Geographical Information System Applications for Pipeline Right of Way Aerial Surveillance

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Abstract: This article deals with a Geographical Information System (GIS) module which complements a video-infrared integrated application system for pipeline leakage detection inspection. This system is based on the theory that under pressure, leakage can occur and part of the product goes from liquid to gas state. In the leaking vicinity (over the land surface or in the waters) the temperature will change allowing appreciate a thermal difference that can be registered by the video-infrared equipment resulting in thermal contrast over the land, so that the infrared (IR) equipment can be used successfully for detecting and determining pollution due to petroleum. Similar arguments follow for the gas case. The system is designed to receive data from various electronic devices which operate in different frequency ranges. Data validation must be carried with suitable formulas to get the best final yield. Three types of information sensors form the major part of equipment: an infrared camera, a video camera and global positional system (GPS). Equipment, software and some inspection results using this system are presented. Tests show that the flight conditions (120-140 km/h, altitude of 400-500 m) are suitable for inspection services.

1 INTRODUCTION

Terrestrial oil and gas transport pipelines are exposed to integrity loss due to physical (corrosion, erosion, etc.) and human activities (digging, building, among others) factors. Because of this, pipeline inspection is fundamental to find anomalies and damage to take the corresponding measures to fix them before they reach a dangerous condition.

Product loss as liquid petroleum, gas or basic petrochemicals can be a serious problem if no appropriate methods are used to detect promptly leaks in pipelines. During the operation processes such as transportation, distribution and merchandising, they can bring about drawbacks due to the product loss, caused by inner corrosion, bumps to the installations from thirds or underground terminals. Pollution is one of the main effects that these phenomena can cause, contamination to the water bodies, water mantles, air quality disturbance and atmosphere damage.

Traditional inspection methods present several difficulties from inaccessible locations for pedestrian inspection over the pipeline to little accurate pipeline paths in aerial surveillance so that new technologies are required, particularly for aerial inspection.

Technologies more accurate and reliable over the detected incidents while inspection coverage is increased, could be those of remote detection, thermography, geographical information systems, image processing and the like. They have allowed the development of methods based on the anomaly's thermal trace such as leakage, excavations, landslides, machinery function, exposed pipelines, buildings, among others.

For better accuracy the above issues can be identified in the thermal spectra using IR cameras and GPS for positioning system.

The convergence of these technologies allows the creation of sophisticated techniques and methods for potential danger, leakage and illegal tapping on transport pipelines.

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The inspection with aerial photography in the visual band of frequency has been explained but to detect the details related with failure of pipelines is important to use the infrared image system in the thermal band of the frequency. This system can detect texture temperature with resolution near or better than 0.1 °K. It can generate the following information: control of land texture above the pipeline; estimation of soil erosion related with the subsurface layer process; gas leakage locations in gas pipelines; thermal mapping areas of the pipeline to be measured, heat leakage information from subsurface layer.

2 SYSTEM DESCRIPTION

Four basic modules conform the system: the operator airborne equipment for recording the pipeline path in infrared and video range, the airborne equipment of data registration and pre-processing, the airborne equipment for pipeline tracking and the in-office equipment for analysis, evaluation and report generation. Figure 1 shows the schema of the overall System.

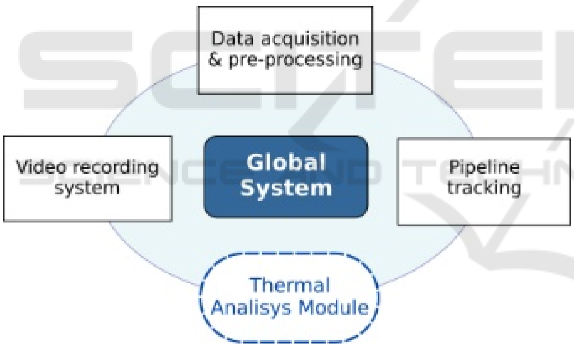


Figure 1: Application software for pipeline tracking.

2.1 Recording Video Equipment

A specific-purpose mechanical frame was designed to mount two cameras, one for the high definition (HD) and the other for the infrared (IR) video recordings. The cameras must be oriented and adjusted in their zoom parameters to make their scenes to match. In addition to this a gyroscope is installed in order to achieve a better stability control on the position when recording. Figure 2 shows the details of this frame.

A fundamental component of the system is an infrared camera (Sadovnychiy et al., 2004) which detects the thermal anomalies that are caused by gas and oil leakages.

There are three basic physical principles in which the detection on the surface of temperature anomalies caused by oil spills can be based. (Sadovnychiy, 2001)

Figure 2: IR and HD video cameras recording frame.

The first principle of temperature anomalies is based on the supposed theory that according to Joule-Thomson effect, the liquid that flow out under pressure from a crack, is converted to a gas phase and lowers temperature of the environment (surface over the pipeline). Thus around the leaking place (over the land surface or in the waters) the local sites will make up with a least temperature, that can be registered by the IR equipment. Visually such leaks are impossible to be detected. A similar mechanism is presented in the gas pipes.

The second principle. There is an IR camera that can produce images at two bands: one in the absorption band of ethane and the other were ethane is nearly transparent.

The third principle is based on the phenomenon of thermal contrast of superficial petroleum stains which leaked from the pipeline. Temperature of petroleum in the pipeline is usually close to temperature of environmental ground. Hence, superficial temperature of petroleum mass which outflowed from the pipeline and which appeared on ground or water surface is determined by conditions of its heat exchange with the environment. The change of temperature is influenced by parameters such as wind, solar radiation, intensity of vaporization, geometrical parameters of petroleum stain.

As shown in (Sadovnychiy, 2001), a difference of temperatures ΔT between a petroleum film (film thickness $h < 0.1$ mm) and water surface during daylight hours can get to $0 \div 5°$ K. For thick films (film thickness $h > 0.1$mm) this difference grows up to $3 \div 8°$ K. The reason of this temperature contrast is that a petroleum film is heated up by the Sun radiation more than the water, but it evaporates less.

If the petroleum get up to ground surface, the temperature difference will be a little bit less at the expense of vaporization of petroleum and therefore, at the expense of cooling the top layer of petroleum. In this case, the difference of temperatures will be greater (from -2 up to + 7 °K).

The sensitivity of the camera is equal or less than 0.1 °K and the three above mentioned principles of leak appearance will form temperature anomalies which have sufficient temperature contrast and geometrical sizes for being detected by an IR camera.

The detected thermal anomalies are not always associated with leakages since these can be generated by means of the atmospheric thermal anomalies, there could be false alarms. Therefore an HD camera is used to compare with the infrared scene to have a more precise knowledge about a specific anomaly.

2.2 Data Acquisition

The GPS receiver provides the position data to the system. This additional equipment help the operator to detect the site of the leakages accurately. The received information is recorded into an electronic memory of an on-board computer.

The principle of leakage detection is based on the analysis of the thermal anomalies, processing of the surface IR and video images and coordinate determination. The co-processing of the mentioned data permits to detect and locate pipeline leaks. The high resolution of the system permits to detect leakage at the time break itself.

A GPS device on board acquires the global position of the system while performing the inspection flight. The sampling rate is of two seconds and the coordinates, speed, height and timestamp are stored in the National Marine Electronics Association (NMEA 0183) format to an on-board computer for later analysis in search of anomalies. In figure 3, the left PC record the IR camera video in *.avi* format. GPS coordinates are also stored on this computer.

The GPS is a GPSMap76S Model. The GPS performance is based on a receiver which continuously tracks and uses up to 12 satellites to compute and update the position. The update rate is of 1 second. It has an accuracy in position < 15 m and velocity < 0.05 m/s. Configuring the GPSMap76S to use the interface as NMEA allowed to output the data to a PC and use any NMEA compliant GPS application on devices to use the GPS data feed from the Garmin handheld. The baud rate is automatically set to 4800 and cannot be changed so that the NMEA transmitted data by serial connection is acquired every 2 seconds.

2.3 Pipeline Tracking

Oftentimes when performing the inspection flight the pilot or personnel in charge don't have the certainty about the pipeline path, sometimes the terrain has changed and the guide get confused or simply doesn't precisely remember the pipe trajectory. When this occurs the flight path becomes erratic and repetitive trying to find and follow the pipeline.

When such inspections take place the analysis and evaluation phase becomes difficult to perform so, a tracking module has been developed in order to get an accurate tracking of the pipeline. This module is composed by a GPS and an on-board computer, which receives the position from the GPS and provide it to an own-design software application which in turn uses a geographical information system to display the correct position respect to a preloaded pipeline path. In this way, it is possible to have a better and almost perfect pipeline tracking since now the reference trajectory is completely known, even though the person in charge doesn't accurately know the path to follow. An alarm algorithm is implemented in the software application to warn when the helicopter is getting to far from the path to track. A maximum distance can be specified as an uncertainty tolerance around the pipeline. Figures 3 and 4 show a flight trajectory with and without the use of this tracking module respectively. In the latter the average distance to the pipeline was 150 m.

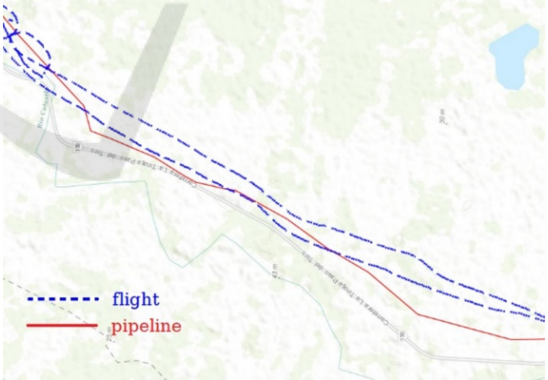


Figure 3: Inaccurate flight without pipeline tracking.

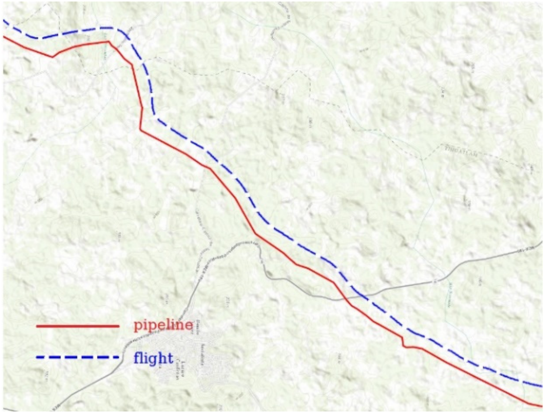


Figure 4: Flight with pipeline tracking.

In Figure 5 the tablet on the right performs the pipeline tracking. It receives GPS coordinates information and the tracking application software updates the helicopter position against the pipeline path.

Figure 5: Acquisition and tracking equipment.

There is also a flight-planning module based on GIS that can be used to trace the flight plan over the pipeline. With this module it is possible to load and visualize the pipe trajectory, build the flight route, perform geodesic length measurements to estimate the time or velocity for the flight, query coordinates elevation over the sea level to generate a topographic profile of the pipe and with this establish a height control of the helicopter or plane over the pipeline. It counts also with complementary tools such as individual and batch coordinates conversion between NMEA format and WGS84 and Web Mercator geographic references. It also has optimization algorithms for the pipeline coordinates (when there are repeated points or the geographic sequence is not correct). Finally, the generation of compatible formats of geographic features such as comma separated values (*csv*), key-hole mark-up language (*kml*), Esri Shape (*shp*) and GPS exchange format (*gpx*) is possible. Figure 6 show the graphical user interface of this module.

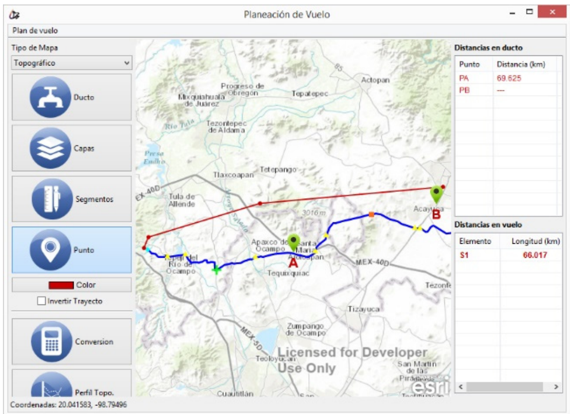


Figure 6: Flight planning module.

2.4 Thermal Analysis Module

Once the inspection flight has been completed it's necessary to analyse all collected information to determine unusual temperature variations, conditions which point to potential leakage or illegal tapping.

For the determination of variations on monitored right of way (ROW) surface a special application software has been designed. The core function of this software consists on the comparison of IR and HD terrain video images around the same instant time or different time. For the same time mode, synchronization of the above images with GPS coordinates is required which in turn permits to know the exact location to be displayed on the GIS visualization.

The program was developed in Java 8 language making use of the following APIs for the core functions:

- *vlcj* (Lee, 2015) and *ffmpeg* (FFmpeg, 2000) for video recordings visualization and control, video segments extraction, screenshots extraction, image filtering adjustment and video recordings information and parameter querying.
- *ArcGis* (Esri, 2016) as geographical information system (GIS) for visualization, distance estimation and mark annotations on the pipeline and flight paths.
- *Google Elevation* (Google, 2016) for terrain elevation queries to Google servers.
- *Eclipse SWT* (Eclipse, 2016) for native operating system graphical user interface.
- *JAK* (Micromata Labs, 2016) *and GeoKarambola* (Santos, 2016) for *gpx* and *kml* files parsing and formatting.
- *OpenCV* (OpenCV, 2016) for image manipulation and temperature estimation.

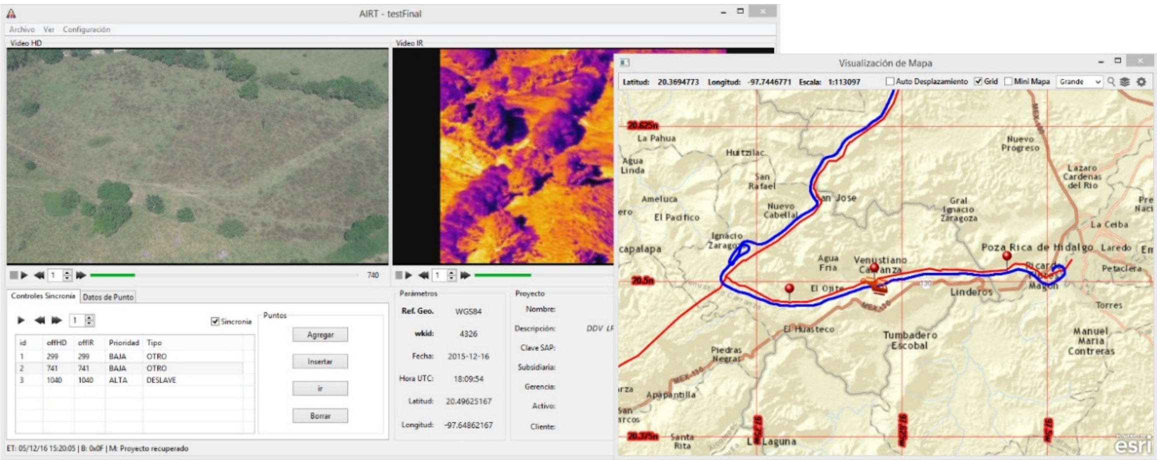


Figure 7: Thermal analysis application software.

- *JasperReports* (TIBCO Software, 2016) for reporting services.

The layout of data mapping windows and control buttons are shown in Figure 7. The software application counts with five core functional modules (see Figure 8).

A pre-processing stage must be carried out on the collected data (Sadovnychiy et al., 2004) for compatibility and synchronization purposes.

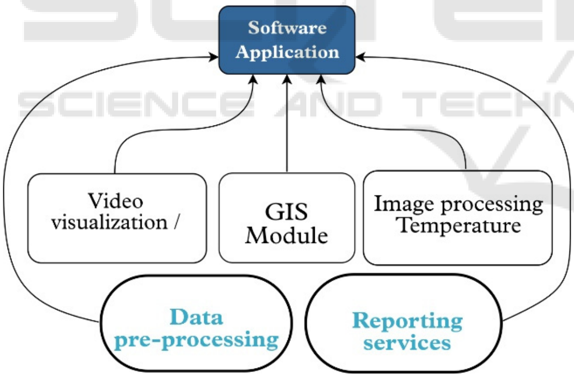


Figure 8: Thermal application core modules.

The GPS route coordinates and timestamp have to be bound to the simultaneous video films reproduction in order to have accurate geographic positions for each specific instant on the video recordings. Such scheme of parameter registration allows receiving identification of image location every second. The information about coordinates that are obtained from the GPS receiver is recorded in the waypoint format. This format is practically supported by any program of GPS navigation and control. The designed special pre-processing module checks the regularity of the database structure by a quantum of 1 second and, if it is necessary, completes the missing data by means of interpolation.

For each GPS sampled and interpolated point there is an elevation information request to Google's servers through its Google Elevation API. The retrieved elevation is in meters over sea level. The final dataset from the pre-processing module is presented in comma separated values.

Video visualization control module is in charge of simultaneous playing of HD and IR video recordings. Videos reproduction has to be synchronized each other and with GPS coordinates so that for every instant, videos screenshots and position in map match. Video format compression is not necessary for the HD film since the video API's can directly handle the reproduction of the common *.mp4* and *.mts* formats and the storage demand can be conveniently bounded to a 32 GB storage device.

The comparison of the images is carried out by the operator through visual observation. If the operator detects some anomaly on the pipeline right-of-way he fixes the coordinates of this object in the report. All main function modes of a video player are accessible for work: rewind - forwards, pause, full screen output etc. Video filters adjustment is also available for both videos reproduction (Figure 9).

The GIS module loads the pipeline and flight trajectories for the corresponding visualization. It also receives timestamp and coordinates from the pre-processing module every second of videos playing thus, it can update a marker position according to a video specific instant. It can get distances between points and load several detail layers. The layer files are QGIS and ArcGIS compatible. It is also possible to generate *.kml* files for Google Earth compatibility. Algorithms for pipelines length estimation and offsets compensation have been implemented in order to

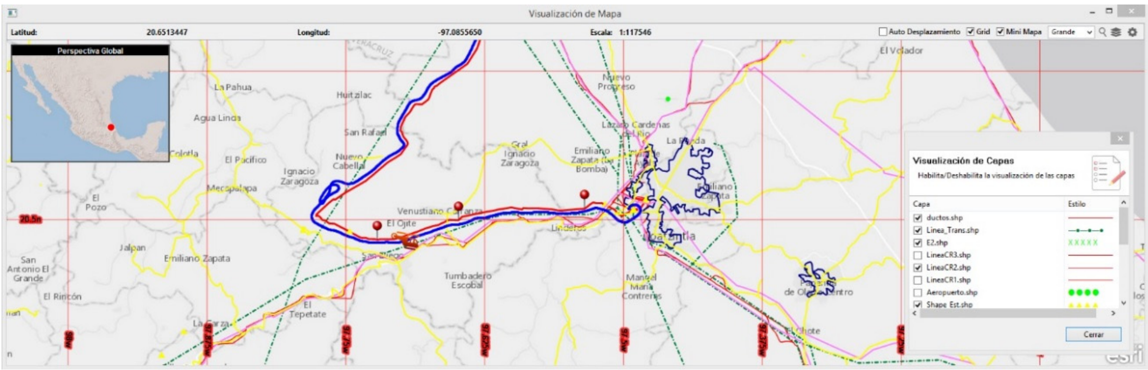


Figure 10: Graphical interface to the GIS module.

match the absolute distance of a reported point with the nominal distances in the pipes. Figure 10 show the graphical interface of this module.

Figure 9: Video filter adjustment.

2.5 Temperature Estimation

The employed IR camera can provide radiometric information just on static images (IR photograph) but not on video recording so that, thermal measurements are not available therefore, temperature estimation is needed in order to know the temperature of a pixel in the image.

Since the only available image information for the system are RGB images and temperature limits (Figure 11) the above estimation has to be estimated through linear interpolation among the pixel value and temperature limits.

This step is easy when the used colour palette can be converted into a linear grayscale palette such as Iron palette, a very common palette in the thermographic area. Figure 12 shows the iron palette and its grayscale equivalent counterpart.

Figure 11: Temperature limits are known parameters.

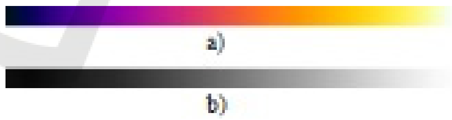


Figure 12: a) Iron colour palette, b) Iron grayscale palette.

In this scenario, the RBG image is converted into a grayscale image yielding in a one-value-per-pixel image which together with temperature limits it is possible to estimate a temperature value for each pixel value. There are several conversion algorithms if a more precise control channel ponderation is required (Parker, 2011)

But, when the colour palette, such as Rainbow palette doesn't have a linear equivalent grayscale (Figure 13) when converted, it's not possible to apply a direct linear interpolation estimation.

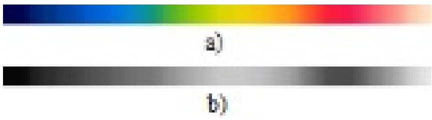


Figure 13: a) Rainbow colour palette b) Rainbow grayscale palette.

Under this scenario there are three values per pixel to estimate the temperature of such pixel. For this, an estimation algorithm based on the minimum Euclidean distance to the 3D palette trajectory in the colour space (see Figure 14) was developed to estimate the temperature for each pixel.

The above algorithm has proven to be effective also with colour palettes whose grayscale equivalent is linear such as Iron palette so, it can be used when such an image conversion is to be avoided.

In Figure 15 the temperature estimation tool is shown. Setting temperature limits is needed to proceed with the estimation so that one must be careful to set the IR camera parameters to show this data.

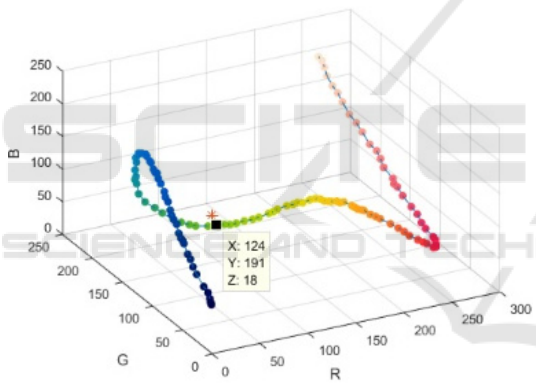


Figure 14: 3D rainbow colour space.

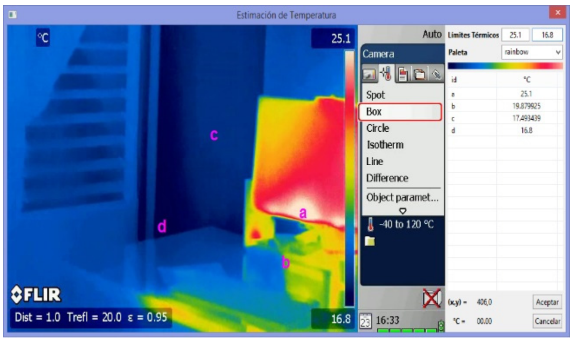
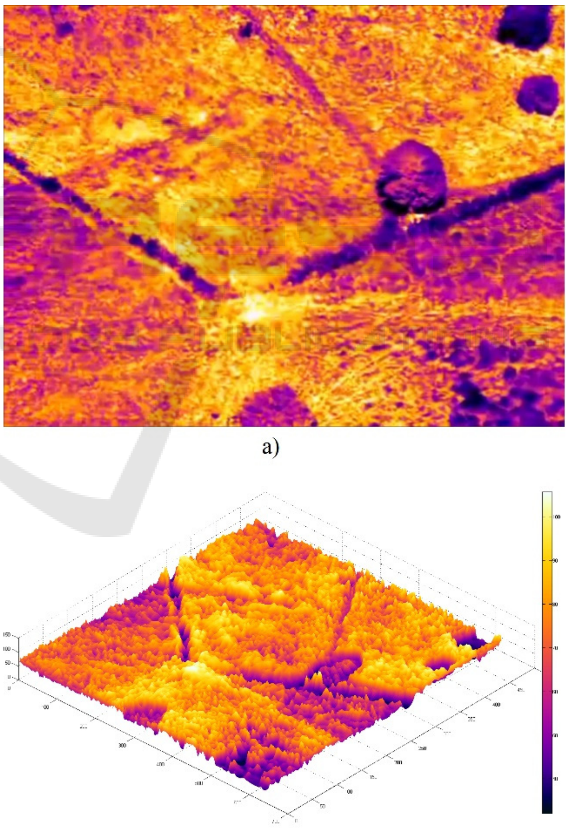


Figure 15: Temperature estimation of an IR image.

A heat map is a 3D surface generated from the thermal image where the height is represented by the temperature estimated for each pixel (Raymond, 2015). Sometimes this visualization tool is necessary to represent the IR screenshot image in order to have an easy and more intuitive visualization. When used, this resource allows to count with a 3D visual representation which can be zoomed, translated and rotated in a manner such that the user can have several perspectives thus facilitating detection points which otherwise couldn't be appreciated. In Figure 16 it is shown an IR screenshot and its corresponding heat map respectively.

Any colour palette can be used for the 3D visualization in Figure 16. The height parameter for temperature can be inverted resulting in an inverted relief. Heat map is showed in Tessellation/Surface representation but can be wire framed or scatter points.

All functions of the heat map tool can be reached under Matlab, OpenGL or Point Cloud Data implementation technologies, among others.



b)

Figure 16: a) Screenshot of a thermal record specific instant b) Heat map of the screenshot.

The overall application was developed and executed on a workstation with Windows 8.1 Enterprise 64 bits OS and an Intel Xeon CPU E5-

2650 @2.3 GHz processor with 32 GB RAM. The most demanding power processor task has to be with the simultaneous and synchronized video playing (one of them is a High Density format), the processing performance was tested with four High Density simultaneous videos and the application was executed very well. The actual requirements just impose the simultaneous playing of a High Density video and a normal video. The pre-processing and report generation and persistence stages are not concurrent operations.

2.6 Reporting

For each reported find during the inspection there exists a generated data point with relevant information such as the nature of the finding, the priority, a detailed description, HD, IR and Map screenshots, video fragments, timestamp, coordinates and temperature estimation points. Every inspection service is composed of several data points, 50 and even more than 100 data points is possible. To manage all the above information the reporting services module was developed.

This module makes possible to organize and accommodate the information of all the data points in a visually attractive and understandable report to be consulted by the interested parts.

This report is generated in *html* and *pdf* formats. Comma separated values (*csv*) and *.kml* files of the reported events are also generated in order to be visualized as layers in any commercial GIS software.

3 TEST RESULTS

The system test was held on an aerial inspection of the right of way (ROW). The flight was carried out over an unknown (for the inspection team) region above an obscure ROW. Only one condition was required as initial information for the test: the helicopter will fly above the pipeline route.

The data were recorded for the 100 km ROW section. The speed of helicopter was about 120 km / hour and altitude of flight was about 400 meters.

After data processing and analysis from surveyed ROW route, 14 places with appearance of a pipeline on a surface were detected. They were caused by reasons such as: landslides, degradation by water, excavation for maintenance functions, emersion of a tube in marshland etc. Besides it were detected 9 thermal anomalies.

One month after aerial inspection the ground-level check on 4 places (which ones had an opportunity of access) with the brightest thermal abnormalities was held. Availability of GPS coordinates and images of anomalies permitted to find them very quickly. Besides, in this period the operator had carried out independent inspection of the same ROW section by means of the special device working inside a tube - intelligent "pig".

Figures 17 and 18 show two finds on pipeline firstly detected by aerial inspection and subsequently corroborated by means of intelligent “pig”.

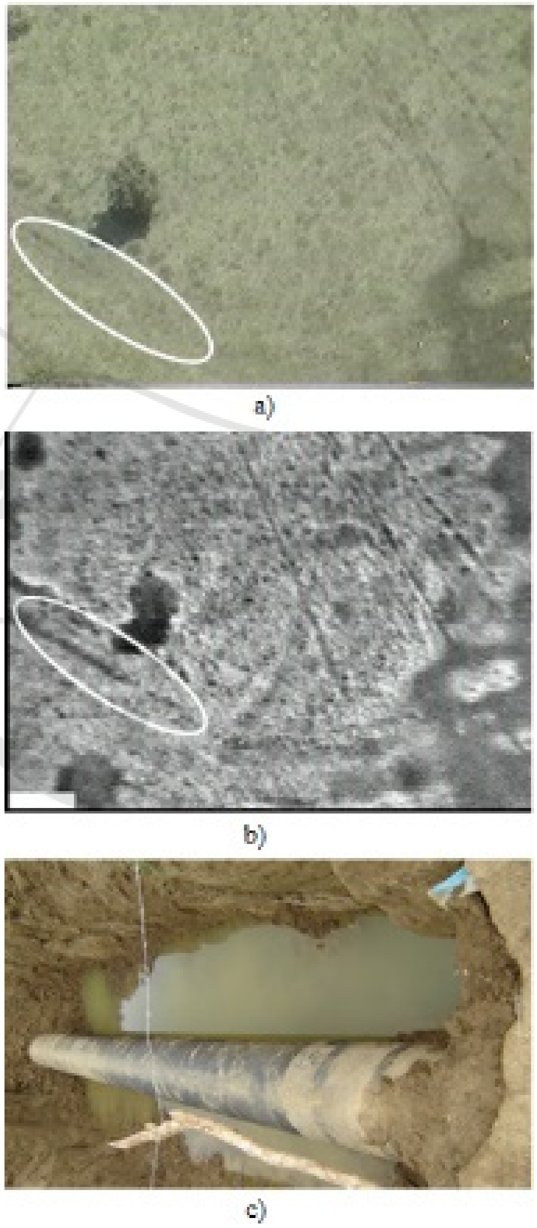


Figure 17: Place that was determined as pipeline with severe problems (loss of insulation covering) by means of aerial inspection and intelligent "pig". a) HD screenshot b) IR screenshot c) Verification photograph.

4 CONCLUSIONS

The designed remote inspection system allows fulfilling the monitoring of the oil and gas pipeline right-of-way. The special software considerably lightens the work of operator and raises the service quality and integrity. The system allows to document the inspection results and store important issues on a database.

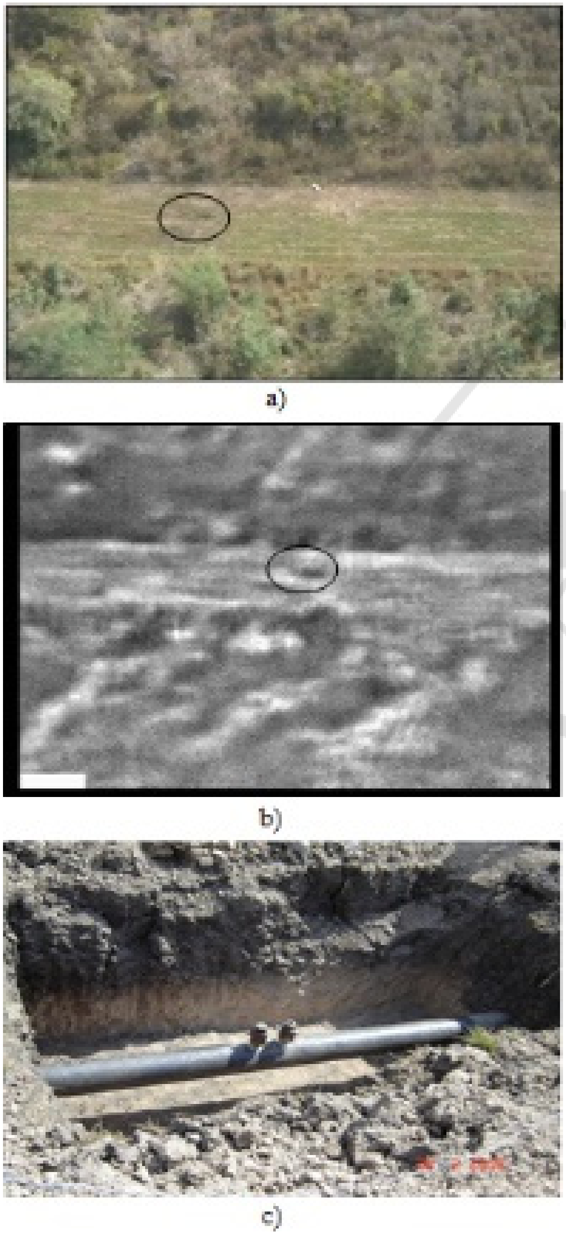


Figure 18: Place that was determined as pipeline with severe problems (illegal tapping) by means of aerial inspection and intelligent pig. a) HD Screenshot b) IR Screenshot c) Verification photograph.

The importance of the GIS implemented modules is foundational for the inspection system since several functions rely on this characteristic which greatly improves precision over location, visualization and reporting on finds over the pipeline.

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