Pipeline monitoring with unmanned aerial vehicles

L I Kochetkova

Tyumen Industrial University, 38 Volodarskogo St., Tyumen, 625000, Russia

E-mail: kochetkova0571@gmail.com

Abstract. Pipeline leakage during transportation of combustible substances leads to explosion and fire thus causing death of people and destruction of production and accommodation facilities. Continuous pipeline monitoring allows identifying leaks in due time and quickly taking measures for their elimination. The paper describes the solution of identification of pipeline leakage using unmanned aerial vehicles. It is recommended to apply the spectral analysis with input RGB signal to identify pipeline damages. The application of multi-zone digital images allows defining potential spill of oil hydrocarbons as well as possible soil pollution. The method of multi-temporal digital images within the visible region makes it possible to define changes in soil morphology for its subsequent analysis. The given solution is cost efficient and reliable thus allowing reducing timing and labor resources in comparison with other methods of pipeline monitoring.

1. Introduction
Pipelines may be laid either above or below ground. Usually they have many branches and their length may reach over one thousand kilometers. Currently, the length of main pipelines in Russia exceeds 280 thousand kilometers. According to the Federal State Statistics Service, the length of main gas and oil pipelines as of 2017 made 73 thousand km, having increased in comparison with 2016 by 4 thousand km.

At times it is rather complicated to quickly eliminate consequences of pipeline leaks since some leak sources cannot always be defined in advance despite prompt and efficient maintenance. Besides earthquakes and soil settlement, pipeline leaks may be caused by unauthorized access of the third parties [1].

The level of pipeline leak consequences may depend on various parameters, such as pipeline pressure and temperature, diameter of a pipeline rapture, layout of pipelines and type of transported fluid. In case of a large liquid spill there is a risk of fire and explosion, which may damage people and the environment [2]. It is noteworthy that hidden leaks from underground pipelines are similarly dangerous since they are difficult to detect and they do not change the soil surface. Restrictions in detection of hidden leaks may result in liquid hydrocarbons getting into the ground up to the water-bearing layer.

2. Materials and methods
At present, various methods are used for pipeline control and monitoring.

Up to now, visual inspection of pipelines by pipeline company workers remains the most widespread and oldest method. Workers patrol the designated areas to detect leaks and check the wells. The main restriction of this method is that it is quite difficult to detect hidden leaks visually or...
olfactory. Besides, another restriction of such inspection is that they are performed according to predefined route based on statistical analysis of available checkpoints, which thereof leaves certain pipeline areas without inspection [3].

The pressure control method implies the use of pressure detectors located in certain sections of a pipeline. The interpolation method of pressure values makes it possible to extrapolate a tendency of continuous pressure in relation to pipe length. The deviation from a trend of expected pressure may indicate the presence of leaks. The advantage of pressure monitoring is that it allows defining pipeline section exposed to leakage. Detectors continuously send signals to the control panel and consequently, it is possible to quickly identify the change of pipeline parameters. Considering the number of detectors along the pipeline length, the major disadvantage of this method is high cost of sensing elements. Another disadvantage is that detectors are unable to identify small leaks, the flow rate of which is less than 2% of the entire transported flow [4].

Ultrasonic flow meters are also used to monitor pipeline leaks. The operating principle of such flow meters is that when the fluid flows through the pipeline, the ultrasonic wave is displaced, which leads to change in ultrasonic wave propagation time: the propagation time decreases along the flow and increases against it. The difference in ultrasonic signal propagation time along and against the flow is proportional to the flow rate and, therefore, to the flow volume. The signals obtained from transformers are used to calculate the following: signal propagation time, flow rate, accumulated fluid volume, and the output frequency proportional to the flow rate. The parameters calculated thus, proportional to the flow rate, volume and time are transmitted to the alphanumeric display. The disadvantage of this method is its failure to detect small leaks and high cost of installation.

Another method to control leaks implies the use of conductive cables along the pipeline. Its operating principle is based on the fact that the hydrocarbon mixture serves an excellent solvent, and in case of hydrocarbon leakage, it acts as a solvent for cable sheath, generally made of plastic, which therefore results in short circuit inside conductors. The main advantage of such monitoring is the ability to detect not only leaks but also fires. Its disadvantage is that it is difficult to detect small leaks, considering the fact that in order to equip the entire pipeline there is a need to cover a cable along the whole pipeline circular length, which makes this method rather expensive.

However, monitoring of a relatively long pipeline laid above ground can be done by a helicopter or a plane. The advantage of this method is that it is possible to transport heavy control tools, which, if needed, can also be combined with each other. High flights allow analyzing a vast territory, but at the same time, this leads to lower image resolution [5].

Besides, there is a method based on the earth remote sensing data. Satellites may be equipped with high resolution cameras within visible infrared spectrums, and hyper spectral or multispectral cameras, which allow analyzing specific spectral bands [6].

In view of efficiency and reliability of data acquisition, it is advisable to use CAD systems with remote control of aerial vehicle to monitor hydrocarbon pipelines. The advantage of this method is that it is possible to install different sensors aboard the unmanned aerial vehicle (UAV), which allows inspecting the pipeline with respect to different criteria. UAV’s light weight provides for continuous scanning without potential consequences and incidents, which is safety-wise critical.

Unlike visual inspection by pipeline company staff, the UAVs ensure scanning of a pipeline at long distances and in hard-to-reach areas (rural areas and woodlands). Moreover, the operator controls the flight diagram of a vehicle. In case of simple visual inspection of a pipeline at long distances, it is recommended to use a fixed wing UAVs with the camera mounted aboard.

In order to detect a hidden pipeline leak due to unauthorized access of the third parties, the expert carries out comparative analysis of a series of images according to aerial survey (orthophoto) and makes a conclusion on the external inference in case they differ.

3. Proposal
The paper suggests high-performance solution to monitor pipeline leaks based on CAD paired with the software to control and process the source data. Different types of sensors installed separately and as a single set provide for extended analysis of a pipeline. Visual flight allows
identifying and analyzing certain deviations in pipeline performance. There are two types of UAVs to ensure such aerial inspection:

- fixed wing UAVs, which allow shooting a wide area in relation to higher flying speed and low energy consumption;
- helicopter UAVs, multi-drones, which make it possible to obtain maximum details for medium and small areas to ensure detailed scanning of subsurface pipelines.

Regardless of the type of aerial vehicles, they can have two types of sensors installed separately or as a single set:

- RGB camera, i.e. a photo or video camera for image acquisition within a visible spectrum;
- spectral cameras to analyze specific spectrums, both visible and infrared [7].

These sensors may form a single set with a thermal imaging camera, which is used to analyze spectrums in far-infrared band.

![Figure 1. Fixed wing UAV](image)

### 4. Results and discussion

#### 4.1 Digital photogrammetry

The image in digital photogrammetry represents a matrix with numbers characterizing density or color of an elementary section of an object. Analytical solutions of photogrammetric tasks also underwent some changes, but still form the basis for digital processing methods.

Photogrammetric method allows identifying faults in earth morphology through the analysis of chromatic variation of relief changes using specialized tolls and software. The result of this method is the KMZ file (compressed version of KML (Keyhole Markup Language) file) or geoinformation file intended to control map data when identifying the location of detected changes. This method can be applied to monitor hydrocarbon pipelines laid above and underground.

Cameras installed aboard the UAV shall have the minimum mass to increase flight duration.

The software for image processing allows receiving two-dimensional and three-dimensional models of the Earth’s surface as its main products. These models are respectively called flat (2D) and hard (3D) orthophotos. The orthophoto represents a georeferenced image [8].

Monitoring carried out through this method covers a cycle of flights with georeferenced shooting of an area around the pipeline. A comparison of data obtained within two serial flights allows identifying potential illegal acts.

The algorithm uses the results of program processing as a source data, i.e. 3D and 2D surface models as TIFF files with RGB color scale and LAS files. Processing stages:

- initial flight imaging and files georeferencing using vectors composed of pixels forming the image;
- secondary flight imaging and files georeferencing using vectors composed of pixels forming the image;
- integrated image processing to reduce the background noise arising due to mathematical subtraction of image levels and colored mapping according to color difference;
- colored mapping;
- combination of two colored maps.

Figure 2 shows an example of obtained results using this method.
4.2 Spectrometric method

Spectrometry implies a set of methods and studies conducted via spectrometers representing tools to measure electromagnetic spectrum (wavelength). Within this study, spectrometry uses the analysis of infrared spectrum based on the principle that when electromagnetic radiation hits a substance or material, one part can pass through it, while another is absorbed by the substance, and the remaining part is reflected.

Two types of sensors are used to detect and identify hydrocarbon leaks in a liquid or gaseous state: multispectral and hyperspectral. Multispectral sensor represents a tool, which registers energy intensity reflected from objects such as land surface at various wavelengths of electromagnetic radiation between the visible and infrared regions of a spectrum. Repeated processing of reflection power values measured by sensors allows analyzing an object or a surface from which radiation originates. Hyperspectral sensor divides electromagnetic radiation reflected from the studied object into a large series of very narrow bands [9].

The results of this method depend on the used software, which makes it possible to get a simple image or video in KMZ or GIS format, to control map data and detect locations of potential deviations. Therefore, this method may be applied to detect potential leaks of both underground and above-ground pipelines that transport liquid or gaseous compounds.

Liquid hydrocarbons have specific spectrum in its short-range infrared region. Figure 3 shows reflective spectrums of two hydrocarbon mixtures. The vertical line marks the boundary between visible and infrared regions of a spectrum.

Figure 3. Spectrum of two hydrocarbon mixtures

Figure 4 shows soil reflection, which is dependent on moisture content in it.
4.3 Geothermal surveying method
As was already mentioned above, thermal imaging cameras make it possible to analyze tendencies of remote IR spectrum; therefore, they consider tendencies of body surface temperatures. Using this method, it is also possible to identify hydrocarbon gases interacting with infrared spectrum [10]. Figure 5 shows the analysis of the methane absorption spectrum.

5. Conclusions
The proposed system, which may use the described detection methods, allows identifying both large and small hydrocarbon leaks in pipelines laid above and underground, which, in turn, provides for prompt measures to eliminate the leaks. The system of unmanned monitoring allows exercising timely and regular control with further acquisition of high-resolution data at considerably low investment and operating costs.

This method may be considered advantageous since it is possible to analyze changes in soil morphology with required frequency in order to detect unauthorized access of the third parties.

6. Acknowledgments
[1] Murvay P S, Silea I A 2012 Survey on gas leak detection and localization techniques J. Loss Prev. Process Ind. 25 966–973
[2] Batzias F A, Siontorou C G, Spanidis P M 2011 Designing a reliable leak bio-detection system for natural gas pipelines J. Hazard. Mater 186 35–58
[3] Hauge E, Aamo O M, Godhavn J M 2009 Model-based monitoring and leak detection in oil and gas pipelines SPE Proj. Facil. Constr. 4 53–60
[4] Gumerov A G, Sultanov R G, Zaynullin R S 2014 Diagnostics and repair of pipelines. Methods, improvement, application. (Moscow)
[5] Omari S, Hua M D, Ducard G, Hamel T 2013 Hardware and software architecture for nonlinear control of multirotor helicopters IEEE/ASME Trans. Mechatron 18 1724–1736
[6] Mahony R, Kumar V, Corke P 2012 Multirotor aerial vehicles: Modeling, estimation, and control of quadrotor IEEE Robot. Autom. Mag. 19 20–32
[7] Krishnamurthy K 2013 Alaska Uses Drones to Inspect Oil and Gas Pipelines at a Fraction Of the Cost. http://www.rawstory.com/2013/06/alaska-uses-drones-to-inspect-oil-and-gas-pipelines-at-a-fraction-of-the-cost/ (accessed on 11 February 2018).
[8] Dermile R, Saniee J 2001 Analysis and algorithms IEEE Transactions on ultrasonics
ferroelectrics and frequency control 787-802

[9] Zibrov V A, Sokolovskaya O V, Zibrova N M, Zanina I A 2014 Remote ultrasound monitoring of underground water mains Sci J. 548-551

[10] Bo Renliu, Dong Zehua 2007 Study on principle of electrical resistance probe based on-temperature compensation for corrosion monitoring. Corrosion Science and Protection Technology 338-341