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THE ANALYSIS OF CONTAMINATION DERIVING FROM THE LEAKAGE OF SUBSURFACE PIPELINE NETWORKS USING REMOTE SENSING

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Abstract

Patches of melted snow on the surface can serve for the easy detection of underground oil or thermal water pipeline networks. This thermal effect can be recognized during the spring as well when vegetation tends to grow more rapidly over the pipeline than in its surroundings. Old pipelines may be fractured or leaking due to different physical and chemical processes and the soil and underground water can become contaminated by natural oil, gasoline and other waste materials. The aim of the research group (Department of Physical Geography and Geoinformatics, University of Szeged, Hungary; A.A. Stádium Ltd. and ERMI-2000 Ltd.) was to develop a methodology for discovering pipeline leakage at a very early stage based on aerial thermal and video images. The GPS coordinates were added to the images and these data were processed in a GIS platform (self-developed ESRI ArcMap extension). An FLIR SC 2000 thermal camera was used; the spatial resolution of the captured images was 30 cm. The video images were less useful than the thermal images in pipeline detection during the spring and the summer when land use changes due to vegetation transformation, and during the winter when a thick snow covers the ground. Due to the spatial and thermal resolution, small spots of leakage on the surface could be recognized on the thermal images. Spatial coordinates of the leakage quickly identified its location and this was a great benefit in allowing for rapid environmental rehabilitation. We hope that the developed methods can be used to monitor the pipeline network on the largest oil field in southern Hungary on a daily basis (or for flood risk assessment or forest fire localization).

Introduction

The fracture or leakage of pipelines very often leads to critical situations, just think about the some last years' rupture of main large-diameter water pipelines in Budapest. The illegal tapping of transportation pipelines via drilling may lead to not only significant contamination at the site but this wanton behavior often claims lives as well. Several hundreds or even thousands of kilometers of subsurface pipeline networks are present in the neighborhood of producing oil and gas fields. The continuous track line monitoring of old pipes is highly desirable, especially in case of the subsurface pipelines established several decades ago, due to the more and more frequent natural ruptures and leakages. The aim of our research was to develop a new remote sensing method, based on the already available technologies, which enables the discovery and localization of leakages at an early stage on the field, well before the appearance of the first signs on the surface. Furthermore, it makes the identification of the type of leakage possible as well. With the help of various measurements carried out on the field, we tried to verify that heat emission from these subsurface pipes causes measurable temperature variations on the surface, making the use of aerial remote sensing devices feasible for the detection of such lines.

Our goal was to assign geographical coordinates to the captured aerial video and thermal images enabling the processing of the acquired data within a GIS platform.

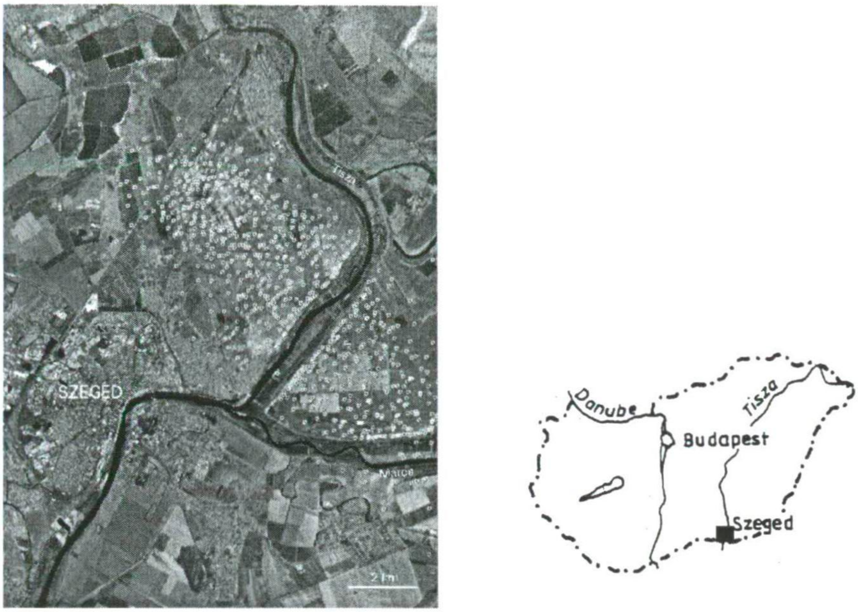

Figure 1. The geographical location of the investigated area and vector coverage of the sites of oil, gas and thermal water wells on a Landsat TM 453 (RGB) satellite image

The resulting self-developed environment-monitoring and decision support system was tested for various surfaces, vegetation types regarding usability and efficiency. The implementation of this idea was greatly assisted by the support from a successful project of the Department of Physical Geography and Geoinformatics, University of Szeged handed in for the IKTA-3 KÉPI-2000 tender of the R+D Secretariat at the Ministry of Education in 2000 under the title "The development of a thermal image recording and processing system (TEKER)". Two local enterprises also took part in the tender, namely A.A. Stádium Ltd. and ERMI-2000 Ltd. The producing gas and oil fields of the MOL Hungarian Oil and Gas Plc., located north of Szeged were selected as pilot area in our study; the necessary papers and documents were obtained from the owner for the execution of the flights and research.

Methods

More than 1000 producing wells and a system of approximately 1700 km-long subsurface pipelines can be found in the producing field of Algyő.

Petroleum prospecting and exploitation beginning in the 1960's has significantly altered the former agricultural landscape. The walls of the different pipes (oil, gas, thermal water pipelines) are subjected to intensive thinning via corrosion with the pass of time. This degradation may finally lead to rupture or leakage caused by physical, chemical or possibly anthropogenic impact and the seepage of the transported material into the soil or groundwater in the pipe's surroundings.

However because of the buried past riverbeds, and the interconnections among the present hydrological systems and River Tisza the material seeping from the pipelines may damage larger areas, possibly living waters as well.

The produced oil, gas and thermal water is transported to the collectors from the wells and then to the main collector in pipes. Following several observation flights carried out in February and May 2000 (MUCSI, 2001a; MUCSI, 2001b; MUCSI–VARGA-FERENCZY, 2001c) it became quite obvious that these pipelines significantly influence the temperature of their direct neighborhood, the outcome of which is observable even with the naked eye. The heat surplus deriving from the pipes enables the rapid growth of vegetation during early spring, however it also leads to desiccation of the soils and vegetation during early summer as well (see **Fig. 2-3.**).

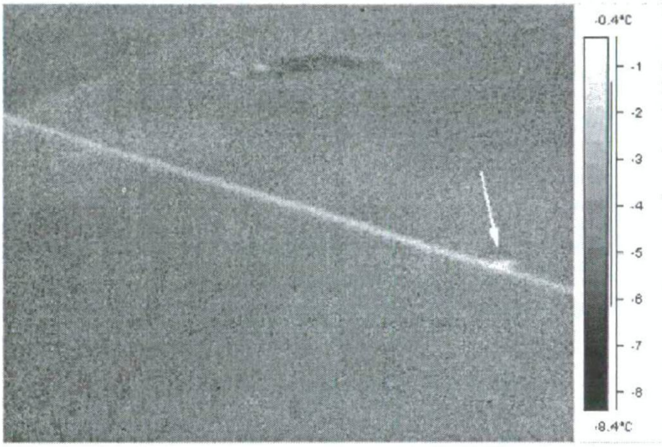

Figure 2. Hot-spot (thermal contamination effect of the fracture) on a thermal water pipeline (marked by the white arrow)

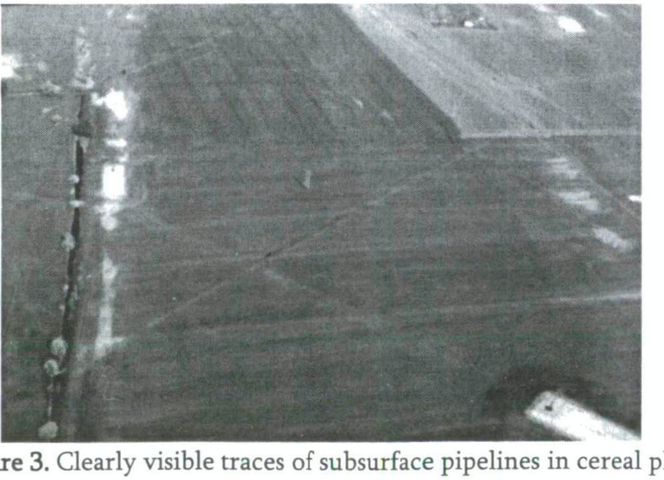

Figure 3. Clearly visible traces of subsurface pipelines in cereal ploughfields
(May 2000, photo by: L. Mucsi)

Figure 4. Patches of melted snow clearly indicate the path of subsurface pipes as photographed on the 26th of November 2000 (by: M. Dzsupin)

The thin layer of snow covering the ground during winter very often melts above the pipelines as it can be seen on the photograph taken in 2000 (**Fig. 4**).

There are several possibilities for monitoring pipeline networks based on domestic and international experiences. A controlling-measuring system (DiTEST) (e. g. fiber-optic cables) can be installed below the pipelines during piping. Continuous monitoring of pressure within the pipes (FLEXIM), acoustic monitoring (SHIFENG, 2000), or feeding radioactive materials into the pipes followed by the measurement of γ radiation (DEVELOPMENT...) may all serve as possible tools for discovering small leakages. The hydrocarbon content present in the air in the soil can also be traced with a suitable device like the German KAMINA (KAMINA), which is, after programming, capable to identify various hydrocarbons (digital nose). Several approaches are known in aerial monitoring as well ranging from the evaluation of simple color aerial photographs (GEOPLACE), to the application of thermal cameras, 3D seismic measurements (FUGRO), or even aerial flame spectroscopic devices analyzing HC compounds (AET).

Aerial pipeline monitoring is carried out on a daily basis in our pilot area, however the success is greatly dependent on the experience and expertise of the monitoring staff. Digital cameras and video cameras are used for documentation. No other devices or systems support the recognition of leakage.

Ruptures and the accompanying leakages are very often recognized too late in this producing field, covering about 150 km^2, and in such cases the expenses of rehabilitation and decontamination may reach several 10 million forints.

Pressure monitoring used besides aerial monitoring of pipes cannot successfully identify minor pressure losses caused by smaller leakages.

Furthermore, even when the pressure loss is identified the precise location of the rupture can not be determined. Based on the governing physical laws and our personal experiences, utilization of thermal cameras of appropriate sensitivity and resolution, and the processing of acquired thermal images in a GIS platform may enable the recognition of such accidents even in their initial stage. This early recognition could greatly reduce damages to the environment as well as the cost of rehabilitation efforts.

Results

A, Soil temperature measurements on the field to determine the spatial distribution of excess heat

Up till now it was unknown exactly to what extent do the subsurface pipelines influence the surrounding temperatures. Thus as a first step, it was analyzed whether or not any temperature difference can be traced in the neighborhood of active pipelines. A soil temperature recording system was designed which enables continuous data recording and digital data storage. The requirements of the system consisting of 16 soil thermometers had been conceptualized, and Astrum 2000 Ltd. was asked for the technical implementation and the development of downloading and conversion software.

A short description of the system:

a, 16 soil thermometers with a 5 m wire link to the data recording unit	**b**, 0.1-0.2 °C accuracy, data recorded with two decimal places	**c**, data recorded every 10 minutes
d, storage capacity is 6-8 weeks	**e**, data read with „Szonda" software via RS-232 port	**f**, power supply of 220 V, with a 2 weeks UPS backup.

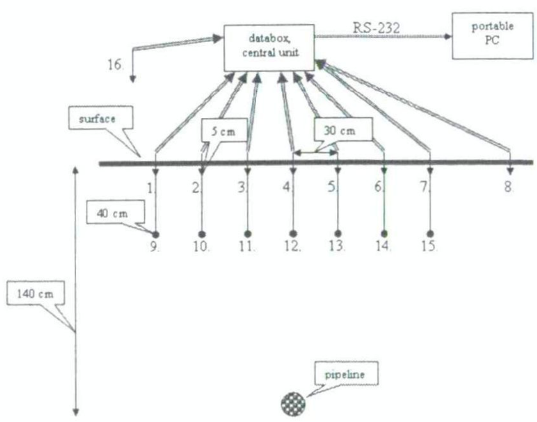

Figure 5. A schematic of the location for soil thermometers – 16-channel soil temperature recording system after installation

The system was installed to the SZT-5 collector station of the pilot area. The thermometers were placed above the pipeline at a distance of 30 cm, 7 of them at a depth of 40 cm, and 7 at a depth of 5 cm in the ground. A single thermometer was placed 5 cm deep into the ground at a distance of 1.7 m away from the pipe, and the last one was settled 2 m above the surface to capture air temperatures (**Fig. 5.**). The installation took place on 30/10/2001.

Data series recorded between 30/10/2001 and 09/01/2002 are depicted on **Fig. 6.** After evaluation the following conclusions can be drawn:

a, there is a decrease in soil temperatures during the winter months, temperatures are well above zero with a well-observable daily cycle

b, the highest temperatures were recorded by the thermometer located directly above the pipeline in all cases

c, the marginal thermometers recorded successively lower values their distances from the pipe increased

d, there was an average difference of 2° C between the central (12.) and marginal (15.) thermometers (located at a distance of 90 cm)

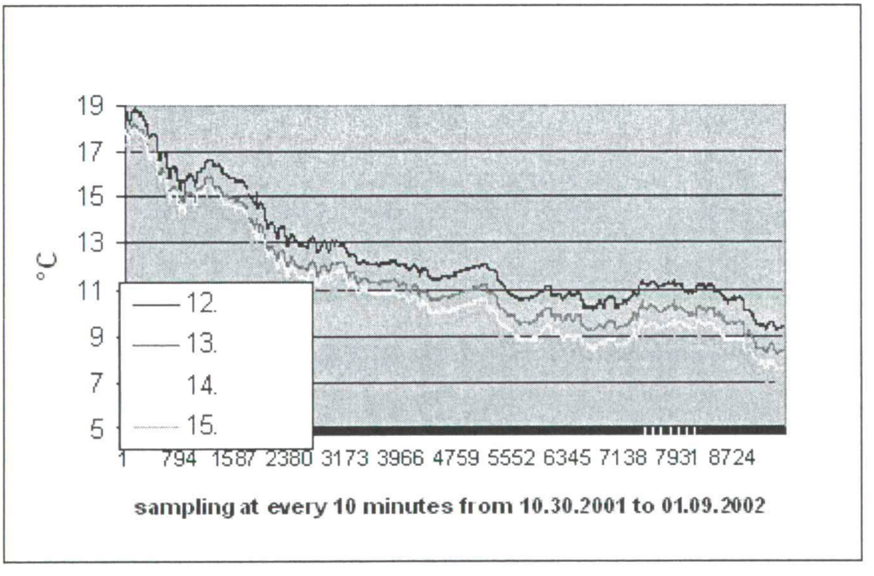

Figure 6. Soil temperatures at a depth of 40 cm on the right hand side of the pipeline

B, Determining the geometric resolution of the thermal camera

The sensitivity of the thermal camera used was rather high (0.1 °C, see **Table 1.**), thus temperature differences reaching larger values than this in the zone above the pipe can be identified at sufficient geometric resolution. However, the distances, inside which further temperature differences can be observed on the right or left side of the pipeline, were also unknown before soil temperature measurement.

The extent of this zone of varying temperatures, a specific field of view (FOV) (α = 24°) and the FPA panel size (320*240 pixel) determine the flight height required for the achievement of sufficient geometric resolution during the flights. If the camera is fixed in a way that the shorter side of the thermal image is parallel to the direction of flight then the resolution of the acquired image can be calculated from the parameters of flight height (h), FOV (α) and the number of FPA rows (240) with the following equation:

Resolution (r) = (2 * h * tg α/2)/240

if h = 240 m (about 800 feet), α = 24° then r = 31 cm.

With such resolution the whole image covers an area of 115x81 m. Considering flight speed of 150 km/h (41.6 m/s), and images being recorded every second, then the outcome is images overlapping with a ratio of 50%. If the camera is perpendicular to the original state then this overlap between the successive images is even larger, 63 %.

Table.1. Technical data for the thermal camera FLIR SC2000

Type:	FLIR SC 2000
Accuracy:	± 2 % of the whole range or 2 °C
Thermal sensitivity:	< 0,15 °C
Angle of view:	24°×18°
Focus:	0,5 m - ∞
Detector type:	Focal Plane Array (FPA), non-cooling microbolometer 320×240 pixel
Spectral range:	7,5 – 13 μm
PC card:	PCMCIA II. or III. FLASH, or ATA compatible Hard Disk
Image storage:	14 bit full dynamic

C, The integration of image data into a self-developed GIS extension

In addition to the thermal camera a digital video camera has also been used. The primary aim was to determine the efficiency of the thermal camera in comparison to video images recorded in visible light. However the larger FOV together with the higher spatial resolution of video images enabled better localization of the leakage.

The acquired images for the same areas deriving from different sources in different formats (video - AVI, thermal camera from IMG to JPG) were synchronized on the ground and registered with GPS data recorded cinematically on the plane with a Topcon Turbo-SII GPS and were processed at a later stage.

The recorded images, GPS data and the orthophoto maps prepared earlier (Aerial photography of Hungary project, 2000) were stored and processed in a GIS platform capable of processing and viewing motion picture as well image is displayed (**Fig. 7.**), while the lower left window contains the thermal images recorded every second with the central coordinates and the time of image capture indicated. This self-developed program is an extension of the ESRI ArcGIS platform, thus its use requires the installation of the ArcView 8 software package.

One of the greatest advantages of using this GIS framework is the availability of all its viewing and processing functions within the extension, granting a wide spectrum of viewing and analyzing possibilities to the researcher.

The system is made up of three individual units displayed in three windows enabling individual positioning on the screen according to the analyzer's will.

One possible arrangement of these windows is seen on **Fig. 7.**. In this case the map of the area is placed in the larger window on the right. In this window, along with the other coverages placed over the original ortho-photograph, a continuously moving symbol indicates the location of the plane or the captured image.

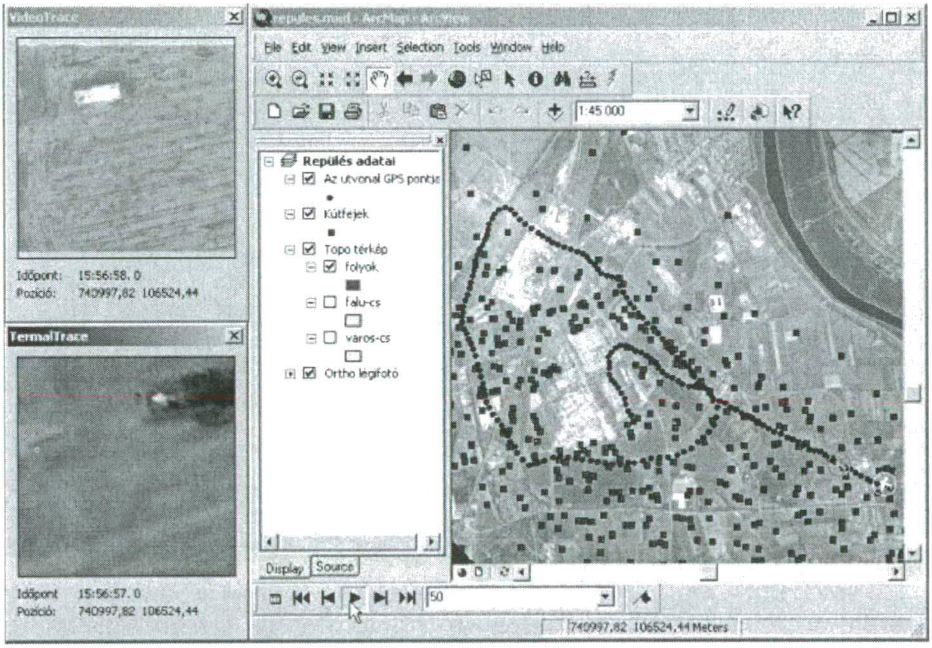

Figure 7. Application view of ArcMap for viewing and analysis of image and spatial data

The menu on the upper side of the window along with the tool buttons are used for the initiation of various geoinformatical commands like zooming-in and out, picture flip and rotation, query of, modification, load and save of attribute data, etc. In the upper left window the video

D, The filtering of thermal images with a self-developed program

The visual evaluation of thermal images is as easy as one, two, three for the professional eye, however the processing software coming with the camera (ThermaCAM Researcher 2000™) makes the evaluation of the images feasible on an individual base as well. In case of our device the acquired images needed to be filtered before processing, because relatively small temperature differences appeared as a veil-like noise on the images, which was quite disturbing during further analysis (**Fig. 8.**).

E, Comparative analysis of video and thermal images

According to our observations made during the flights, the traces of pipelines can be easily followed on the thermal images even in areas with dense vegetation.

Temperature differences were around 2 °C in the zone of 3-4 m above the pipelines during the time of analysis. Maximum temperatures were recorded above the lines as seen on the temperature profiles with a gradual decrease towards the sides.

Changes in soil structure can be observed on barren surfaces, but the traces are a lot sharper on the thermal images. If the trackline is complex or more pipelines are running next to each other, the application of thermal imagery is even more successful (see **Fig. 9.**).

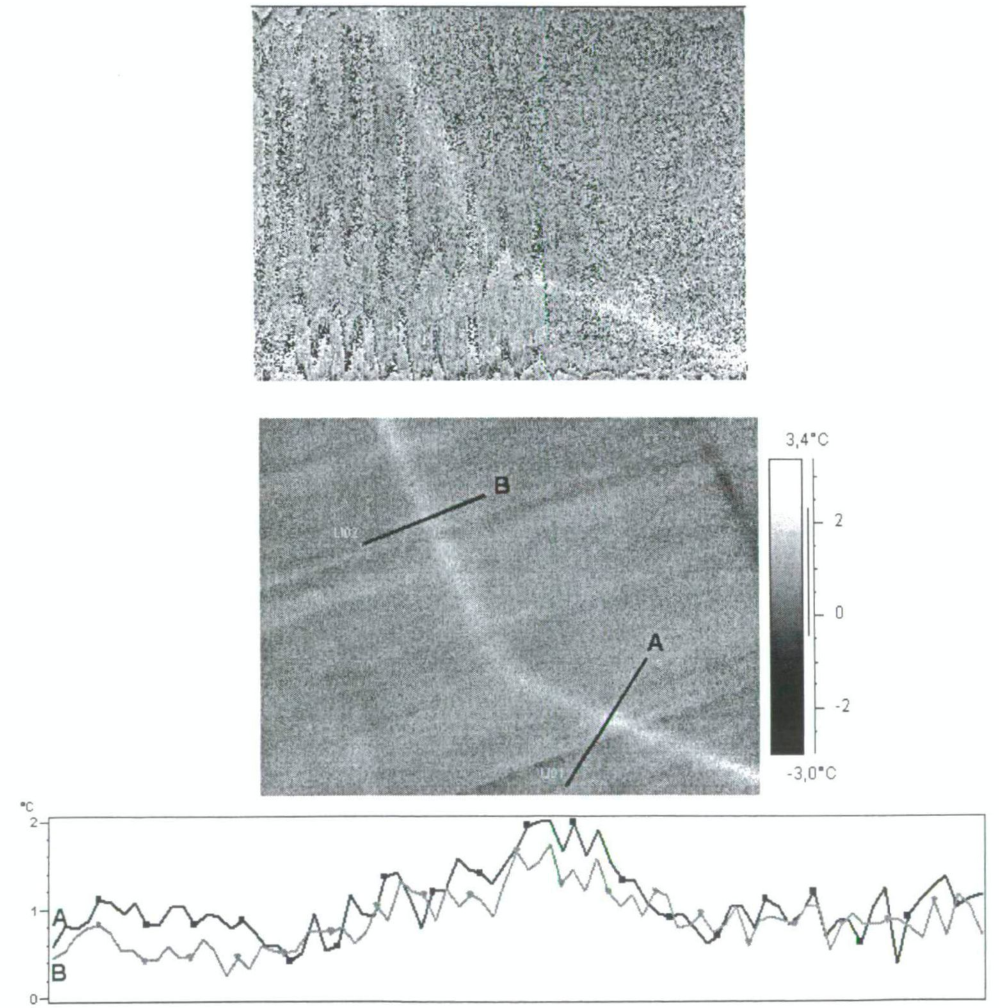

Figure 8. Original and filtered images of a hot thermal pipeline with two observed temperature profiles

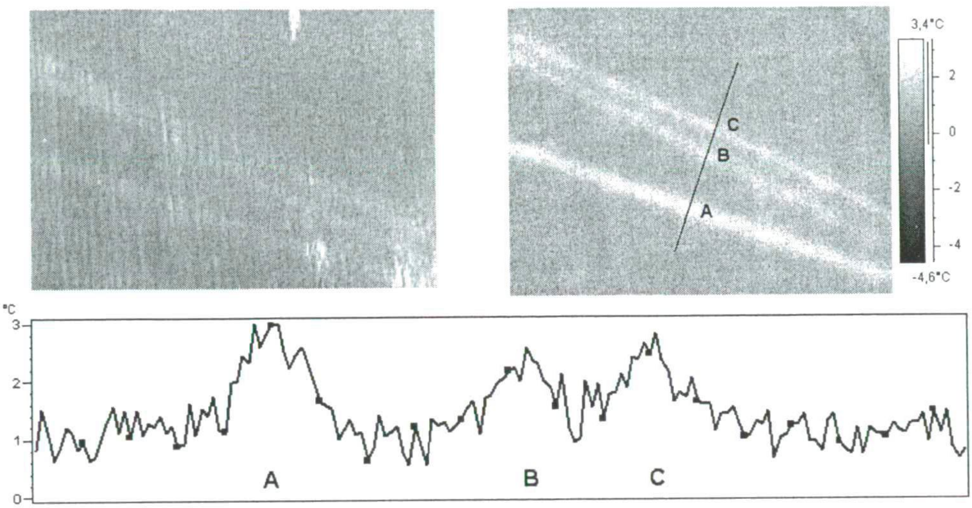

Figure 9. The trackline of three pipelines on video and thermal images and the observed temperature profile

Thirty flights have been carried out as part of the project yielding the discovery of some leakages. In the following few examples for the leakage of cold- (**Fig. 10.**), and hot (**Fig.11.**) pipes can be observed.

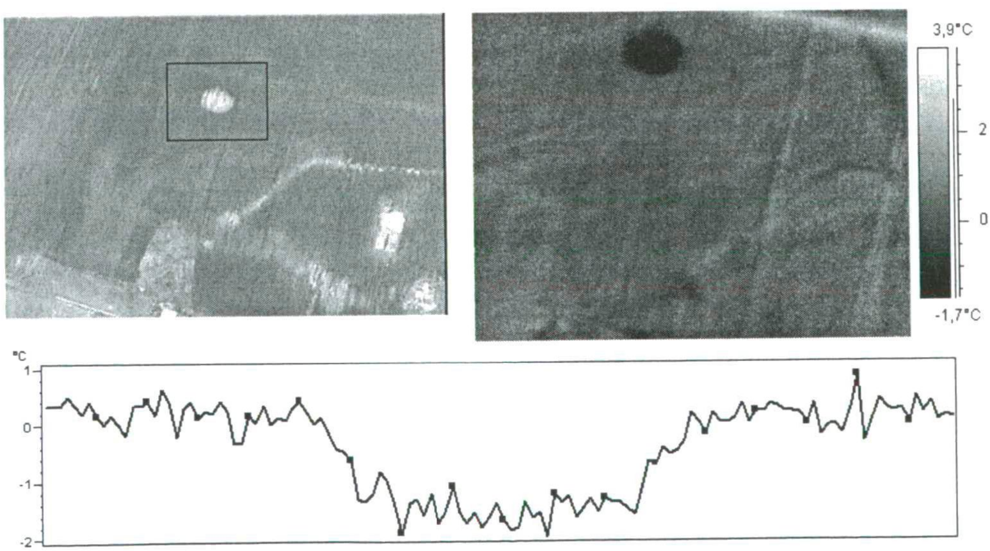

Figure 10. The spot of a leakage in cold (gas) pipe on a video and a thermal image with an observed temperature profile

The spot of leakage in case of the hot pipe (oil) is almost undetectable on the video image but it is clearly observable on the thermal image (**Fig. 11.**).

The diameter of the light patch, in the circle on **Fig. 11.**, is about 1,5 m. As it can be seen on the temperature profile there is a steep increase in surface temperatures towards the center of the leakage with a 5 °C higher value in the center of the spot than in the surroundings of the pipe (the normal difference was around 2 °C).

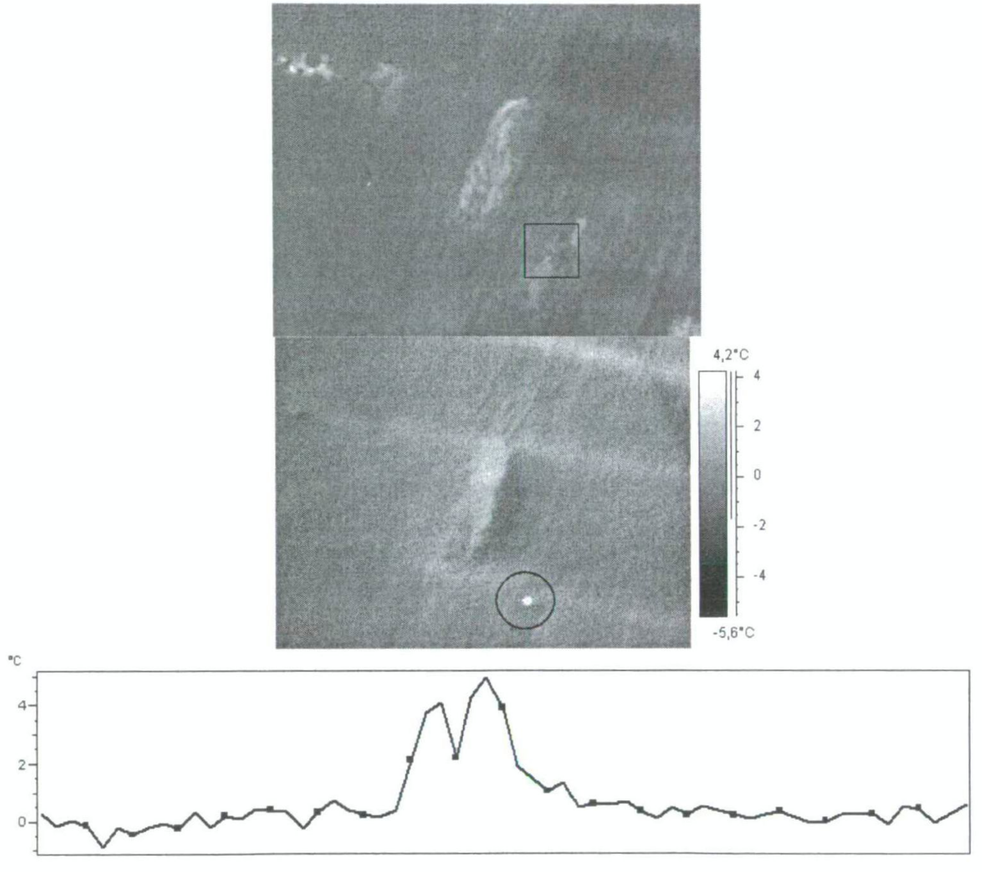

Figure 11. The spot of a leakage in hot pipe on a video and a thermal image with an observed temperature profile

F, Further processing of thermal images

The thermal images can be processed further by the application of various filters and image analysis procedures making the spots of leakages more accentuated in the images, more contrastive compared to their neighborhood as it can be seen on the 3D image of **Fig. 12.** or the filtered images of **Fig. 13**, (the image on Fig. 11. was further filtered with a Sobel filter).

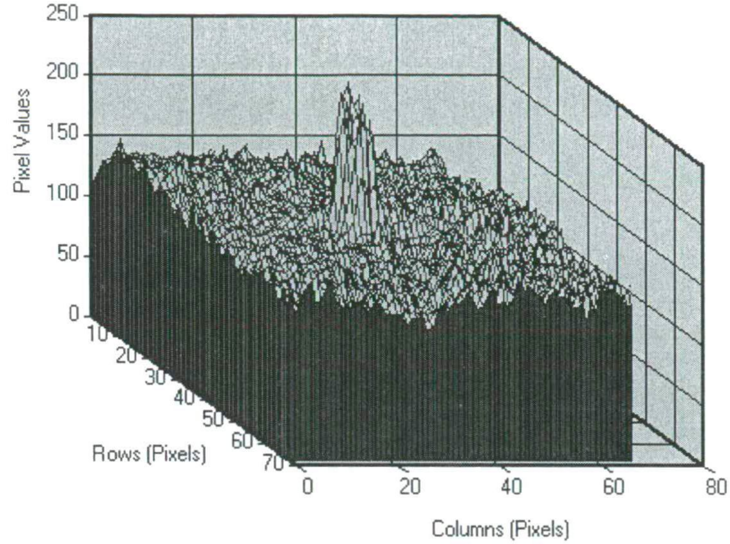

Figure 12. 3D view of the thermal image of the leakage depicted on Fig. 11

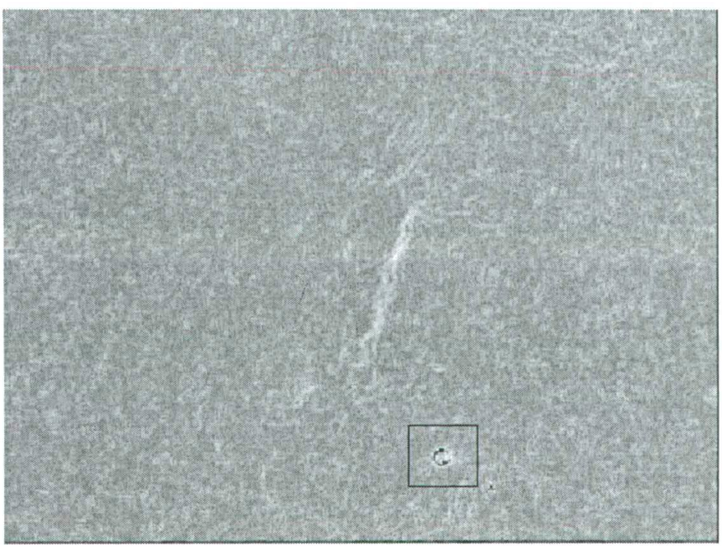

Figure 13. The image on Fig. 11. further filtered with a Sobel filter (darker spot marking the site of leakage)

Summary

According to our findings, the active subsurface pipelines significantly alter the temperature of their surroundings, especially during the winter season. The field analysis of the extents of the affected zone enabled the calculation of parameters necessary for the successful aerial imaging of these pipeline networks (flight height, geometric resolution).

The image data recorded on the plane was integrated into a self-developed GIS platform based on the captured GPS coordinates enabling further visual processing and evaluation of the data for the more accurate localization of the sites of leakage. The analysis of thermal images enabled not only the determination of the exact site of leakage but also its type (hot or cold pipes) along with the possible spatial extent of the contaminant plume.

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