, thus obtaining a tool that enables understanding the relationships among some relevant variables with the use of this non-destructive visualization technique.

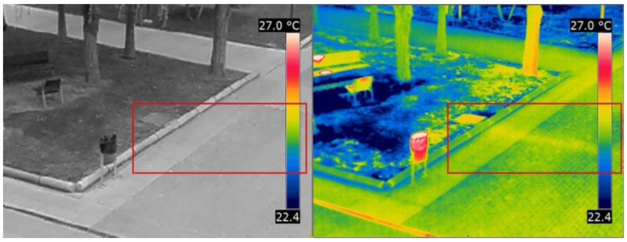

Fig. 1. Comparison between a conventional picture and a thermographic image

Fig. 2. Thermographic image, same site, different day

2. Concepts, problem description and theoretical approach

2.1. Concepts and variables

Infrared light (IR) is a form of electromagnetic radiation of long wavelength. It is emitted or absorbed by molecules when they change their rotational-vibrational movement. Infrared radiation is well known as heat radiation. Objects at room temperature emit radiation. Emissivity is a property of the object's surface that describes how its thermal emissions deviate from the ideal black body. If emissivity of an object is known the temperature of the object can be determined.

The characteristics of thermal radiation depend on various properties of the surface. The thermal radiation of a body is a form of emanation, depending on its temperature, its spectral absorptive and its spectral emissivity power.

In addition, it is of great importance to identify how thermographic images are obtained and, in particular, the right time to get the images is of great interest. It is clear, for example, that in a hot day, the relation between the pipe and its surroundings will be different than in a cold day.

2.2. Problem description

Object's emittance (emissivity), relative humidity, atmospheric temperature, distance to the object, thermal sensation, are factors that must be taken into account by the camera operator. However, these values are not easy to be determined if there is not enough amount of radiation.

Here then a couple of questions arise: what is the importance of elements such as objects appearing in the images that do not belong to the site?; how can we decide whether they alter the image and, in doing so, which is our ability to visualize the elements we are looking for?; and last, how can we relate all of the above in a simple manner?

The external elements, that is to say, the ones not related to the camera itself, that affect the IR images are season, hour of the capture, temperature, humidity, type of day, etc. These factors must be taken into account and be processed in order to get better and clearer images (with good definition) of the object studied. As a benefit "it enables relatively large areas to be investigated effectively in less time and consequently less cost" [2].

2.3. Theoretical approach

Technology evolves fast, bringing better and cheaper cameras; this makes data acquisition nowadays simple, so simple that huge amounts of information can be obtained in no time. However, this raw data must be later analyzed, which may be a very time-consuming process. As a result, simple, while efficient and fast methods of data analysis, are necessary.

In IR images interpretation plays a crucial role, because of the contrast between temperature and thermal external stimuli. However, the possibility of getting a huge digital repository of images gives a chance to compare results. The use of the infrared camera is simple, and it can be used any time during day or night [3]. However, training is necessary to obtain the best images, mainly because there is not enough information about the procedure.

In this study, a series of pictures were taken with a thermographic camera in the same place, where it was known there was a buried pipe. Environmental data variables were also taken, to generate a database with the various conditions. To contrast the images, different factors were considered, such as temperature variation due to season change, the type of day (cloudy, sunny, etc.) and, finally, sporadic elements, such as objects or human beings triggering temperature scale variation, were also considered. Various tests were performed to get images to observe the buried pipe, allowing us to devise better conditions for taking the pictures. With the image analysis process it is possible to get the most convenient condition for the test, with a clear visualization of the buried pipe. This process will hopefully make it easier to find the pipes in an unknown area, for maintenance or prevention, or simply to update the piping system layout, therefore saving time and money.

3. Methodology

In the present investigation, a FLIR 600 camera was used. We defined an area with a buried pipe, and then a series of images was obtained by the process shown in Fig. 3, which describes the flowchart of a run, subsequently repeated in several occasions. Images were taken on 13 days during the period between October and February, in order to get information data from two seasons (autumn and winter) to be contrasted in the investigation. Then all of the information was compiled in a database. The variables considered are: temperature of the day, wind, type of day, and humidity; notice that wind and type of day are qualitative variables.

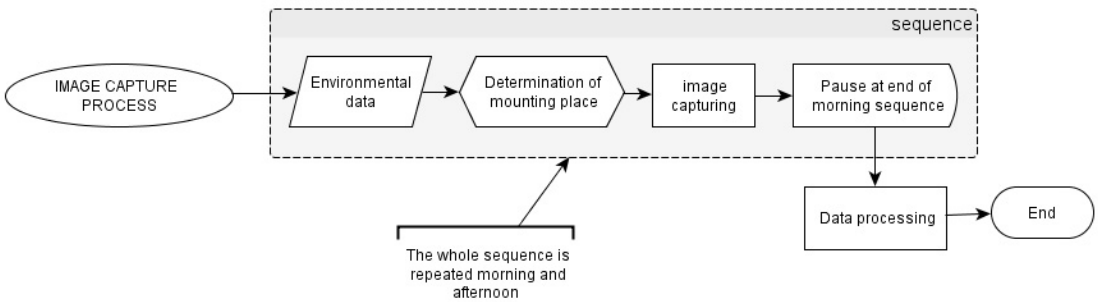

Fig. 3. Flowchart of a run

The camera was programmed and took one image approximately every 10 seconds; 25 images were taken in each test. A test consists of a set of measurements in the morning and the afternoon; it begins by capturing the environmental data, and then determining the mounting of the camera, turning it on, and allowing it to make pictures in a period of 4 to 5 minutes in the morning. The same process is then repeated in the afternoon.

A few situations were observed that affected some of the images. Two examples are a time when a motorcycle was left on the site and its temperature altered the camera's range, and other day when a passer-by with a cigarette raised the temperature up to 120 degrees. These effects may well happen in cities where the area of study cannot be completely isolated.

3.1. Data compilation

The environmental variables were taken from the local meteorological services, and can be represented the same way with the simple representation shown in Fig. 4, assuming for the wind variable the following qualitative classification; windless: 0, slow wind: 1, strong wind: 2, while the rest was information from the thermograpic image.

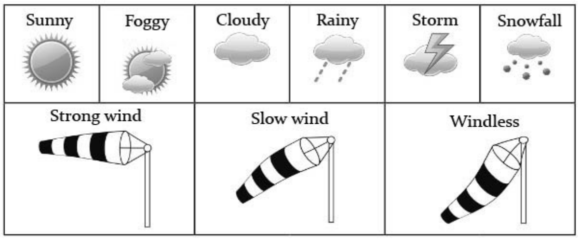

Fig. 4. Standard environmental classification.

Once the information corresponding to all the tests was collected, the database, including the images and the environmental data, was compiled. The database contains 626 thermographic images from a total of 26 tests.

As can be observed in Fig. 5, it is important to note that the measured temperature of the day was always between the maximum and the minimum of the image ranges, as was the temperature of the buried pipe. These both will be related when adjusting the range of temperatures for pipe visualization.

Then data mining techniques were applied to reveal the relation among the variables. Specifically, the package KNIME (Konstanz Information Miner) [4] was used in this application. For an initial analysis a representative sample of 24 images, two (morning and afternoon) from each test, was selected. Various numerical matrices were obtained to be processed using Matlab.

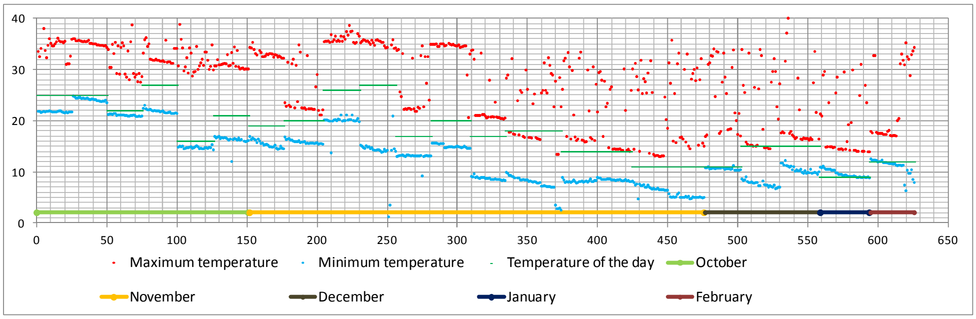

Fig. 5. Compiled temperature data

4. Analysis process

The analysis of the termographic images starts with a full visualization of the 24 images of the sample in a multi-matrix, including two images from each test in an ordered (left to right and downwards) way, as shown in Fig. 6 (left). In the particular case shown in Fig. 6, the processed image produced results that are not clear, because the temperature scale rises up to 120 degrees, while the average of the maximum temperatures is around 30 degrees. This fact represents a clear distortion for the analysis. After careful examination, this increment was identified. It was induced by a passer-by with a cigarette during the test. The image was identified and suitably treated. As a result, it is possible to observe in Fig. 6 (right), that the temperature scale may have an upper bound at 35 degrees, and the pipe can be observed in some snapshots.

As mentioned, the images were taken during 4 months; a time interval devised enough to capture the season change from autumn to winter so as to make representative the temperature decline. This is clearly reflected in the snapshots in Fig. 6, as the pipe is visible in the images on the lower half of the figure, corresponding to winter days.

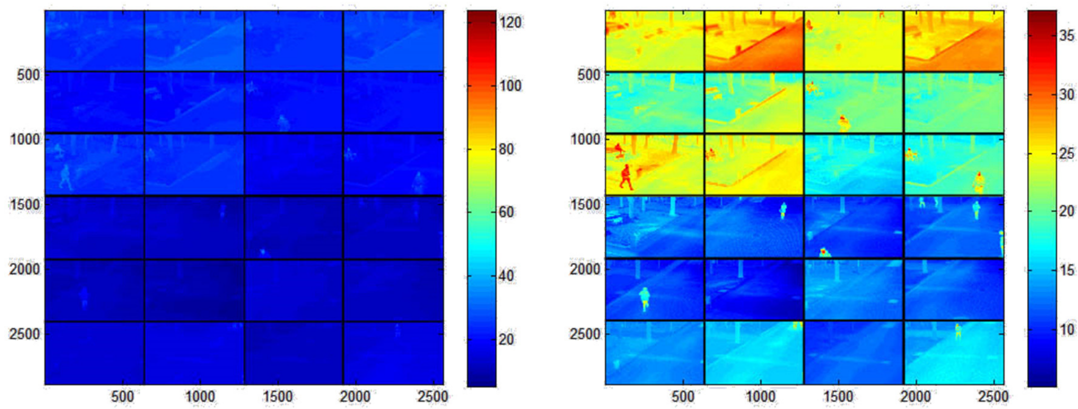

Fig. 6. Original plot of the sample (left) and its normalization (right)

With the information available from the sample temperature ranges were determined where the pipe can be observed on each image. To demonstrate the process, the following example is presented: Fig. 7a is the original image. Fig. 7b is the image with a range defined to better show the pipe. In Fig. 7c the image is converted to binary data, where all the temperatures outside the chosen range are discarded. Finally, Fig. 7d is the image with real temperatures; its blue areas correspond to white areas in Fig. 7c that have been eliminated; Fig. 7d is only shown for comparison purposes, Fig. 7c being our target.

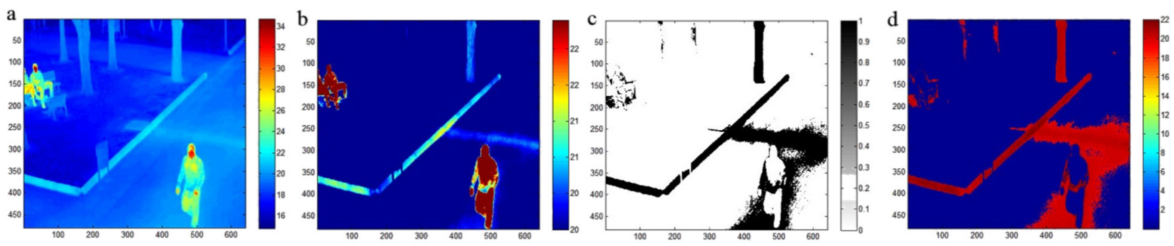

Fig. 7. Process to pipe visualization.

Linear regression applied to each image, taking into account errors between data in figures 7b and 7c, and the day temperature, enables to obtain a new sequence of images, as shown in Fig. 8. The main interest of this process, which we omit for brevity reasons, lies in the fact that once the relation among parameters has been established, better images can be obtained by predicting the phenomena that affects them by just processing the images.

5. Results and discussion

KNIME – Professional Open-Source Software is a modern data analytics platform that allows to perform sophisticated statistics and data mining on data to analyse trends and predict potential results. Its visual workbench combines data access, data transformation, initial investigation, powerful predictive analytics and visualization. KNIME also provides the ability to develop reports based on the available information, or automate the application of new insights back into production systems. Also, it allows to incorporate processes from other software tools, such as Matlab, R, Weka, etc.

A simple model in KNIME was developed with the database plus the information obtained from the processes of the images. As a result, we can observe relations among variables, and use them for the image process. For example, it is easy to know how many days were sunny, or if the pipe can be seen in those days, etc.

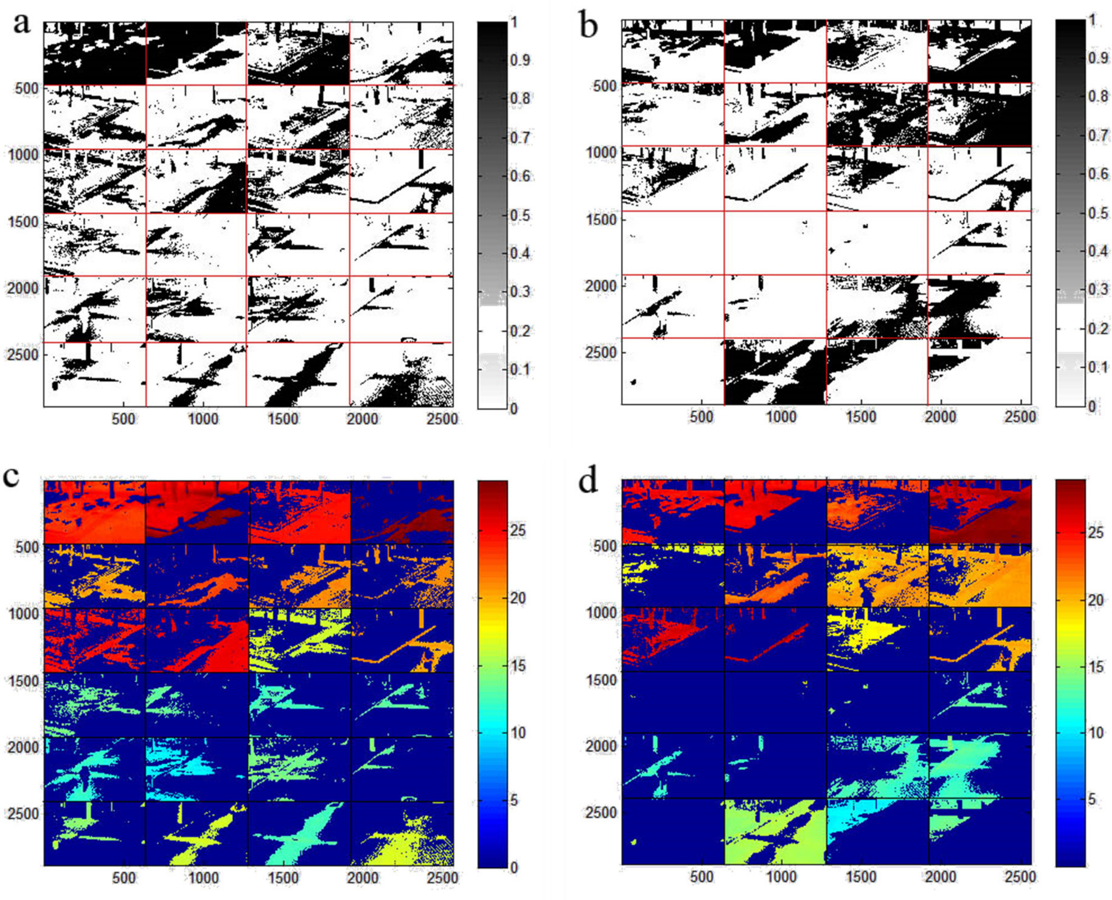

Fig. 8. Sample process.

With the graphics obtained from KNIME, it is possible to state, for example, that it is easier to observe the pipeline in a cold day than in a hot one. Also, passers-by increase the temperature in the images in cold days, and affect the range of visualization of the pipe in the image. As the night falls it is possible to observe with more clarity the pipe because during winter the heat is transferred from the deeper soils depths to surface [3]. All these factors can be mitigated with the process that simplifies the range of temperature in the images.

Figure 8a is the binary representation of the sample, where the white area represents no-value, and the black area the information of the range of the temperatures for the pipe to be visible. Figure 8b is obtained by using the linear regression above mentioned. Figures 8c and 8d are the corresponding matrices with temperatures recovered from the original image, where it is necessary to note, that the blue areas do not hold any value.

As can be observed in some images in Fig. 8, better adjustment is required, since the linear regression applied produces good results in some cases making the pipe more visible, while bad results in others not producing any visualization improvement. This suggests that a better numerical regression is needed so as to get a better image of the pipe for all the images.

6. Future investigation

The work described in this paper corresponds to the first steps of an on-going project aiming at developing a tool based on thermography as non-invasive methodology to be useful for various aspects of water utility management. It is clear that the simple linear regression we have used does not comply with a convincing percentage over the target. Future investigation lines may be devised that would produce better descriptions obtained by using more sophisticated techniques from Statistics and/or Data Mining.

The next step in the analysis, once the process of identification of a buried pipe is fine-tuned, will be the development of an algorithm that enables to better identify the pipe and know its diameter, and if there is more than one buried object in the site, among other things. To this purpose, more information is needed in order to determine the behaviour of the algorithm in a whole range of circumstances.

On the implementation side, further work would be necessary to complement and integrate the model with KNIME, to attain full automation of the information access and analysis.

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