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Evaluation of Thermal Images for Detecting Leakages in District Heating Networks

-A case study in Örebro City

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Preface

This research has been carried out on behalf of Digpro Solutions AB (Digpro) and E.ON. Värme AB (E.ON.). Digpro is a geographic IT company which provides solutions for all kinds of network-owners in the society, for example water, gas and district heating. This study has been focusing on the district heating application dpHeating. E.ON. is an electricity and energy company, which provides its customers with electricity, gas, heating and cooling.

Acknowledgment

First of all I would like to thank Digpro for the opportunity to work with this thesis, the warm welcome and all experience I got during the work of this thesis research. Especially I would like to thank my supervisor at Digpro, Axel Bronder, for invaluable help, feedback, inputs and suggestions. I also would like to specially thank Martin Johnsson, Lars Ellenfors and AnnMari Skrifvare for great expertise and comments.

I would like to express my gratitude to Alexander Jacob, my supervisor at Division of Geoinformatics at KTH, for priceless guidance and support.

Also, a lots of thanks to Patrik Nilsson and E.ON for sharing extensive knowledge and providing me with data for this thesis. Thanks also to all district heating experts attending on Digpro's user meeting for listening to my presentation and answering my questionnaire.

Last but not least I would like to thank Professor Yifang Ban for valuable input and examination during the course of this thesis research.

Abstract

Leakages in the district heating networks is a current and growing problem. To find the leakages today many district heating companies use manual techniques that are both time consuming and insecure, the methods can leave a lot of leakages in older pipes undiscovered for a very long time. These undetected leakages cost the district heating companies a lot of money and can even be fatal. It is therefore of great importance that the leakages are found in time, thus the methods for leak detection need to be improved.

The main purpose of this thesis was to investigate the ability to use thermal images to automatically search for leakages in district heating systems. To investigate this aerial thermal images from 2013 were collected. Image analysis was performed using ArcGIS and ENVI. This included, among other things, image preprocessing such as to define the projection of the images and unsupervised isodata classification to find potential leakages in the thermal images.

This automatic analysis resulted in many false alarms. One example were false alarms caused by vegetation, since vegetation absorbs heat during the day it appears warmer than the surroundings at night. To deal with this problem an unsupervised classification algorithm, isodata, was used again to classify the vegetational areas and the non-vegetational. This algorithm decreased the number of false alarms drastic and thereby increased the usability of the algorithm.

Other false alarm that has not been automatically rejected in this thesis were for example false alarms caused by heat leaking from buildings. One way to map such false alarms could be to analyse the shape and the linearisation of the potential leakages close to buildings. This would hugely increase the accuracy of the used algorithm.

The provided thermal images used in this thesis consisted of several confirmed leakages. All these confirmed leakages were found by the used algorithm. Although, the accuracy of the used algorithm could be discussed since many false alarms were generated. Nevertheless, to reject false alarms are much less time consuming than manual leak detection for an entire city. Thereby the conclusion that an automatic leak detection in district heating networks is possible, furthermore a leak detection tool like this would be usable for the district heating companies.

The evaluations from several different district heating experts who are using Digpro's district heating application, dpHeating, today shows that a leak detection tool using thermal images would be a useful addition in dpHeating.

Sammanfattning

Läckor i fjärrvärmenäten är ett växande problem, gamla rör som rostar och sättningar i marken är de största bidragande orsakerna till att läckor uppstår. I dagsläget används manuella metoder, som både är tidsödande och relativt osäkra på grund av den mänskliga faktorn, för att upptäcka läckor. På grund av att det är ett tidsödande arbete görs läcksökning i fjärrvärmenätet relativt sällan. Till följd av detta ligger vissa läckor oupptäckta en längre tid, dessa oupptäckta läckor kan kosta företagen väldigt mycket pengar och kan i vissa fall även medföra dödlig utgång. Det är därför av yttersta vikt att läckorna hittas i tid och därmed behöver metoderna för att hitta läckorna förbättras.

Huvudsyftet med detta kandidatarbete är att undersöka möjligheten att med hjälp av termograferingsbilder upptäcka läckor i fjärrvärmenät. För att undersöka detta har bildanalyser på termograferingsbilderna gjorts i GIS-programvarorna ArcGIS och ENVI. Den använda algoritmen genererade ett stort antal potentiella läckor i en shapefile.

En automatisk process som denna resulterar dock även i många falska alarm. Ett exempel på falska alarm är sådana orsakade av vegetation, eftersom att vegetation absorberar värme under dagen så kommer den att vara varmare än omgivningen på natten och därmed visas som en potentiell läcka av algoritmen. För att förhindra detta har också en algoritm för att segmentera vegetation från icke vegetation använts i analysen. Den ovan beskrivna segmentationen minskade drastiskt antalet falska alarm orsakade av vegetation. Därmed ökade användbarheten av algoritmen.

I datat som analysen i detta kandidatarbete är gjort på finns flertalet konstaterade läckor. Alla dessa läckor har hittats av den använda algoritmen: automatisk läcksökning i fjärrvärmenät är alltså möjlig. På grund av de många falska alarm som denna algoritm har resulterat i är osäkerheten i algoritmen ganska stor. Men den tid som det tar för fjärrvärmeföretagen att utesluta falska alarm i en lista är mycket mindre än den tid det tar att manuellt leta efter läckor i en hel stad. Därför kan en algoritm som denna vara av stor användning för fjärrvärmeföretagen, trots den relativt låga säkerheten.

Baserat på åsikter från flertalet fjärrvärmeexperter som använder Digpro's fjärrvärmeapplikation dpHeating idag har en utvärdering av användbarheten av automatiskt läcksökning gjorts. Denna utvärdering visar på att ett verktyg för läcksökning är ett eftertraktat tillägg i applikationen.

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1 Introduction

1.1 Background

District heating means that central power plants produce and deliver heat in form of hot water to whole districts through a underground network of pipes. Many of these underground pipes in Sweden are quite old and thus have started to degenerate; this could potentially lead to many leaks. Leakage can also occur in newer systems as a result of ground subsidence. (Sjökqvist et al., 2012). The lack of good methods to discover leakage in the district heating network leads to unnecessary cost, not only in terms of money, but also environmental and even human life. For example: As a result of a big leakage in the district network in Lund in southern Sweden this year a man died and several people got injured, (Asker, 2015).

Leakages that lies undiscovered for a long time can also cost the district heating companies a lot of money. If the leakage is spreading through the network it can be necessary to replace many meter pipe that could be saved if the leakage was discovered in an early stage. (Nilsson, 2015).

Today many district heating companies use manual techniques to discover leakages in district heating systems, for example measure the amount of water that leaves the hating facility and compare with the amount of water that reaches the households. From this method, (FLIR) states that it can be concluded that there is a leakage in the network but not where the leakage is located. Searching for the leakage manually involves digging up the pipes for inspection, sometimes several diggings are required to find the location of the leakage. Every digging is very costly and requires a lot of time. Thus there is a great need of improved methods to discover leakages in the networks and one potential method is airborne thermal imaging. This technique allow the users to visually see the heat distributions in the image. By placing the thermal image under an image covering the district heating network potential leakages can be localized. One problem with this method though is that it takes a lot of time and energy to manually localize leaks over a big area. It is therefor of great interest to analyse the possibility to detect potential leakages automatically.

1.2 Objectives

This thesis will investigate the capacity of thermal images to automatically detect leakages in district heating networks. Thus the main issue is: How can potential leakages be determined in an automated way using thermal images? To answer this question the thesis has been divided into the following steps:

1. Identify the problems in the current solution for leak detection used in Digpro's district heating application dpHeating.
2. Suggestions of algorithms to find potential leakages in district heating networks and reject false alarms caused by other heat sources.
3. Show how an automatic leak detection tool would work in dpHeating with a mockup: A model over the proposed solution in pictures.
4. Evaluate the suggested leak detection algorithm.

2 Literature Review

2.1 Airborne Imaging

Aerial imagery is the principle of taking images of the ground from an elevated position. The camera can be mounted onto almost any airborne platform. In this thesis though, only the data captured by airplanes will be treated.

To collect the data the airplane flies over the area of interest with a nadir oriented camera mounted on the airframe. That the camera is nadir mounted means that the images are taken from straight above. Such vertical aerial image is a central projection and is not corrected for variations in the terrain, i.e. the scale is not constant, (Lantmäteriet, a). To get a uniform scale the images needs to be orthorectified, this means that the images are radiometrically processed and geometrically projected onto a orthogonal map with an elevation model, (Lantmäteriet, b).

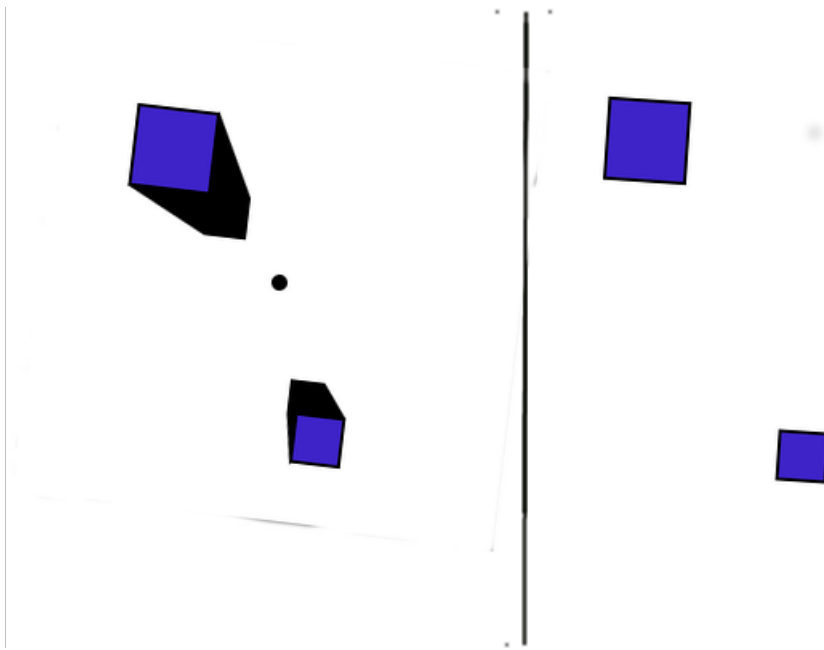


Figure 1: Left: Central perspective, Right: Orthorectified

2.2 Thermal Imaging

In the past years thermal imaging technology has become a very important tool for different kinds of heat detection. All objects with a temperature above the absolute zero more or less emit infrared energy; the warmer an object, the more infrared energy it emits. A thermal camera can capture and present differences in temperature based on the infrared energy emitted by different objects. Thermal images are often in gray scale where black representing cold spots and white representing warm spots, (Rose, 2011). Due to atmospheric effects the thermal scanners are restricted to the wavelengths 3-5 μm and 8-14 μm , (Lillesand and Kiefer, 2008).

Thermal imaging has several very important applications such as fire location rescue operations, minefield location and heat loss detection. Different applications has different requirements on conditions. For most of the applications it is better to take thermal images during night time when the sun is not heating up the surface and most of the cars are parked and cool. It is also of great importance that no snow or leaves are covering the ground, (Friman et al., 2009). According to (Nilsson, 2015) the best thermal images for district heating network applications are provided when the temperature is just below zero degrees.

2.3 Thermal Image Processing

2.3.1 Atmospheric Correction

The atmosphere consists of several different particles, for example water vapour, carbon dioxide and ozone. These different parts of the atmosphere effects the thermal infrared part of the electromagnetic spectrum; atmospheric absorption and scattering and atmospheric emission are atmospheric effects that are affecting the thermal radiation. (Mahiny and Turner, 2010). The atmospheric effects causes a difference in the true surface temperature and recorded reflected temperature, (Meier et al., 2010). The atmospheric absorption and scattering makes the objects on the ground appear colder than they are and atmospheric emission make the objects appear warmer than they are. Thus, if the thermal images should be used for absolute temperature studies, atmospheric corrections is necessary. (Lillesand and Kiefer, 2008).

2.3.2 Thermal Image Classification

The main purpose of classification methods are to classify all pixels in an image in particular classes based on statistical characteristics of the spectral properties. There are different ways of doing this and in this thesis two of the methods are tried and evaluated: supervised classification and unsupervised classification. (Lillesand and Kiefer, 2008)

In the supervised classification algorithm the user has control over the classification by defining training areas. Training areas are areas that representing the spectral patterns in each class. Each pixel in the image are then compared with the training areas and labeled within the class it resembles. The definition of the training areas are a very important step in this algorithm since the whole results is based upon them. For accurate results it is important that the training areas are representative and complete. Therefor, defining trainings areas are a quite time consuming and bothersome process. (Lillesand and Kiefer, 2008)

A more automated process are the unsupervised classification algorithm. This method uses algorithms instead of training areas to map the pixels into different clusters. This method is working well if the data is greatly spectral separated. Although the name of the algorithm indicates that it is an unsupervised classification some human interaction is still needed. The human interaction consists of assigning informational classes to the spectral clusters. (Lillesand and Kiefer, 2008)

2.4 User Interface

According to (Fadeyev, 2009) there are eight things that needs to be considered when creating a successful user interface. First of all the user interface needs to be clear. If the people that interact with the interface don't understand how the application works they most likely don't want to use it again. Besides clear the user interface also needs to be concise, if there are too much text and explanations the users will spend more time reading than doing. This will probably keep the users away. Next important thing when creating a user interface is to keep it familiar, this way the users will know how to navigate in the application. Further the system must be responsive. By this (Fadeyev, 2009) means that the system needs to work fast and the users must know if the system is responding when for example a button is clicked on or if the system is stuck. The fifth important thing when designing a user interface is that the interfaces is consistent. By keeping applications similar to each other the users will learn which buttons do what and how to interact with the applications. Furthermore, to keep the users and making them look forward to use the application the user interface needs to be attractive. What is attractive is up to the user to define, it is therefor important to customize the design for the intended users. Additionally it is important to have in mind to keep the user interface efficient, i.e figure out what functions the users would like to have. Moreover, what needs to be considered when creating user interfaces is to make it forgiving. The users will be doing mistakes and it is therefor important that the mistakes can be undone.

2.5 Leak Detection in District Heating Networks using Thermal Imaging

(Friman et al., 2009) have carried out a study in methods for large-scale monitoring of district heating systems using airborne thermal imaging. In this study the authors discuss how a leakage in the network can be detected and modelled. The conclusion in the report is that a leakage is very hard to model in terms of shape and gradient functions since the ground temperature is a function of not only the studied object temperature but also for example weather and air temperature. Therefore the authors claim that the best way to approach the problem is to treat it as an anomaly detection problem, which is solved by creating a model of normal temperature changes from the thermal images and treat outliers as potential leakages. The potential leakages should then be analyzed manually by a human that is familiar with district heating leaks to sort out the actual leakages from the false alarms.

In the same study as mentioned above the authors claims that the highest amount of false alarms occur close to buildings. Therefore the authors discuss the ability to automatically segment buildings and thereby sort out many false alarms; this method would make the human involvement minimal, (Friman et al., 2009). (Friman et al., 2009) don't mention anything about how to automatically reject other false alarms than the ones close to buildings.

FLIR is a company that has developed a system with airborne thermal imaging to monitor district heating networks. By scanning the city from the sky with a thermal camera a thermal map can be produced. This thermal map is then used together with an automatic detection system to automatically find potential leakages. For the automated detection system to work properly some false alarms needs to be sorted out: for example vehicles, pedestrians and heat leaks from buildings are things that easily could be mistaken for a leak, (FLIR). In this study nothing is mentioned about how the false alarms are sorted out nor how the potential leakages are found.

3 Study Area and Data Description

3.1 Study Area

The study area in this thesis was Örebro City which is a locality located close to the sea Hjälmarén. Örebro has a population of approximately hundred thousand people. The image analysis in this thesis was performed over an area in the city center of Örebro with the size of approximately sixteen square kilometers (4x4 km). The ground area consisted of many buildings and a lot of vegetation such as trees, gardens and bushes.

3.2 Data Description

Thermal images covering the district heating network owned by E.ON. in Örebro were provided. The thermal images were created by Sky Movies and had the projection Sweref 99, the spatial resolution 20cm/pixel and the images were acquired with a FLIR SC8400 camera on 29 November 2013 between 2.15 a.m and 06.20 a.m. local time. The images were georeferenced, orthorectified and corrected for atmospheric effects.

The district heating network data was provided from E.ON. This data was used to reject areas outside the network that easily could be classed as potential leakages otherwise.

An orthophoto covering Örebro was provided by the Geodata portal, GET. This image will be used to segment the vegetational areas from the non-vegetational areas.

4 Methodology

4.1 Identification of the Problems in the Current Solution Used in dpHeating

4.1.1 dpHeating

dpHeating is an application used for managing district heating systems. In dpHeating not only the network can be visualized but the networks-owners can also make network calculations, project planning, maintenance planning and outage management. In dpHeating the GIS data meets the quality standards required for advanced planning and operation. (Digpro).

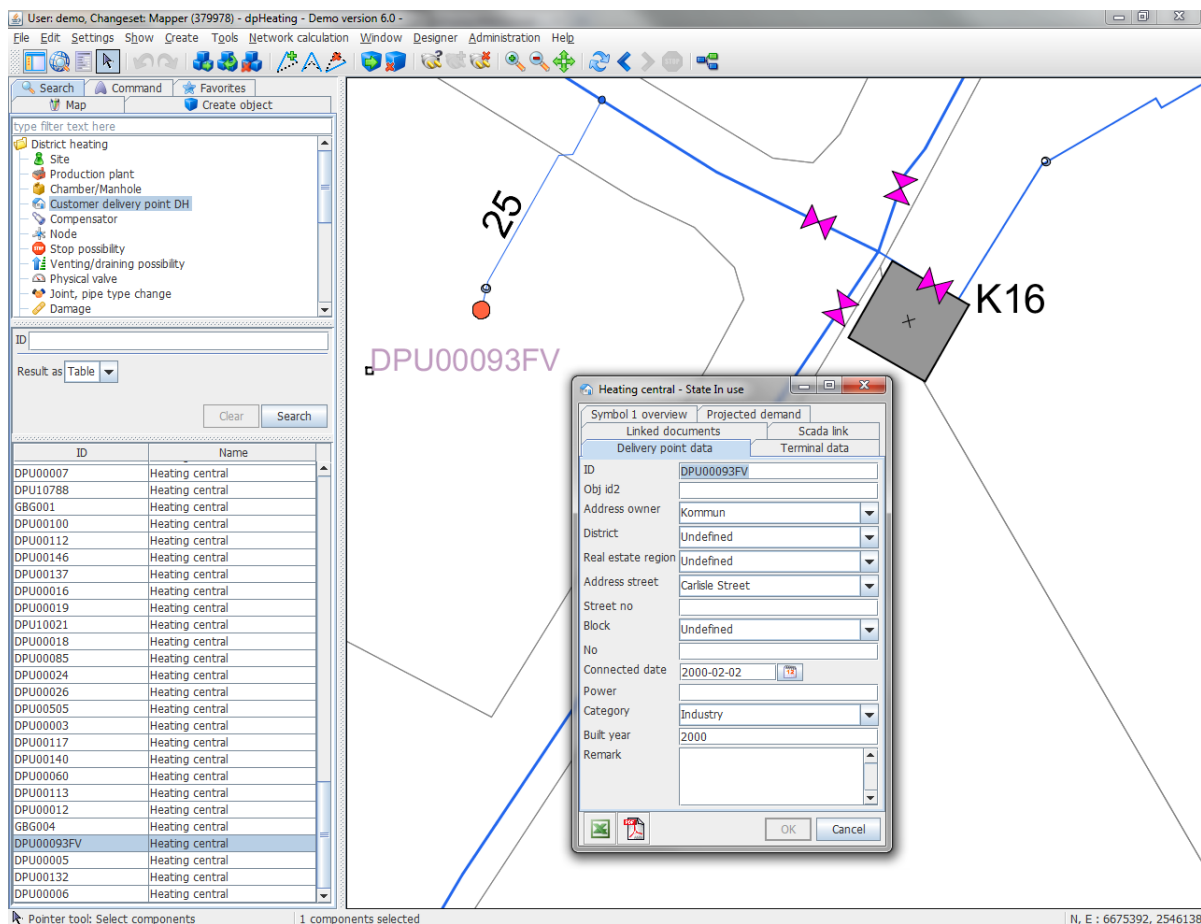


Figure 2: A screen shot from dpHeating.

4.1.2 Problems in the Current Solution in dpHeating

To identify the problems with the current solution used in Digpro's district heating application, dpHeating, the first step was to learn the application. To understand what was missing in the application and what the customers, i.e. the district heating network owner, wanted a needs analysis was done. This analysis took place as an interview with a district heating expert from E.ON. From this analysis knowledge about what the customers tasks and goal were and what needs they had was collected. The outcome of this interview was that the current used leak searching process is time consuming, therefor this process is rarely performed and a better method is desirable, (Nilsson, 2015). This information was then used to identify the current problems and to suggest future improvements.

4.2 Automatic Detection of Leakages in Thermal Images

The method of finding potential leakages in the thermal images included preprocessing of the images before the spectral analysis could be performed. The first step was to define the projection, Sweref 99 TM, of the thermal images. Next step was to create a mask from shapefile consisted of the district heating network. To find the hot-spots in the thermal images and to reject false alarms caused by vegetation an unsupervised classification algorithm, isodata, was used. The flowchart over the used methodology is presented in Figure 3.

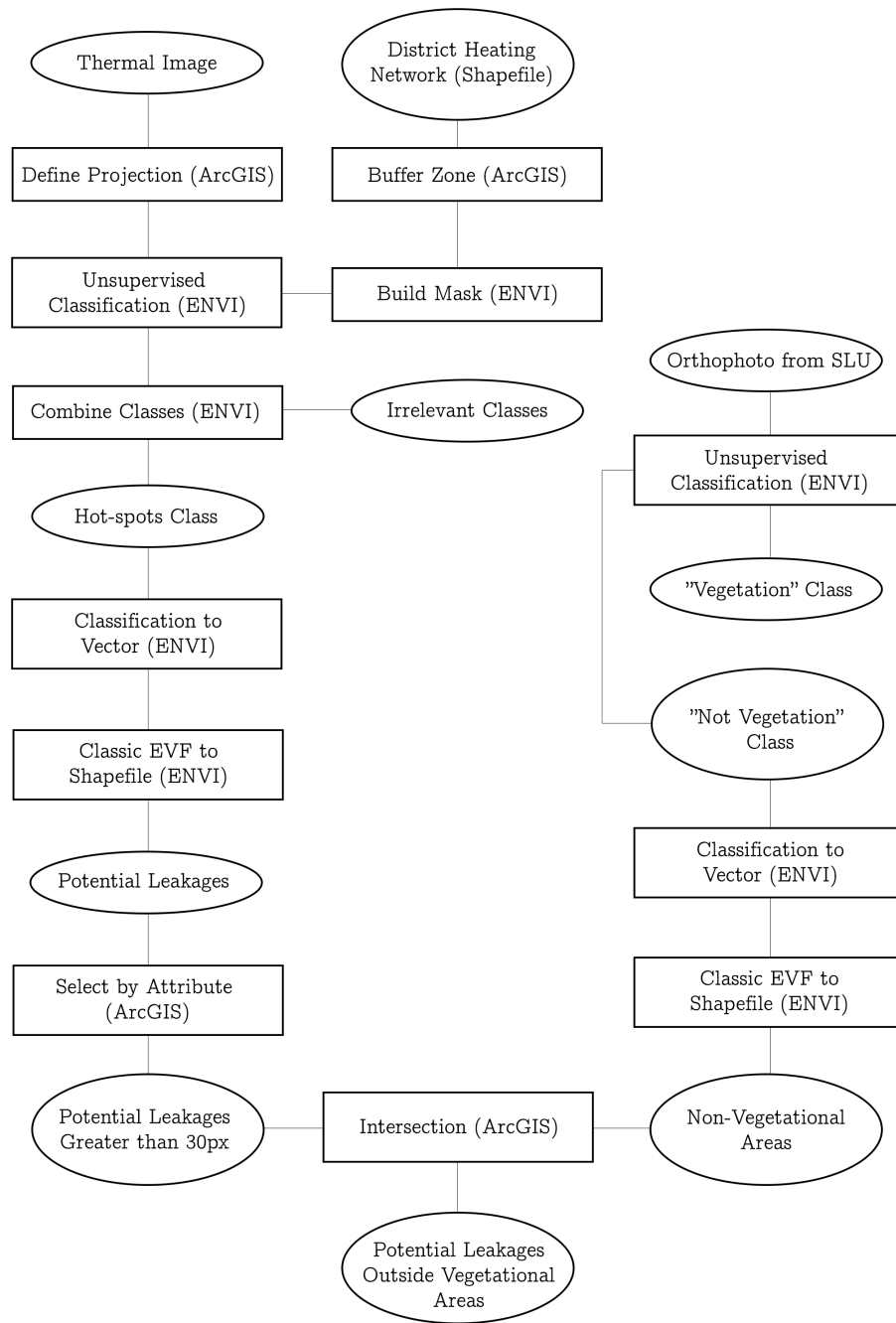


Figure 3: The flowchart over the used algorithm.

4.2.1 Preprocessing

Since the provided thermal images were already normalized and corrected for atmospheric effects this process could be ignored in this thesis. When the images were opened in ENVI the projection were not correct though, the projection Sweref 99 TM was therefore defined in the software ArcGIS. This was done with the tool "Define projection". Thereafter, since the district heating network consists of two pipes, to and from, a two meter wide buffer zone was created around the shape file of the network. This was done with the tool "Buffer".

The first step in ENVI was thereafter to import the shape file and thermal images and create a mask from the buffered network to be able to reject hot-spots outside the network. This was done with the tool "Build mask".

4.2.2 Finding Hot-Spots Through Classification

Next step was to perform a classification on the thermal images to get all the hot spots in one class. Several different classification methods were tried, both supervised and unsupervised, with different number of classes and iterations. The unsupervised classifications algorithms performed were Iterative Self-Organizing Data Analysis Technique (ISODATA) and K-means Classification. The supervised classifications algorithms performed were Maximum Likelihood Classification and Minimum Distance Classification. These supervised classification methods were chosen since these were the most familiar ones to the author of this thesis.

The classification was done inside the mask and the classes consisted of the hot-spots were merged to one class with the tool "Combine classes", these classes were the the same in every thermal image. The combined class was thereafter exported to vector areas with the tool "Classification to vector". This tool generated a EVF file, therefore this file was exported to a shapefile with the tool "Classic EVF to shapefile".

Since very small areas of hot-spots were irrelevant in this case, the larger areas were sorted out. To do this the shapefile with the vector areas was opened in ArcGIS and the polygons with an area over 30 pixels were selected with the tool "Select by attribute". This process also sorted out the areas

above chambers and wells, since the temperature above chambers and wells most of the time is higher than the surroundings these areas are out of interest when searching for leaks with thermal imaging, (Nilsson, 2015). The selection was thereafter saved to a new layer to get only the greater areas together in one layer.

4.2.3 Classification of Vegetation

Since trees absorb heat during the day they appear warmer than the surroundings at night, therefore many false alarms occur over what actually are trees. To deal with this problem in this thesis the trees were segmented from the surroundings. This was done on the orthophoto over Örebro provided from SLU with the unsupervised classification tool "Isodata Classification" in the software ENVI. The generated classes were combined into two classes, "vegetational areas" and "non vegetational areas". The class "non vegetational areas" was then exported to vector with the tool "Classification to vector" and was then exported to a shapefile with the tool "Classic EVF to shapefile". To sort out the potential leakages that intersected with the vegetation the tool "Intersection" in ArcGIS was used.

4.2.4 Implementation in dpHeating

The shapefile consisting of the hot-spots inside the network but outside vegetation areas was imported into the application dpHeating as a reference file. The hot-spots were then compared with the thermal imaging and the district heating network.

In the future the shapefile consisting of the hot-spots could be imported into dpHeating as a shapefile, which means that the hot-spots will be objects. This way it would be quite easy to get all the potential leakages in a list and thereby be able to analyse each potential leakage one by one. The work flow of this process is presented in the mockup.

4.3 IsoData Classification

The isodata classification algorithm is, as the name implies, an iterative method of producing subset of patterns from a set of multi-dimensional patterns. In the isodata classification the centers of each

cluster is randomly placed in the data and pixels are divided between the subsets based on shortest to center distance. Next the algorithm computes the average of each of the subset, the standard deviation of each component and the number of patterns in each subset. If standard deviation is higher than the defined threshold parameters the clusters are split. Splitting also occurs if it is an odd iteration or if the number of clusters is less than one-half of the desired number of clusters. If the distance between the clusters are less than the threshold parameters the clusters are merged. The clusters are also merged if it is the last iteration, an even iteration or if the number of classes is twice as many as desired. After every splitting or merging the next iteration is performed with the average points are used as new cluster points. Iterations are performed with the new cluster centers until the number of pixels in each cluster changes by less than the pixel change threshold or the maximum number of iterations are reached. (Ball and Hall, 1965).

4.4 Mockup

The mockup, i.e how the the suggested solution would look like in the application dpHeating in pictures, was done with screen shots from dpHeating and GIMP, the GNU Image Manipulation Program. The screen shots was manipulated to look like the suggested solution would look like in the application. The user interface was designed based upon how the rest of the application looks like and works. When creating the mockup the user interface guidelines described in section two was taken into consideration.

4.5 Evaluation of the Leak Detection Tool in dpHeating

The results of this thesis were presented on Digpro's user meeting. On this meeting district heating experts from across the country were participating. After the presentation a questionnaire survey was sent out to the attendants to analyse their point of view on the suggested algorithm to solve the automated leak searching problem. The questionnaire was done in Google Drive with guidelines from (Kaden, 2007) and was e-mailed to the participant. The questionnaire survey and the results can be found in appendix B. The results were summarised and used to evaluate the suggested algorithm.

5 Results and Discussion

5.1 Needs Analysis

In the application dpHeating there is no automated function to handle leak detection today. What the customers can do is to upload a thermal image as a background image, draw the district heating network and manually search for potential leakages.

Since leakages that lies undiscovered for a long time can cost a lot of money and get very dangerous, for example if several meter pipes needs to be replaced. An automation of the process of detecting leakages would be very interesting for the district heating companies, if the price is reasonable. From such atomisation of the process the customers wish to get a list with all potential leakages in which they manually can asses the areas and reject any false alarms, (Nilsson, 2015).

5.2 Leak Detection

The one classification algorithm that delivered the best results were the unsupervised isodata classification. This algorithm delivered the classes that best coincided with the true color shifts in the thermal images. One reason that the unsupervised classification delivered better results than the supervised classification could be that the trainings areas used in the supervised classification was to few or poorly placed. It is quite hard to visually see small changes in colors, which might be a reason that the unsupervised classification worked better than the supervised classification.

Another reason that unsupervised classification was chosen instead of supervised classification is that it require less human effort and can therefor easier be used in dpHeating. If the users needs to define trainings areas for each thermal image the amount of manual work would increase wildly. Furthermore, the results of supervised classification are very depending on how the training areas are defined. Therefor the results could be different every time this process is performed. Consequently, the unsupervised classification algorithm is the best approach in this case.

The algorithm described in the methodology section with the unsupervised, isodata, classification generated a file with 72 hot-spots. When comparing the hot-spots generated by the algorithm and

the hot-spots identified by visual inspection, they match relatively well. All four confirmed actual leakages in the data set was also found by the algorithm, see Table 1 and examples in Figure 4 and Figure 5. 13 of the hot-spots generated automatically by the algorithm could be sorted out as false alarms by visual observation immediately since one could tell by the shape of the hot-spot and the surroundings that they are trees, heat leaking from buildings or similar and not a leak in the district heating system, see example in Figure 6.

Table 1: Number of existing confirmed leakages in the data set and how many of them that were found by the algorithm.

	Existing	Found by the algorithm
Confirmed actual leaks	4	4



Figure 4: The thermal image with the overlaying district heating network and a potential leakage generated by the algorithm that is a actual concluded leakage.



Figure 5: The thermal image with the overlaying district heating network and a potential leakage generated by the algorithm that is a actual concluded leakage.

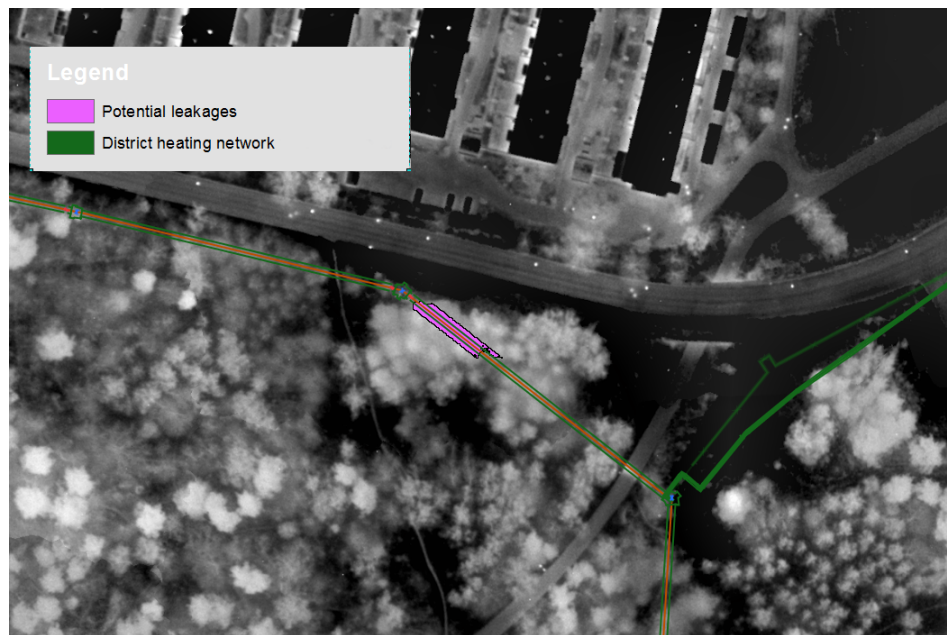


Figure 6: The thermal image with the overlaying district heating network and a potential leakage generated by the algorithm that clearly is a false alarm caused by vegetation.

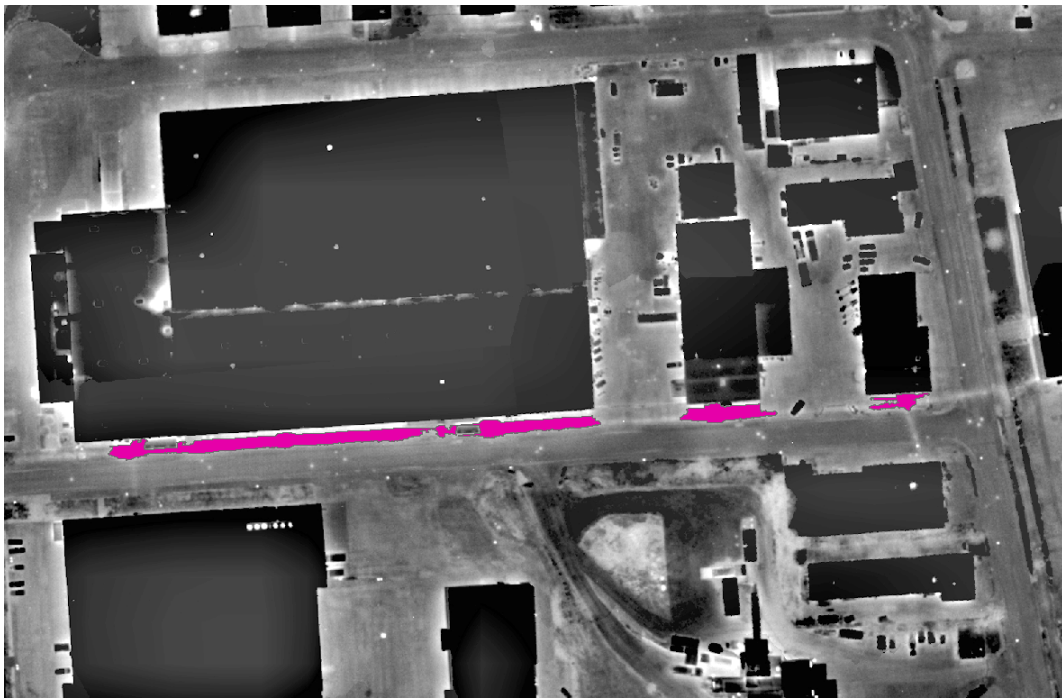


Figure 7: The thermal image with the overlaying district heating network and potential leakages generated by the algorithm that clearly is false alarms caused by heat leaking from buildings.

5.3 Classification of Vegetation

When segmenting the vegetational areas from the non-vegetational areas the IsoData classification was used. From the process described in the methodology section two classes; "vegetational areas" and "non vegetational areas" were collected, see figure 8.



Figure 8: The classes "vegetational areas" (green) and "non vegetational areas" (blue).

After the "Intersection" tool was used in ArcGIS with the "non vegetational areas vegetation" and the "potential leakages" shapefiles only the potential leakages that were intersecting with the "non vegetational areas" were selected and kept. The potential leakages that were intersecting with "vegetational areas" are not actual leakages and were therefore deleted. The number of potential leakages decreased by 15 in the analysed area, this means that 15 false alarms were automatically rejected. In Figure 9 the false alarm presented in Figure 6 are rejected. In Table 2 the number of potential leakages and obvious false alarms before and after the segmentation of the vegetation are presented.



Figure 9: The false alarms caused by the trees in Figure 6 are rejected.

Table 2: Number of potential leakages and obvious false alarms before and after segmentation of the vegetation.

Potential leakages	Found	Obvious false alarms
Before segmentation of vegetation	72	25
After segmentation of vegetation	57	10

5.4 Evaluation of the Accuracy and Usability of the Algorithm

In Table 2 the number of potential leakages in the area after the classification of the vegetation decreased to 57. With only four concluded leakages in the data set one can wonder if the rest of the generated potential leakages are false alarms. Many of them are probably false alarms caused by other heat sources like heat leaking from buildings or similar. But some of them are probably leakages that just don't have been concluded by the district heating companies yet. Since the number of false alarms is presumably higher than the amount of actual leakages the accuracy of the used algorithm is not as high as wished.

Many of the generated false alarms are easily rejected by experts and if the district heating companies can find four or five leakages in an area this way with just a few days of work it is still way faster and easier than the manual methods that are used today to find leakages. To look for leakages in an entire city manually is more time consuming than go through a list of potential leakages and manually reject false alarms. Therefor this used algorithm for leak detection, despite the quite low accuracy, would be a good tool for the district heating companies.

More accurate results and less false alarms could probably be solved by another method to find the potential leakages, for example to use a temperature gradient on the raw data. With this method big temperature changes, two-three degrees, could be located and marked as hot-spots. With this data even physical properties as how low the pipes lies could be taken into consideration and the IR-radiation for each pipe could be analysed. Furthermore, when knowing the temperature changes of the hot-spots the leakages could be ranged with respect to the temperature differences.

The raw temperature data were available in a format that only could be opened in a specific software. When using the data in this software approximately 5000 images that neither were georeferenced or orthorectified were generated. To work with this data would have taken too much time and this method was therefor rejected in this thesis.

Another method for more automatically rejected false alarms and thereby better accuracy could be to segment all the buildings as Friman did in their study. However, some leakages actually occur nearby buildings, for example the concluded leakage in Figure 4. These leakages would be missed if the areas close to buildings were segmented and rejected. It is therefor not optimal to reject all potential leakages close to buildings. One way to solve this problem might be to analyze the shape and the linearity of the generated potential leakages. Since the false alarms caused by heat leaking from buildings are somewhat linear if the buildings are located next to each other (see Figure 7), it would probably be of great value to analyse this. This analyse require more time than provided for this thesis though and was therefor not performed.

5.5 Mockup

The mockup is based upon the tips from (Fadeyev, 2009) described in the second section of this thesis and the requests from (Nilsson, 2015) collected during the interview. A few examples of the results is presented below.

In Figure 10 the report for the potential leakages is shown. In Figure 11 the attribute form for the potential leak is shown and in Figure 12 it is shown how the potential leak could be tracked down to the pipe that is causing the leak.

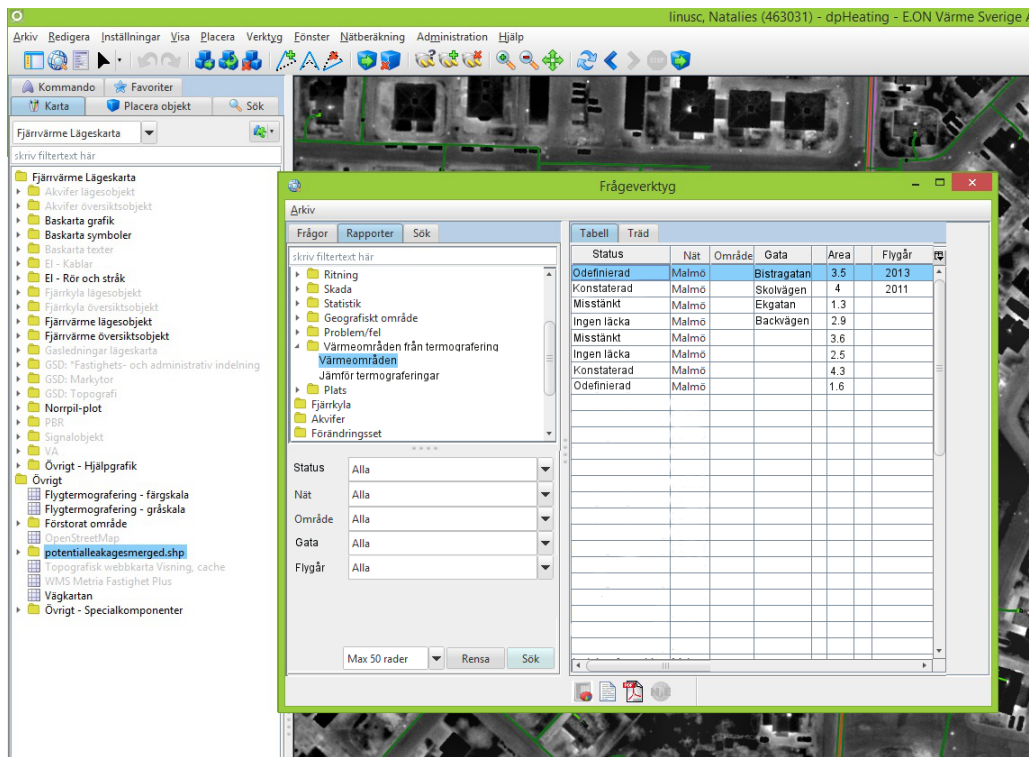


Figure 10: "Heat areas from thermal imaging"

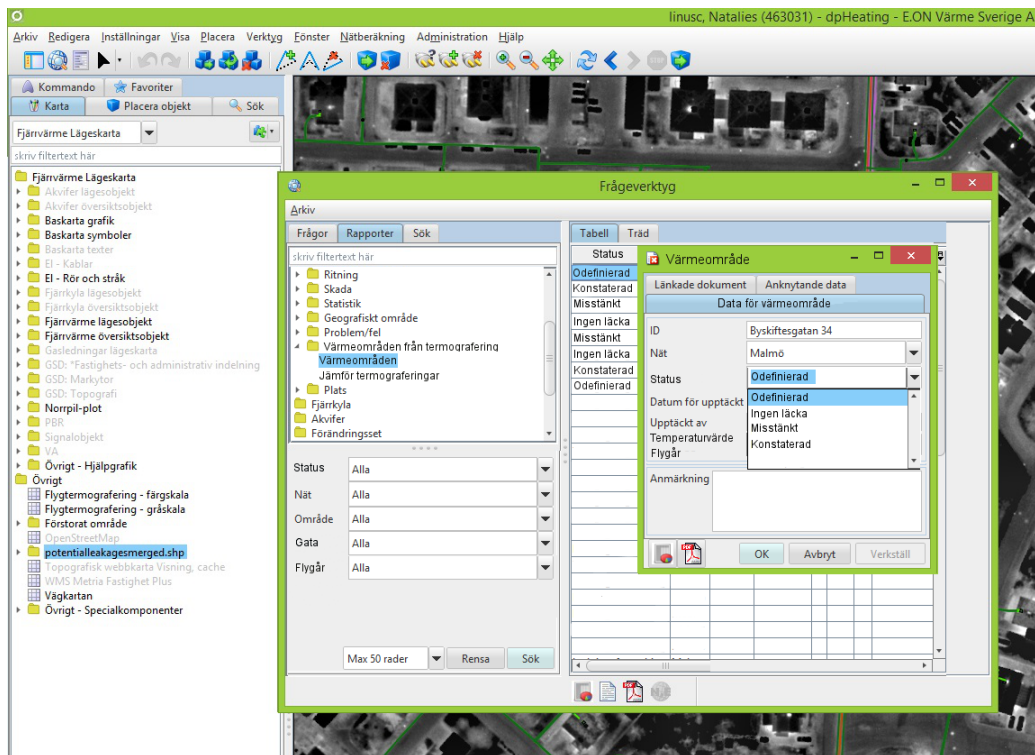


Figure 11: The attributes of the potential leak could be changed.

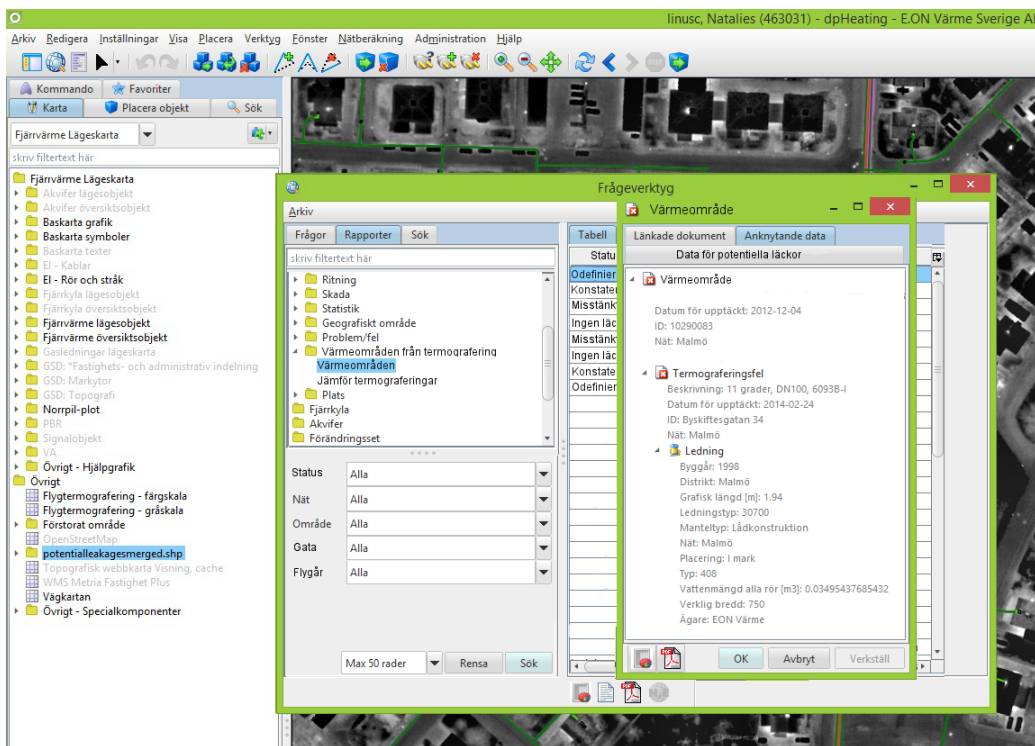


Figure 12: The attribute form, tab: Related data

5.6 Evaluation of the Suggested Leak Detection Tool in dpHeating

A questionnaire was sent out to the district heating experts participating on Digpro's user meeting where the outcomes of this thesis were presented. The attending experts were from different companies with different area of expertise in district heating systems, the details about this can be found in appendix B. All of the attending experts have great experience with the application dpHeating. The evaluation is based upon answers from 12 subjects.

When looking at the answers collected from the questionnaire one could tell that an automatic leak detection tool is welcomed by the subjects. The subjects are overall positive with the suggested solution of the problem and many of those who uses thermal images for leak detection today thinks that a lot of time could be spared if the process became more automated. All of the subjects also thinks that the proposed leak detection tool would be useful in Digpro's application dpHeating and that the suggested user interface seems easy to follow and understand.

One of the subject thinks that the suggested algorithm is a great first step for further more advanced leak detection algorithms where the IR-radiation of each pipe could be analysed.

6 Conclusions and Further Work

6.1 Conclusions

Automated leak detection in the district heating networks would be useful for the district heating companies since the current method, manual search for leakages, is very time consuming. The proposed algorithm in this thesis has proved to be useful and since it finds the actual confirmed leaks in the data set the results is satisfying. The number of false alarms with this method is relatively high though, but compared to the amount of time the manual leak detection takes it is still a great improvement. Automatic leak detection in district heating network is thereby possible. More studies over bigger areas and with more confirmed leakages needs to be done to be able to tell whether or not the algorithm is useful in every scenario.

The used method to segment the vegetational areas from the non-vegetational areas automatically reject many false alarms caused by vegetation. This decreases the work for the uses and thereby increases the usability of the algorithm. More profound studies needs to be done to be able to handle other false alarms such as heat leaking from buildings.

A better way to solve this problem could be to work with temperature gradient, this would be more accurate and one would be able to range the potential leakages from hottest to coolest and thereby increase the usability even more.

6.2 Further Work

6.2.1 Short Term

As mentioned in previous section it would be valuable to look at several different methods to find the hot spots in the thermal image to be able to tell which one is the most reliable and effective. With more time the best way to solve this problem would probably be, as mentioned above, to use the raw data file with temperature information. Since this file generated approximately 5000 images that neither were orthorectified or georeferenced the time was not enough in this thesis but for future studies this

would be appropriate.

It would also be of great importance to analyse further how the number of false alarms could be automatically rejected. It would probably be valuable to look at the shape and the linearisation of the potential leakages close to buildings.

6.2.2 Long Term

In long term it would also be of great interest to analyse the amount of the heat losses from the leakages. With this information the amount of costs for every leak could be calculated. To be able to do this knowledge about how the heat moves in different material, the factors affecting the transfer and the physics involved when determining the IR signature is necessary. To be able to tell the exact radiation of object several things needs to be taken into consideration, not only the properties of the sensor and the atmosphere but also the emissivity and the reflectivity of the target, (Stockton, 2007).

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Questions to Patrik Nilsson E.ON.

- Is there any concluded leakages in the data set?
- When are the images from? Which time of the day/year? How much does the time of the images matter?
- How do you detect leakages today? Which role has dpHeating in this process? How do you find interesting points (potential leakages)? How do you conclude that it actually is a leakage?
- How much time do you spend on finding leakages? How often do you search for leakages?
- How much does undiscovered leakages costs every year?
- Do you think that you will save much time and money to get the process automated?
- Which needs do you have of an atomisation of the process? What do you think is the most important with an atomisation?
- What is acceptable temperature changes close to wells and chambers? Are these areas of any interest whatsoever?

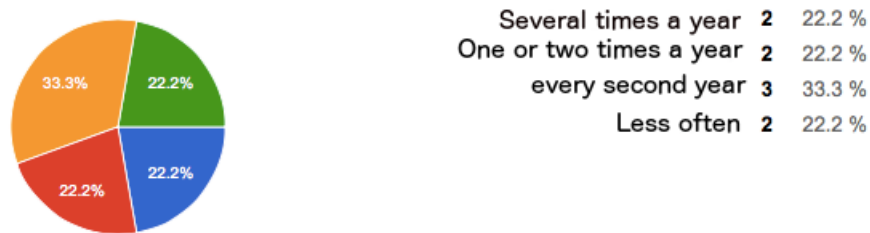
Survey

Participating Companies E.ON Värme, Norrenergi, Umeå Energi AB, Fortum Värme, Bodens Energi, Göteborgs Energi, Alingsås Energi Nät, Krafringen Energi.

1. Do you use thermal imaging when searching for leakages today?



1b. If yes, how often do you search for leakages?



1c. If no, why not? What methods do you use instead?

Snow melting, experience, water in chambers.

We tried to use thermal images in early 2000, but the technique was not so good back then and it didn't work as hoped.

Comment to question 1: We usually order the leak detection analyse from the companies that provides us with thermal images. Other method for leak detection is alarm wires in the pipes and inspections.

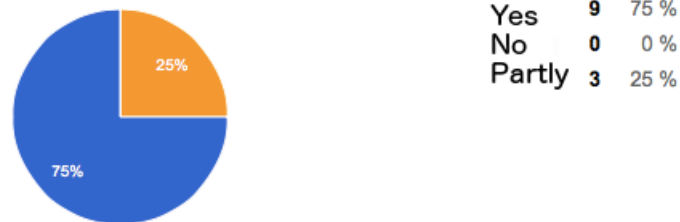
Vi uses alarm wires in the pipes. We don't have any old pipes in concrete culverts or similar.

We don't have any other methods for leak searching, it is probably a question of money.

2. Would an atomisation of the leak searching process be helpful?



3. What do you think about the suggested user interface in dpHeating? Does it seems easy to follow and understand?



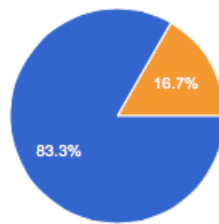
3b. If no, why not?

4. Do you think it is good to get the potential leakages in a list in which the users can go through one by one?



4b. If no, how would you like to have the results instead?

5. Do you think this leak searching tool would be used if it existed in dpHeating?



Yes	10	83.3 %
No	0	0 %
Partly	2	16.7 %

5b. If no, why not?

6. Other comments or suggestions

It was a nice presentation you had and it seems to be a interesting subject. It sounds like a very good addition in dpHeating! It would spare time and/or money at the same time as more more control in the company is gained if we can do the analyse ourselves. I'm not so familiar with our thermal imaging but I will talk to my college who is in charge, he most likely interested in your work.

We think that we also would like to look at the thermal images manually and compare with the automatic, often we know what is a leakage and what is not a leakage.

This is a very good first step for further more advanced analyses based on the specific IR-radiation from the pipes in the ground.

Very good presentation that was easy to understand and follow. The application you have developed is requested among the maintenance engineers at my place of work.

Good luck with your further studies. I hope that the answers from Alingsås Energi came in fast enough, I also made an questionnaire for my thesis and I know how hard it can be to gain enough answers.

It seems exciting, since I'm alone with dpHeating we don't have the organisation to do this at this point though. It would be fun to gain further information about this project, price and workload.