Unmanned aerial vehicle system for pipeline inspection

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Abstract: - This paper deals with the inspection of pipeline by means of Unmanned Aerial Vehicle (UAV). The different methods of pipeline inspection, its technical and economic efficiency have been examined. The theoretical and experimental base for air monitoring on base of On Board Infrared Equipment (OBIE) have been examined. The method of pipeline inspection by means of UAV has been proposed. The descriptions of the equipments and services are presented.

Key-Words: - Pipeline, leakage, inspection, unmanned aerial vehicle.

1 Introduction

Loss of product through liquid petroleum, gas or basic petrochemicals, can be a serious problem, if non appropriate methods are used to detect promptly fuels leaks in pipes. During the operation processes, transporting, distribution and merchandising, they can bring about operating problems due to the products loss, caused by inner corrosion, bumps to the installations from thirds or due to underground terminals. The effects that these phenomena can cause are contamination to the water bodies, water mantles, air quality disturbance and atmosphere damage.

The kind of defects in the gas and petroleum pipes in Russia has an average level of 0.28 defects in a year over 1,000 kilometres (as a reference: USA has 0.6-0.8, in Western Europe 0.8) [1]. The reasons for such defects in Russia were: defects in the pipes manufacturing - 15%, defects in the installation work - 25%, mechanical failures - 30%, corrosion - 23%. Statistics of causes for defect over the pipes from the United States are similar.

Pipeline companies of the whole world are faced with ever-increasing regulatory and operating pressures. New regulations are proposed or enacted each year that require mapping, facility inventories, pipe inspections, rehabilitation, environmental reporting, and public safety and notification programs [2]. About 50 000 km of main oil pipelines passes on Mexico territory. Most urgent problem is operative inspection of a condition of these objects.

These and other technical issues suggest the need for new and innovative mapping techniques, database design and management strategies, and approaches to providing system accessibility by means of use different sensor's system in visual and infrared bands of frequency.

The use of digital aerial photography (in visual and infrared (IR) band) provides an economic and versatile alternative. The images provide the locations of roads, hydrology, wetlands, cleared rights-of-way, structures, and other cultural features.

Many monitoring applications of digital aerial photography exist for pipeline right-of-way, including general map updating, marketing, pipeline planning, and wetland delineating. Pipeline companies that handle crude and refined products are concerned with environmental damage from pipe rupture. They can use the imagery for location sensitive areas and to plan access and boom placement in case of emergencies. Gas pipeline companies are required to perform annual dwelling surveys. These studies involve the determinations of dwelling densities within 200 meters of each pipeline.

Payload of aerial vehicle for digital photography of the pipeline monitored can increase the accuracy of these regular safety-related surveys and include on the inspections needs depending:

two or three video cameras; the types mentioned above; one infrared camera with one video camera.

The inspection with aerial photography in the visual band of frequency has been explained but to detect the details connected with failure of pipelines it is important to use the infrared imager system in the thermal band of the frequency. This system can detect the temperature texture with resolution about or better than 0.1K. It can give the following information: control of land texture above the pipeline; estimation of soil erosion connected with into subsurface layer process; location of gas leakages in gas pipelines; thermal mapping of areas of the pipeline to measure heat leakage from subsurface layer.

2. Most common methods for pipes inspection

The current detecting devices for leak detection operate on actual time, thru air inspection, terrestrial by vehicle and or on foot. All current leak detection methods do present some characteristics, some of them advantages and or disadvantages, and are considered as complementary instead of excluding. Its operating principle and thus its response time and sensitivity for on time leak detection, will determine its effectiveness.

While designing a system for pipes leak detection, the following should be considered: does it operate on actual time or is it only manual, terrestrial or aerial; at what concentration rate of leaked product is the system operating; at what level of accuracy in meters distance, is the leak detected; does it operate for liquids of for gas products; does it need to be installed all around the pipe or only in specific places along it; is it resistant to the place weather conditions; is it safe against vandalism.

The Table 1 display the comparison characteristics of different methods that the Mexican Official Norm NOM-009-SECRE-2002 “Monitoring, detection and classification of leakage of the natural and L.P. gases in pipelines" establishes.

Table 1. Methods for detecting leak in transporting and distribution pipes.

	Method	Advantages	Disadvantages	Price	Observation
1	Gas indicator	High authenticity of leakage detection	It is necessary to test the air sample from prospective place of leakage. The process is very slow.	$2,600 U.S.D. per kilometre [3] (Monthly inspection)	It can be used only as an additional method
2	The visual inspection of vegetation above the pipeline		The method can be applied only in areas where the vegetation is clean-looking. Authenticity depends from the soil humidity and from the time of vegetation growth	$90 /km	It should prove to be true by other methods
3	Pressure decrease	Real time	For outflow more than 1.25% – 1.5% of a pipeline flow	The price of equipment installation is more than $90,000 /km	
4	Bubbling	Visibility	The soapy water utilization for show of leakage on the surface	Not available data	It can be used only as an additional method
5	Ultrasound	Real time	It is necessary to install the sensors inside of pipe. The compressor motors generate ultrasound that cause the false alarms	The price of equipment installation is more than $10,000 U.S.D. per kilometre [4]	
6	Fibre glass	Real time	For buried ducts and in ducts in operation it is very difficult	The price of equipment installation is more than $47,000 U.S.D. per kilometer [4]	
7	Infrared thermography (Aerial or	The exact localization of the	It is not real time	$20 /km	

	ground-based)	leakage. High productivity.			
8	Trained dogs		Low productivity	$90 /km	

One method more is a "pig" (the device that moved inside of pipe line together with the fluid or gas flow). It is very widely applied to definition of the state of a tube (corrosion attack, mechanical damages etc.), but the big cost (up to 15, 000 dollars) does not allow to apply regularly this method for definition of leakages [5].

Despite the advantages each of the methods and technology offers for hydrocarbons leak detecting in pipes, none of them brings about a full and absolute solution, meaning that it is necessary to use as a complement combined technologies for terrestrial and aerial inspection to detect the exact site of leaks.

In other cases, it is necessary to implement operatives along with the municipal, state or federal authorities, to stop those responsible of distilled products leak in flagrancy, as in the cases of underground terminals.

3 Theoretical and experimental base for air monitoring

On board Infrared equipment (OBIE) carries out the surface inspection over a flying carrier route (aircraft or helicopter) and registry and or insight of the received thermal images. Compared against space equipment (satellites), it counts on a better solution, the most operative inspection of the soil objects and counts on a less cost.

The method inspection disadvantages are the impossibility to determine non visible defects in pipes, this means if there is not a product loss it is not possible to detect them. It also decreases electronics effectiveness in highly density fog situations.

Inspection chance through OBIE in pipes is based on the supposed theory that under the pressure it leaks, a part of the product turns from a liquid state to a gas state. As a result of the second Law of JOULE, the atmosphere temperature reduces in the place of the leak. 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 OBIE equipment. Visually such leaks are impossible to be detected. A similar mechanism is presented in the gas pipes.

The oil radiation factor in thermal spectrum differs from any other (land, water, etc.) and the oil generated with the pipes leak has a thermal contrast over the land surface. By this reason, the OBIE equipment can be used successfully for detection and determining of land pollution due to petroleum.

The most favourable aspect for thermal anomaly detection is presented with the atmosphere conditions during the night, when thermal differences on the land surface are minimal.

Weather conditions in the research achievement are defined by work peculiarities of infrared equipment. During rain and especially with snow, the effective contrast of the soil objects decrease severely. After the rain, the thermal differences contrast of those formed when the soil surface gets cold due to a product leak are increased as damp soil counts on a higher thermal conductivity.

When the atmosphere has clouds thermal differences decrease on the earth surface due to the lack of thermal shades from trees and bushes.

As an example of OBIE possibilities, it is possible to present experimental research for leaks detection with the support of OBIE that was carried out in summer (August 1989) in the western part of the Ural-Siberian regions ducts near the Towns of Maktama (Tataria) and Oropachevo (Chelyabinsk Region) [6].

The total flight investigations volume has been of 115 hours. During the total of researches 212 thermal anomaly images were registered, caused by the product leak, including: 23 - atmosphere leaks, 8 - in the water, 133 - under the earth surface, 13 - directly in snow, 17 - in the land covered by snow.

The following are General Research Results [6]:

1.- Experimental research stated that surface thermal anomaly in the product leaking place from the pipe, can be determined through OBIE not considering pipe depth , in two ways. First it is an actual time, and second laboratory images processing. With the decreasing of the OBIE sensitivity limits, thermal contrast and the detected anomalies are reduced, and probabilities of false alarms grow (detection of atmosphere anomalies).

2. - In the case of product irruption from the pipes directly in the atmosphere the thermal anomaly that is due for its detection, takes place almost immediately after a product leak. In the case of a product blow-up from the pipes in to

atmosphere through the surface that is covered by vegetation the leakage can be detected after 5 - 15 minutes.

In the case of a product irruption directly from the pipes to a land (with a depth between 1 and 1.5 meters) superficial thermal anomaly can be detected after a few hours. This period of time is reduced with the increase of leak pressure and it continues to grow with the air temperature. In the case of a product irruption to the snow or in water (with 0.5 meters depth) thermal anomaly is made up in a period of 30 to 40 minutes after propelling.

3. - Superficial thermal difference between a product irruption and atmosphere surface depends on a big quantity of aspects (pipe parameters, type of defects, defects location, atmosphere thermal conditions, timing conditions, etc.). Difference can rank up to 7º K and continues to grow with the air temperature and the land dampness.

4 Pipes inspection practice results and growing effectiveness perspective

Experimental research shows a high OBIE effectiveness for pipe inspection [7]. But from the point of view of achieved experience with such researches we are in the position to state that:

1. Conclusion on the pipes status based on thermal images, can be given only after a detailed analysis of large video data volumes, this is to say, that a period of laboratory analysis is necessary.

2. Detected thermal anomalies are not always associated with a defect, because they can be made up thru atmosphere temperature anomalies, and this can be a false alarm cause.

3. Thus to decrease detecting time and to increase inspection reliability in the OBIE infrared band it is necessary to back up with devices in the video band. This added equipment helps the operator in the defect detection with the help of the achieved features in the video band.

OBIE, with the support of researches carried out was used in the operation during 1991 - 1996 for pipes inspection in Western and Northeast Siberia on an 800 km. extension. Inspection was carried out every month for over 4 years. 190 thermal anomalies were detected during this time, being the causes of same the defects on some joining units (valve, faucet, manometer) and minor pipe cracks. The number of defects grows in the pipe lines in autumn and winter, possibly to land movement in Rainy Season.

Figure 1, shows a distribution of the number of thermal anomalies A (three months) located in the pipes with the help of the on board infrared equipment [6]. In the same figure same pipe statistics are presented (number of defects per year D). Comparing softened curves (dotted lines), we detect that after periodical pipe inspection start by on board devices, effects are eliminated as soon as they are detected by a special emergency team in its starting line phase, pipe defects are not shown as high risk problems.

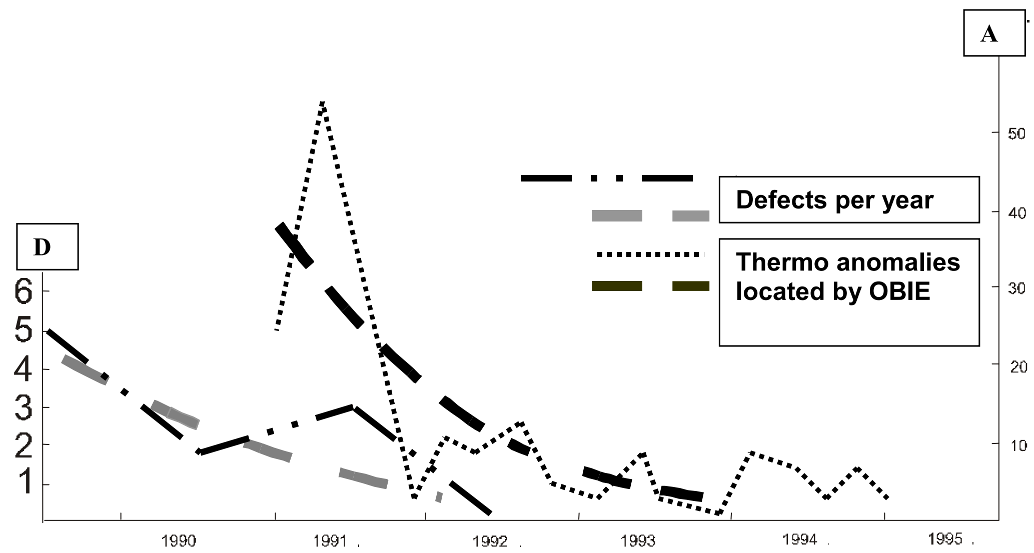

Figure 1

5 Proposal

At the moment, for example, for inspection gas and oil pipelines, the maintaining their organizations rent helicopters and aircrafts or satellite. Satellite in this quality has as large advantages as beside defects. The spatial resolution offered by satellite technology could not fulfil most user needs because have only from 30 to 10 meters resolution, whereas optimal image resolution for most pipeline applications range between 0.3 and 1.0 meters. The development of aircraft requires significant capital expenses on creation new prototype of aircrafts. But many problems, carried out by aircraft, helicopters or satellite, it is possible to decide with the help of the Unmanned Aerial Vehicle (UAV).

Its vehicle, equipped by system of navigation, with high accuracy can repeat a given route at any time and to receive photography of pipelines. The technology of reception photography with the help UAV allows to receive the information already for the following day. Financial expenses for use UAV are much less, than at alternative technologies.

A modern level of computer facilities, electronics, aerodynamics and materials, allows to create apparatus capable in an automatic mode to make long flights on large distances. To creation of UAV in the advanced countries more attention is given.

According to a data of [8] charges of the budget USA on development UAV in 1993 have made 275 millions Dollars and in 1994 250 millions dollars. On estimations of the experts, by 2000 volume of sale will make 1 billion of dollars, from them 50 % will make sale UAV of civil application. By 2010 the share civil UAV should increase up to 70 %. If to take into account, that in 1994 this share makes total 10 %, it is significant growth of volume of sale.

The problem of creation of competitive in the world market of UAV is quite soluble in Mexico at the moment, as does not require significant financial expenses.

6 Descriptions of the equipments and services

The start of the UAV comes true from the starting installation, landing - under a parachute, that does not require special strips. UAV, the starting installation and board of management are transported on a tow by the automobile [9].

UAV (Fig. 2) has twin tailbone layout with pusher propeller that allows to create air vehicle with wide possibilities for interchangeable equipment accommodation and high weight efficiency. Onboard GPS navigation system provides high accurate flight path over 250 km distance. Radio command guidance system with range up to 80 km can be fitted optionally. Terrain survey can be carried out in optical, infra-red and radio bands with provision for onboard data recording and/or real-time data transmission. UAV is launched from trailer-mounted rail and recovered by parachute. UAV, launcher and ground control station are transported by truck.

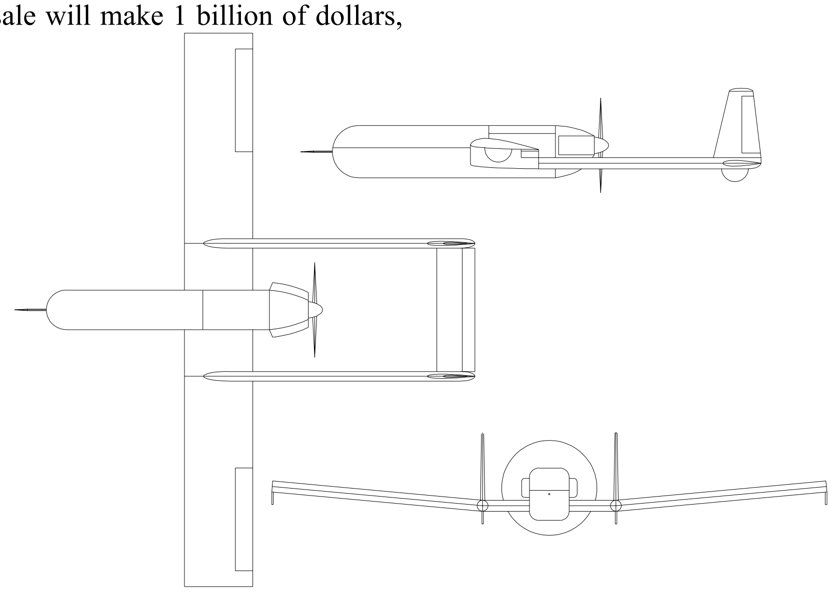

Figure 2

UAV for above mentioned purposes is reiterative item, equipped with integrated digital automatic control system with external navigation correction. The UAV's flight occurs in automatic regime with fulfilling all the necessary manoeuvres and operations according to the program. With the distance between UAV and the control post less than 80 km there is a possibility to translate the radio commands for changing the flight program.

The registration of the flight parameters takes place by means of saving on photo, video cassettes and onboard magnetic tape memory. The take off occurs in automatic regime by means of ground launcher of catapult type. If there is necessity, there is possibility of take-off correction within the sight from the control station post.

The landing (recovery) occurs with remote control and glide path by means of parachute. It can take place with descending either on ground directly of in special unit "trap".

Apparatus is equipped with piston engine and has the classic two beam's scheme with pusher prop.

The weight of the modern infrared scanners is up to 2 kg and could give the resolution to 1024*1024 or better. The visible or near infrared images on the basis of existing CCD-matrixes camera with weight up to 100 g can be created. It has supplied the efficiency of application of short range UAV with weight of a payload up to 15 kg. Such UAV has take-off weight up to 65 Kg, range of flight speeds from 100 up to 180 km /hrs, duration of flight till 8 o'clock, altitude of the flight for 5000m, approximate length 2.7m, wing span 4.0m, and height 1.1m.

The body of the UAV is produced of composite materials from glass and organic reinforced plastics and aluminium alloys.

In fuselage the onboard equipment, payload fuel storage and power unit are situated. In the nose part of fuselage the parachute container and fuel tanks are placed in the unit. The ski is fixed to middle part of fuselage.

Attending personnel. Departure team consists of: specialist in airframe, power unit and launcher; specialists in radio electronics (and control operator at the same time); payload specialist.

There is a necessity of having the specialists for data processing and producing final reports about pipelines' condition with having more than 20 UAV. Their duties include: infrared and video cameras data processing; creation and support of the pipelines database; analysis and forecasting of the pipelines condition.

4 Conclusions

A modern level of computer facilities, radio-electronics, aerodynamics and materials, allows to create apparatus capable in an automatic mode to make long flights on large distances. These vehicles, equipped by system of navigation, with high accuracy can repeat a given route at any time and to receive photography of pipelines. The described system for pipeline inspection and leakage detection allows considerably decreasing the expenses for oil pipelines service.

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