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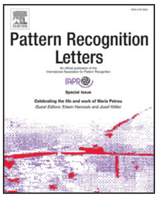

Enhanced analysis of thermographic images for monitoring of district heat pipe networks[☆]

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ABSTRACT

We address two problems related to large-scale aerial monitoring of district heating networks. First, we propose a classification scheme to reduce the number of false alarms among automatically detected leakages in district heating networks. The leakages are detected in images captured by an airborne thermal camera, and each detection corresponds to an image region with abnormally high temperature. This approach yields a significant number of false positives, and we propose to reduce this number in two steps; by (a) using a building segmentation scheme in order to remove detections on buildings, and (b) to use a machine learning approach to classify the remaining detections as true or false leakages. We provide extensive experimental analysis on real-world data, showing that this post-processing step significantly improves the usefulness of the system. Second, we propose a method for characterization of leakages over time, i.e., repeating the image acquisition one or a few years later and indicate areas that suffer from an increased energy loss. We address the problem of finding trends in the degradation of pipe networks in order to plan for long-term maintenance, and propose a visualization scheme exploiting the consecutive data collections.

1. Introduction

District heating networks distribute heat through underground pipes carrying media, i.e., hot water or steam, from a central power plant. Heat leakages due to damaged insulation or media leakages due to cracks are common problems. The pipes degenerate with time [17] and in some cities the pipes have been used for several decades. Loss of media (water/steam) or energy is expensive and has negative impact on the environment [11]. It is therefore of great interest to the network owners to find methods to detect and localize the leakages reliably. The fact that the pipes are placed underground increases the need for correct localization. Moreover, major leakages (in the order of 50–150 m^3 of media per day) may cause the ground to collapse due to erosion, whereby large amounts of water at boiling temperature are exposed.

Potential district heat pipe leakages can be de detected by analyzing imagery captured by airborne thermography. While this method has been very successful in recent years, it suffers from large numbers of false detections, since there are several types of objects and phenomena that are likely to be detected as well. Examples are areas that, for some reason, are warmer than their surroundings, such as, chimneys, cars, and heat leakages from buildings. In a large city, there might be several thousands of false detections. Another problem is that thermography gives a snapshot of the network's status, from which it is difficult to see the trends in network degradation that is needed for long-term maintenance planning.

In this paper, we present a method to reduce the number of false detections while maintaining the true positive rate at a fixed level. In order to achieve this, we follow a two-step classification procedure:

- Extract building locations from publically available geographic information, and remove all detections located on buildings.
- Extract image features and use a machine learning method to classify detections as true (media/energy) or false detections.

Moreover, we propose a novel method for temporal characterization and visualization of the energy loss of the network. Long-term degradation of a pipe cannot be detected as a single leakage. Instead, we analyze larger areas and compare the radiated energy at two different times, separated by one or a few years. The area covering the district heating network is divided into square cells

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and the comparison of energy loss is done for each cell individually.

1.1. Related work

Various methods for monitoring of district heating networks have been developed over the years, for example methods based on frequency response or change in electrical impedance for a thread installed inside the pipe insulation. It is also common to measure the flow of water or steam in the inlet and outlet. If it differs, there is a leakage somewhere along the pipe. Such methods can be used to detect the presence of a leakage and sometimes its approximate location (which pipe segment). However, the exact location, needed for digging, is not revealed.

Methods for large-scale monitoring by aerial thermography, that is remote sensing from an aircraft using a thermal camera, was investigated already in the 80s by [15] and [1]. The results are somewhat antiquated due to the drastic development of thermal cameras during the last two decades. Also, ground-based thermography using hand-held cameras has been investigated by [4] and [20]. Compared to aerial thermography, this has several drawbacks, such as restricted access to many areas of interest and less scalability.

The first system with automatic image analysis was presented by [10]. The system uses anomaly detection in order to detect abnormally warm areas along the pipes. However, the problem is the large number of false alarms since there are many areas that, for one reason or another, are warmer than the surroundings. To reduce the number of false alarms, buildings are segmented in order to avoid detections due to, e.g., chimneys when the pipes pass under buildings.

Temporal characterization of remote sensing data can be regarded as a form of change detection, which has been extensively studied. Applications include various kinds of environmental monitoring (e.g., land use and land cover (LULC) change, deforestation and crop monitoring; see [6] for a review of such applications), urban change [14], and military target detection [7,16]. The employed methods usually assume multispectral, sometimes even hyperspectral data, or SAR data [14]. Methods vary greatly, depending of the type of change to be detected, and they can be pixel-based [3,16,19] or object-based [3].

1.2. Contribution

The main contribution of the present work is to *characterize* detections obtained using the method presented by [10], and then to *classify* them as real leakages or false detections. The two subproblems of feature selection and choice of classification methods are both addressed. Second, we propose to do the *building segmentation* differently compared to [10]. Third, we propose a method for *temporal characterization* and *visualization* of district heating network energy loss.

1.3. Outline

The outline of this paper is as follows. In Section 2, the acquisition of data and the resulting data sets are described. Section 3 describes our method for false alarm reduction and how it adds on to existing methods. Section 4 describes the proposed method for temporal analysis. Experiment and results are described in Section 5, and, finally, Section 6 contains our conclusions.

2. Data acquisition and leakage detection

This section briefly describes the data acquisition process, preprocessing of the thermal images and the employed detection method. This corresponds to the scheme described in [10], but is included here in order to make the paper self-contained.

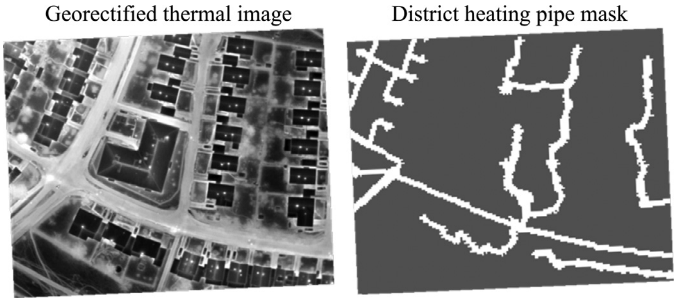
Georectified thermal image
District heating pipe mask

Fig. 1. An example of a georectified thermal image and a pixel mask of the district heating pipes obtained by rasterizing a GIS layer of the district heating system.

2.1. Image data

The thermal images are acquired from an aircraft. GPS and IMU are used to record the position and orientation of the aircraft in order to facilitate georeferencing. The imagery is georeferenced using semi-automatic commercial off-the-self software and stored in GeoTIFF format.

The thermal camera is a cooled mid-wave infrared FLIR SC7000 Titanium with a resolution of 640 × 512 pixels and a field of view of 11°. At an altitude of 800 m, this yields a pixel footprint of 25 × 25 cm. The mid-wave camera was chosen because of its fast, cooled detector that allows to capture images without motion blur at the present ground speed.

In order to minimize the number of false detections, data collection is mainly done during the night or at dawn during spring or autumn. At this time, neither vegetation or snow is blocking the view, the effect from sun heating is minimal, and the streets are not covered with cars blocking the view [18].

The number of night flights required in order to cover the whole area depends on the size of the area. For a medium-sized Swedish city (150.000 inhabitants), about three flights are needed.

2.2. GIS data

The network owner provides pipe location information in the form of vector maps. This information is projected on top of the georectified images creating a rasterized pipe mask for each image, Fig. 1. The mask is then used to limit the search for unexpectedly high temperatures to areas where pipes are buried.

2.3. Detections

A detection is in this context an area with a certain shape and location pointed out as abnormally warm. That is, it is an extended object, not just a map coordinate. In order to extract the detections from the images, we use the anomaly detection method from [10]. Statistics of the ground temperature inside the pipe mask are calculated from all images captured during one flight and the most deviating pixels above certain thresholds in the high end of the distribution (i.e. the “warmest pixels”) are marked as detections. The percentage thresholds are; 0.05%, 0.1%, 0.5%, 1%, 3% and 5%, resulting in six different layers of detections.

2.4. Ground truth data

Acquisition campaigns during the last couple of years have resulted in thousands of thermal images from 17 Scandinavian towns and cities. Three of the most recent acquisitions were selected for

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