Threat detection to pipelines using an automated aerial surveillance system

G. Pognonec, M. Lecchi, GDF SUEZ (France)
B. Raguin, GRTgaz (France)
M. Sohlbach, Trimble (Germany)
A. Scholtz, Technische Universität Braunschweig (Germany)
J.A. Lana, Enagás, S.A (Spain)

In the context of the iNTeg-Risk project (EU funded project, Grant agreement number CP-IP-3213345-2), an innovative gas transportation safety barrier has been developed to improve safety performance on the one hand and to reduce carbon foot print and costs on the other hand. This solution is based on the use of Unmanned Aerial Systems (UASs) for image acquisition and software for automated detection of potential threats to the surveyed pipeline.

The project has demonstrated the feasibility and the efficiency of automated data collection and automated threat detection processes by means of experimental flights. Test flights have been conducted in Germany and demonstration flights have been performed over transmission pipelines sections in France and in Spain.

I. Introduction

Although third party interferences as cause of unintentional gas leakages from pipelines in Europe are reducing with years, they still remain as the main one, about a 50 % of all causes, according to the European Gas Incident Group statistics (www.egig.eu). It is worth to say that this failure frequency has declined from 0.87 per 1,000 (km × yr) in 1970 to 0.35 per 1,000 (km × yr) in 2010, although very slowly in the last years [1].

The reduction has been reached due to continuous improvements with years in the surveillance and coordination system through Europe between civil work contractors and pipeline operators.

Anyway, due to the importance of a gas leakage, or only hit, in a pipeline, pipeline operators are looking for new systems that allow improving surveillance and, at the same time, the gas transmission cost.

One of the options studied has been the use of *Unmanned Aerial Systems (UAS)* for image acquisition and software for automated detection of potential threats to the surveyed pipeline.

In the context of the *iNTeg-Risk project (EU funded project, Grant agreement number CP-IP-3213345-2)* [2], Enagas, GDF SUEZ and its subsidiary GRTgaz, as pipeline operators, and Trimble and Technische Universität Braunschweig have developed this system.

This paper shows the last results and development of this collaboration [3], [4].

II. Automated Aerial Surveillance System

The automated aerial surveillance system developed is based on two main parts:

- An Unmanned Aerial System for image/data acquisition.
- Automated threat recognition software.

II.1.- Unmanned Aerial System for image/data acquisition

An Unmanned Aerial System (UAS) is the combination of a drone, as well known as Unmanned Aerial Vehicle (UAV) or Remote Piloted Aerial System (RPAS), carrying on board sensors able to perform the desire function.

For the purpose of pipeline surveillance, image acquisition starts with choosing the right UAS with regard to size, costs, payload, range, cruising speed, etc., and implementing an adequate camera system.

An autopilot which allows programming of the flight route and precise positioning based on a Global Navigation Satellite System (GNSS) information is crucial. The geographic coordinates (x, y, z) of every image are known from the UAS's position and attitude (roll, pitch, yaw) provided by an Inertial Measurement Unit (IMU), **Figure 1**. All this information is handed over to the next stage and determines the accuracy of image pre-processing.

It is of particular importance to have a precise integration of the camera and the autopilot system. Otherwise the geographical information of the images will be inaccurate or even wrong.

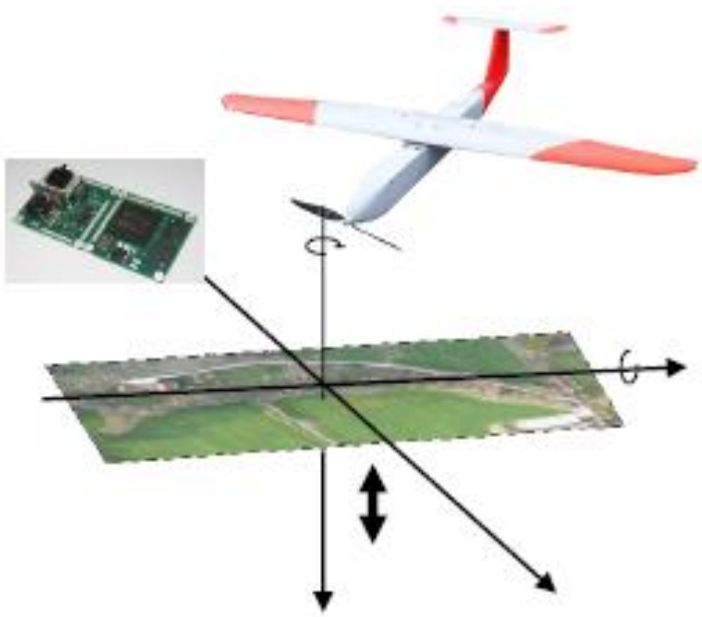


Figure 1. UAS movement: roll, pitch & yaw.

II.2.- Automated threat recognition software

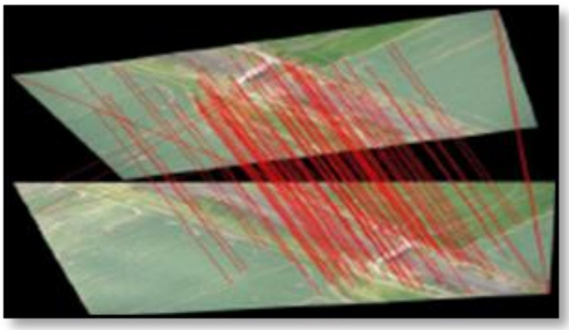
This part of the system is composed of three sub-systems.

II.2.1.- Image pre-processing

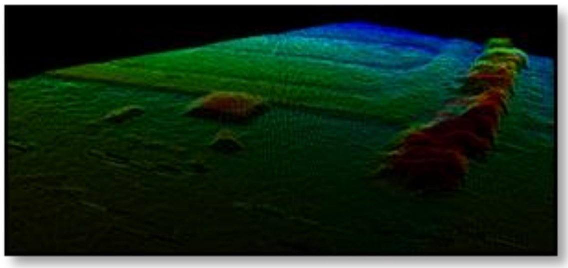
Raw images acquired with a UAS are re-positioned pixel by pixel to a defined geographic reference and provided with coordinates. This allows comparison with other image data and maps as well as a precise localization of relevant changes or threats to the pipeline respectively.

Initially the images are roughly aligned based on the provided position (x, y, z, roll, pitch and yaw), **Figure 2**.a. In a second step special algorithms are used to detect similar points in overlapping images to do a more precise alignment (aerotriangulation), from which a height model is set up, **Figure 2**.b. Based on this height information and the aligned image data, orthophotos are generated. Finally the orthophotos are stitched to a seamless geo-referenced orthophoto mosaic covering the pipeline right of way (**Figure 2**.c). This mosaic can consist of thousands of single images. Its relative geometric accuracy (image to image) is crucial for the next step – change detection. If the orthophoto mosaics of two different times do not properly fit onto each other, spatial inaccuracy will result in a high number of false alarms.

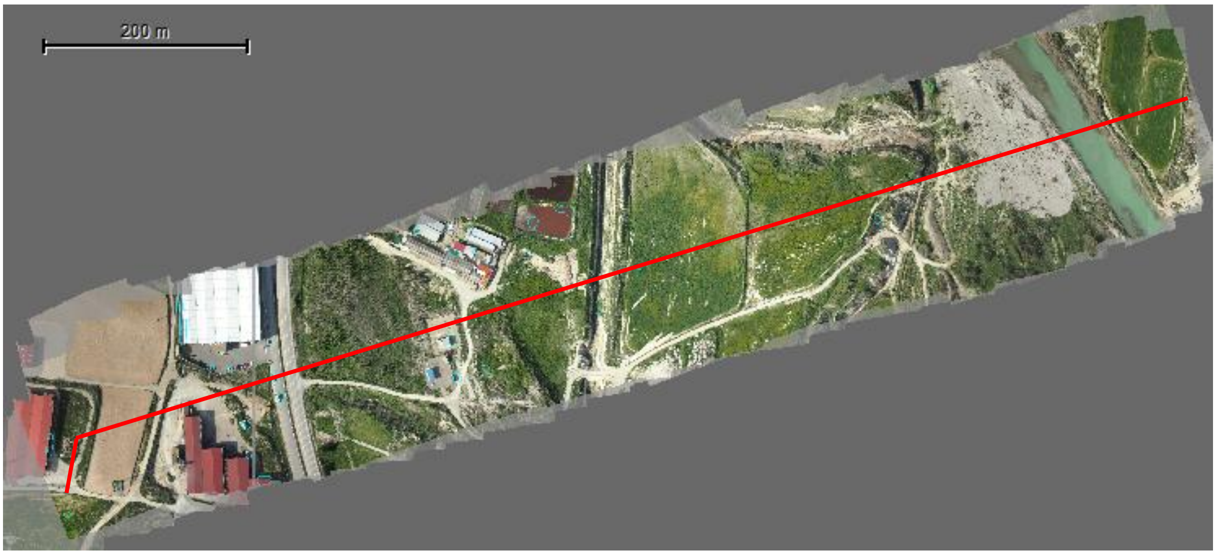
Figure 2.c is a good example of the result get using a good combination of UAS/camera and image pre-processing software. In this image taken during one of the experimental flights of the project, the pipeline is laid in the axis of the orthophoto mosaic.



a) Re-positioning of raw images



b) Height model of images



c) Orthophoto mosaic of a section of pipeline. This is laid in the axis of the image.

Figure 2. Image processing steps.

II.2.2.- *Change detection*

This step is dedicated to the identification of changes near the pipeline that represent potential threats. The developed solution is based on Trimble's *eCognition* ™, a software suite for development and application of object-based image analysis workflows. The solution automatically identifies changes between pictures (**Figure 3**) of the same area but at two different times. Since changes can be quite diverse when comparing photos taken at two different times, the solution includes many algorithms concentrating on avoidance of misclassifications related to changed shadows and colour intensities as a result of different lightning conditions and spatial shifts between compared images.

As it can be seen in **Figure 3**, the software does not only detect potential threats, like digging machines, but recent changes on soil surface that can be due to earth moving works above the pipeline quite often not notified to the pipeline operator.

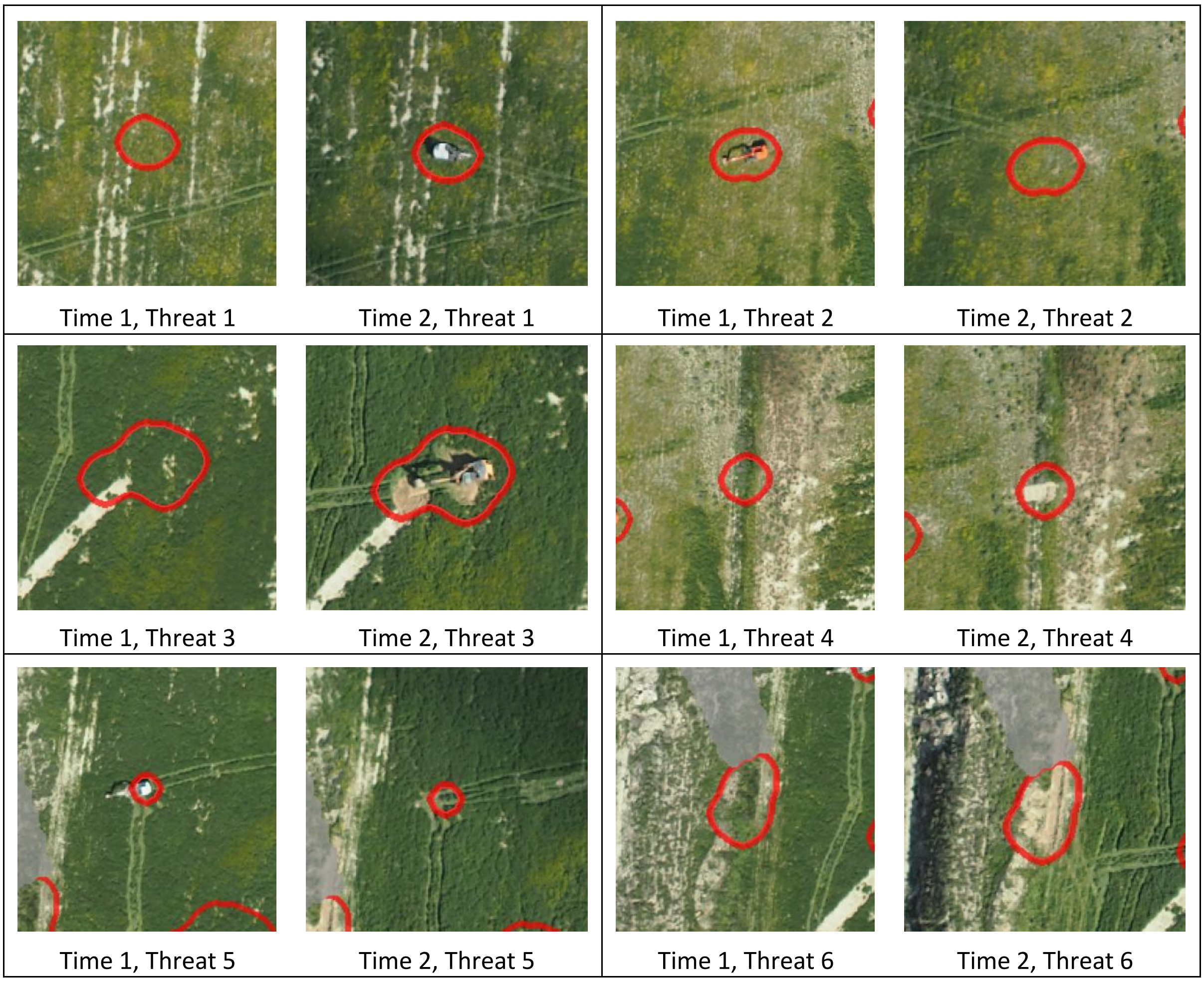


Figure 3. Detected threats at two different times.

II.2.3.- Threat candidate validation

Finally the detected threat candidates are visually verified and either accepted as a threat for immediate field validation or declined. For the final prototype it was resigned to integrate a process to search for threats not automatically detected. This would redundantise automatic change detection, since the whole corridor would have to be visually screened.

The validation process is done with a special desktop client, based on the *eCognition* ™ software suite but with a customized graphical user interface. Main emphasis during development was on usability and highly reduced complexity to keep training phases as short as possible and processing speed as high as possible. The process can be controlled with only two keyboard shortcuts to accept or decline threats. The application automatically pans and zooms to the next candidate to avoid long lasting searching for the next candidate.

III. Regulatory context

Regulation governing the use of UASs for civil applications in France, Spain and Germany were investigated prior to the different experimental flights. It is worth to say that regulations have changed in some countries during the development of the project and, possibly, will change again in the future, once experience in the utilisation of UASs will be acquired.

III.1. French Regulations

At the beginning of the project (2008), there was no regulation in France. In 2012, two decrees were published by the *Direction Générale de l'Aviation Civile (DGAC)*, and to date, they govern the use of unmanned aircraft [5], [6].

These documents define several UAS categories and several scenarios. In the context of pipeline surveillance, the most relevant scenario is called S4. It allows the use of a 2 kg UAS (consistent with aircraft collision resistance specifications), which can be operated out of the pilot's visual range, away from populated area and below an altitude of 150 m above ground.

A certification of the UAS is needed, therefore the system has to fulfil specific technical requirements. In addition a qualification level is required for the pilot. In particular, he must have a theoretical knowledge level similar to that of an aircraft pilot and prove at least 100 flight hours on a classical aircraft.

This change in regulation in France, from the beginning of the project (2008) and the last experimental flights in 2012, oblige to use different UASs each time which had an important influence in the results.

III.2. Spanish Regulations

During all the duration of the project (2008 – 2013), there was not any regulation in Spain. The only similar regulation was the air model one, which said that flights below 300 m height do not need authorization and therefore there is no procedure in place to provide authorization. There were no restrictions related to the area overflown (except for restricted airspace, like airport or national security), to the need of licenses or to out-of-sights flights. And since UASs were not considered as part of aviation there were no technical requirements specified (e.g. manual or automatic control system). The only recommendation in place was to have an insurance certificate to afford any responsibility and/or damage in case of an accident.

On 5th July 2014, a provisional regulation has been published by the Spanish authorities [7]. This regulation specifies the requirement for certification of UASs (divided in three weight categories) and the responsible person/company who is operating them. Under this new regulation, flights are only allowed below 120 m and automatic flights are forbidden, so the flights made during the project are no longer possible.

III.3. German Regulations

In Germany responsibilities for civil aviation are shared between three institutions, at the time of the project there was a lack of regulation for UASs but some recent regulations made clear that a UAS is not a model plane and every flight campaign of a UAS requires a dedicated permission from the responsible state office.

Commonly accepted requirements for operating a UAS are:
- Operation in class G (non-controlled) airspace.
- Maximum flight height of 300 m to 1,000 m, depending particular permission.

- Every aircraft operator (usually the pilot on board) is responsible to avoid collisions with other air traffic participants, *see and avoid*. As a result the UAS/pilot shall be capable to detect other participants and avoid collision. Therefore operation of UASs is allowed within the line of sight around the pilot in charge on the ground (1.5 to 1.8 km, depending on the state).

IV. Experimental flights

An important part of the project, in order to develop the automated aerial surveillance system and to evaluate its performance, was to set several experimental flights in Spain, France and Germany. In total there were 5 flight campaigns.

In the campaigns two different UASs were used, **Figure 4**:
- Carolo P200, developed by the Technische Universität Braunschweig, 6 kg weight
- DT18, belonging to the French company Delair Tech, 2 kg weight

Carolo P200 ***DT 18***

Figure 4. *UASs during Spanish campaign in 2013.*

IV.1. Spain: 1st flight campaign, 2009

Between June 22nd and 26th 2009, a first flight campaign was carried out in Spain, in the North of Zaragoza covering a total distance of 100 km.

In total, 4 UAS flights were performed, using the Carolo P200 UAS. The aims of this campaign were:
- Test performance of UAS.
- Test performance and settings of camera system.

The flights in Spain were a significant step forward in terms of drone operation: *it was the first time the UAS followed a corridor in automatic mode over a long distance (25 km)*. The UAS was monitored by a pilot following it in a car. The autopilot of the UAS demonstrated its efficiency to follow the uploaded pipeline route (see **Figure 2**.c). Different camera settings were tested in different flights.

A comparison of the photos acquired with the UAS and traditional orthophotos of the same area showed that the quality of the new photos should be sufficient to detect many types of activities near the pipeline. Anyway, it was expected that improving the camera system should show positive effects on subsequent processing.

IV.2. France: 1st flight campaign, 2009

Between November 27th and 29th 2009 another test campaign took place in the East of France. A total distance of 120 km was covered in three flights.

The aims of this campaign can be described as follows:
- Evaluate technical feasibility of automated aerial surveillance.
- Evaluate performance of automated aerial surveillance, using artificial targets.
- Evaluate performance of UAS.
- Improve social acceptance by public and authorities.

At the same time a classical surveillance flight with a plane was conducted.

In 2009, and in the absence of any regulations, Carolo P200 was used, after getting the permission from the Authorities.

The main lessons learned were:
- The need for using wide-angle lens.
- The importance of meteorological conditions and electromagnetic interferences in UAS control.
- The need of reducing false alarm rate by improving image processing (spatial accuracy) and image analysis.

IV.3. Germany: Development Flights, 2012

In the second part of the project, three additional flight campaigns were performed by Technische Universität Braunschweig (TUB).

The main purpose of these flights, performed between July and September 2012, was testing the UAS, its new camera system and data acquisition for further development of the automated threat detection system based on *eCognition* ™ technology. Development flights covered a distance of 200 km. 140 km was covered with image data.

The used UAS was also a Carolo P200, but equipped with a new camera: Olympus E-PL3, including a pan cake lens system. This new camera system provided a significantly improved level of image quality related to resolution, radiometry, distortion and lag time (shutter response).

To simulate potential threats for development and training of the software system it was decided to use standard automobiles in different colours (van, estate car and compact car) and canvas placed on the ground and on a table. These objects were moved between flights to simulate changes.

IV.4. France : 2nd flight campaign, 2012

Another test campaign in real conditions was organised during the week of October 22nd 2012 in eastern France.

The release of the new regulations in March 2012 meant that the UAS used in 2009, Carolo P200, was no longer allowed to fly in France as its mass did not comply with the legal requirements.

Therefore, the UAS flyovers were performed by an external company, Delair-Tech, to iNTeg-Risk project, using their DT-18 UAS, which is certified and has a 100 km flight range. The flight altitude was near 150m, as required by the new regulation.

Three flights took place. 37 targets (including 28 civil works machines), representing potential threats to the pipelines, were installed along the flight path.

The main outcomes of these flights were:

- The UAS can be safely operated and its deployment is fast. Anyway, recognition of the overflown area is needed during the mission planning.
- UAS was very silent and difficult to detect by noise and sight.
- The flight stability of the UAS and the accurate camera integration is of particular importance, to provide images of good quality with correct geographical coordinates.

IV.5. Spain: 2nd Flight Campaign, 2013

A second flight campaign in Spain was carried out between April 8th to 10th 2013. In this test campaign, Carolo P200 and DT-18 were used.

Main difference with the 2009 campaign was that some targets (civil work machinery) were placed on the pipeline right of way, to verify the behaviour and efficiency of the whole threat detection system.

The total number of flights and distance flown over the pipeline by the two UASs were:

- Carolo P200: 5 flights, 200 km.
- DT 18: 5 flights, 149 km.

Some of the flights were carried out under quite windy conditions with strong gusts.

These flights highlighted the importance of adequate flight stability and a precise and vibration free integration of the camera in the UAS. These flights allowed testing the first prototype version of the image-processing and threating detection software, which was able to produce results in about 24 hours after the flight using a standard laptop computer, **Figure 3**.

V. Automated Image Processing Efficiency

The effectiveness of the image processing steps, change detection and verification to detect, identify and localize threats can be characterised by key performance indicators typical for traditional inspection/surveillance:

- *POD:* Probability Of Detection = True positives / Total number of real targets.
- *POFA:* Probability Of False Alarm = False positives / (False positives + True positives).

The operationally significant items are related to POD and POFA, and to the following considerations:

- The number of false alarms (false positives) after automatic detection of changes needs to be kept low to reduce the amount of work for subsequent validation process (fatigue effect).
- False positive alarms can cause trouble, but are not dangerous.
- False negatives (not detected possible threat) should be near 0 %. An omission of a potential threat can have severe consequences.

Table 1 shows the results of the flight campaigns and corresponding processing carried out while the iNTeg-Risk project. Due to incremental development of the change detection process and changed regulations in France, and the associated use of a different UAS not designed within iNTeg-Risk project and a third party change detection approach, the results are not directly comparable, but they are an indication for the quality of available systems and the need to improve their accuracy, especially related POD.

Table 1.- *Results of threat detection: automatic processing and visual verification.*

Flight Campaign	UAS	Threat Detection	Automatic		Verification		Comments
			POD [%]	POFA [%]	POD [%]	POFA [%]	
France 2009	Carolo P200	iNTeg-Risk Version 1	94	93	89	6	Test of first threat detection system including visual search for omitted threats
Germany 2012	Carolo P200	iNTeg-Risk Version 2	100	35	100	0	Data acquisition for further development of threat detection system
France 2012	DT-18	Third party	50	98	97	0	Verification of automatically detected changes and visual search for omitted threats
Spain 2013	Carolo P200	iNTeg-Risk Version 2	76	91	76	0	Final test of threat detection system with real world data; no visual search for omitted threats

VI. Risk of Critical UAS Failure

UAS failure and resulting accidents and crashes are a major concern when talking about the commercial use of UASs. But reliable statistics are not available since the use of UASs for civil applications is part of a young industry. Most extensive use of drones has been by military organizations and most information on drone failure remains confidential.

Contact with UAS associations, manufacturers and service providers did not result in usable feedback. The only information gathered during this project is referred to the used Carolo P200. According to the flight statistics collected from 2009 to 2013 only a single crash happened within 66 flight hours (99 flights with an average of 40 minutes) caused by interferences between remote control and receiver, but could be fixed by replacement.

Taking into account that the used UAS was developed for research projects, that commercial UAS and crash avoidance systems are rapidly evolving and finally that the kinetic energy of a small UAS (< 2.5 kg) is quite low compared to a manned fixed wing aircraft or a helicopter, it can be expected that light weight UASs will find their way into commercial applications and replace traditional manned aircrafts if it makes sense.

VII. Recent and future developments

At the end of iNTeg-Risk project, only in France there was clear regulation for the utilization of UAS. For this reason, GRTgaz is currently studying how to continue the works of this project, but after analyzing the result and 2012 regulation, which only allows flights out of sight with drones under 2 kg, it was concluded that it is not profitable enough to replace the traditional aerial survey with planes or helicopters.

Currently, GRTgaz has decided to concentrate the next experiments on short sections of pipelines where planes or helicopters are not adapted for leading survey:

- Pipelines located in forest with narrow band of visibility.
- Pipelines concerned by ground movements (3D survey easy with drones).
- Pipelines located in mountainous terrain where planes have difficulties to fly.
- Above ground pipelines, such as attached to a bridge.
- Elevated installations in stations, such as lightening protection located on a roof.

GRTgaz is leading a new campaign of tests in 2014 to evaluate the profitability of UAS in these situations.

In parallel, GRTgaz with GDF SUEZ and other transmission network owners (electricity, rail) are still working with the Civil Aviation Agency and UAS manufacturers to allow bigger UAS to fly in France and be capable of replacing planes and helicopters in the future.

For its part, GDF SUEZ CRIGEN (Research and Innovation Center dedicated to Gas and New Energies) is currently working on UAS to specifically address others energy industry needs. A team of engineers, able to perform experimental flights, develops for example specific UAS for integrity management and energy efficiency issues based on multirotor UASs.

VIII. Conclusion

The work done in the framework of the iNTeg-Risk project has allowed developing a new and innovative safety barrier for improving the safety level of natural gas transportation by high pressure pipelines*: an automatic aerial surveillance system able to detect threats for the pipelines.*

The activities performed by the iNTeg-Risk partners have allowed:

- To develop and to test the automatic threat detection methodology based on the utilisation of UASs and a set of software tools.
- To work on social acceptance issues related to the UAS use.

A particular result of the project is the importance of the right integration of the UAS and the camera, in order to get images with accurate enough geographical information able to be used by the automatic image-processing and threat detection software.

Another issue highlighted by the project is the importance of regulation. If very restrictive regulations are put in place, this can avoid the utilization of UASs as a surveillance tool for industrial infrastructures.

Finally it is worth to say that thanks to the iNTeg-Risk project, and with some additional developments still pending, this new surveillance system will be ready for being deployed as a new surveillance procedure for hydrocarbon transmission pipelines.

IX. References

[1] *8th EGIG Report: 1970 – 2010. GAS PIPELINE INCIDENTS, 8th Report of the European Gas Pipeline Incident Data Group. 11.R.0402 (version 2). December 2011.*

[2] Jovanovich, A.S. & Löchter, M., *iNTeg-Risk Project: How much nearer are we to improved "Early Recognition, Monitoring and Integrated Management of New Technologies Related Risks*"?, May 2013.

[3] G. Pognonec, *First steps in developing an automated aerial surveillance approach*, Proceeding International Gas Union Gas Conference 2011, 19th – 21st October 2011, Seoul, South Korea.

[4] M. Zarea , G. Pognonec, M. Lecchi, J.A. Lana, M. Sohlbach, A. Scholtz, E. Rigaud and C. Mazri, *Emerging risk issues of an innovative safety barrier: Automated Aerial Surveillance System developed within iNTeg-Risk Project*, Proceeding 5th iNTeg-Risk Conference 2013, Stuttgart, Germany, 21st – 22nd May 2013.

[5] *The 11/04/2012 decree relating to unmanned aircrafts design, use and requirements to qualify pilots to operate them (NOR:DEVA1206042A).*

[6] *The 11/04/2012 decree relating to the use of airspace by unmanned aircrafts (NOR:DEVA1207595A).*

[7] *Royal Law Decree 8/2014, 4th July, on the approval of urgent measure for the growing of competiveness and efficiency. Section 6. Remote operated civil aircraft (Real Decreto-ley 8/2014, de 4 de julio, de aprobación de medidas urgentes para el crecimiento, la competitividad y la eficiencia. Sección 6ª Aeronaves civiles pilotadas por control remoto).*