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FIRST STEPS IN DEVELOPPING AN AUTOMATED AERIAL SURVEILLANCE APPROACH

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ABSTRACT

This paper details the first steps in developing an automated aerial surveillance approach of industrial infrastructure. The development of a set of new technologies to automate aerial surveillance by collecting images with a UAV and automatically processing them to identify threats to buried oil & gas transmission pipelines is also described.

Progress on two aspects is presented, on one hand, technology development, and on the other hand, dealing with the emerging risks associated with these new technologies.

Technology development covers three functions assembled in a workflow:

- Image collection via a light UAV with an autonomous navigation system and image GPS referencing capabilities.
- Image automated pre-processing: image assembly and georeferencing.
- Threat detection: image analysis by change detection is performed using software for identifying external interferences like construction work and excavations threatening the pipeline.

This set of technologies is perceived as an emerging risk that is appraised from several points of view:

- Technology: UAV, image georeferencing and assembly, change detection for threat identification,
- Human and Organisational & Communication: investigate the acceptance of this technology by the population and local authorities,
- Regulatory: check conditions that will ensure acceptance of operational use of light UAVs in some European countries

This general approach is needed to ensure both technology optimisation and the shortest path to reliable practical applications.

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1. BACKGROUND AND OBJECTIVES

Gas pipelines are considered as very safe, with a failure frequency of 0.18 per year per 1000 km, and a fivefold failure frequency decrease over three decades, despite sustained growth in pipeline length (EGIG 2007). This could be achieved through an adequate combination of technologies, practices and organizations to address the full range of non-voluntary (external interference is the dominant failure cause) and natural threats. Failure frequency for the main cause, external interference, has stabilized over the last decade, calling for breakthroughs in order to decrease risk.

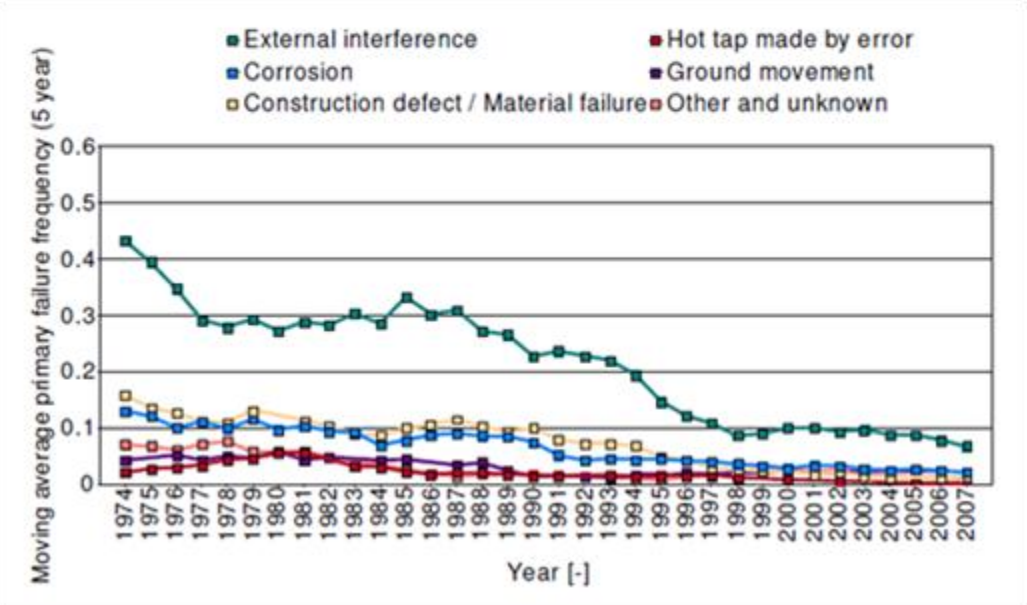

Figure 1: Evolution of gas transmission pipelines failure frequency over the last three decades - From 7th EGIG Report [European Gas Pipeline Incident Data Group].

It is very challenging to tackle this failure cause, as it involves ground-working equipment hitting pipelines when digging in their vicinity. This equipment is operated by and for stakeholders that are independent of pipeline operators.

One of the possible ways to further improve safety is to optimise surveillance.

Currently, surveillance is performed as a combination of aerial and land patrols with different frequencies. A new alternative is explored with the support of the 7th R&D Framework Programme of the European Union. It consists in developing a set of new technologies to automate aerial surveillance by collecting images with a UAV and automatically processing them to identify threats to buried oil & gas transmission pipelines. This work is part of the iNTegRisk integrated project, which global objective is to develop an integrated risk management methodology for emerging risks. The partnership is composed of pipeline operators – GDF SUEZ and ENAGAS, Technology providers – Trimble, and University of Braunschweig, and research organisations – INERIS and Mines Paris Tech, Chair of Industrial Safety.

Progress on two aspects is presented, on one hand, technology development, and on the other hand, dealing with the emerging risks associated with these new technologies.

The current status of technology development will be illustrated with some preliminary results of processing images collected in the first flights in Spain and France.

This set of new technologies is perceived as an emerging risk that is appraised from several points of view according to the iNTegRisk emerging risk management framework:

- Technology: UAV, image georeferencing and assembly, change detection for threat identification,
- Human and Organisational & Communication: investigate the acceptance of this technology by the population and local authorities
- Regulatory: check conditions that will ensure acceptance of operational use of light UAVs in some European countries.

This general approach is needed to ensure both technology optimisation and the shortest path to reliable practical applications.

These activities lag with respect to technology development, as the latter provides necessary inputs to the former.

2. PROGRESS OF TECHNOLOGY DEVELOPMENT

The functions of aerial surveillance are mainly to detect threats on or close to the right of way, leak detection, ground movement and right of way maintenance. To cover most of these functions, the list of objects to be detected includes a variety of classes:

- Construction work, earth movement and excavations, laying of cables, sewers, ducting and pipes, erection of buildings, foundations, pylons, etc., boring and pressing,
- Preparing activities, such as building sheds and pickets, assembling machinery, laying drainage cables,
- Soil upheavals, erosion, deep vehicle tracks, water-logged surfaces,
- Planting of new shrubs and trees,
- Discolouring of vegetation above the pipeline,
- Temporary deposition of materials and agricultural products.

Technology development of automated aerial surveillance covers three functions assembled in a workflow that delivers the expected outcome – predefined threats are detected, identified and localised:

- Image collection via a light UAV with an autonomous navigation system and image GPS referencing capabilities,
- Image automated pre-processing: image assembly and georeferencing,
- Threat detection: image analysis by change detection is performed using Trimble software for identifying external interferences like construction work and excavations threatening the pipeline.

2.1 Workflow and steps

Major prerequisite for pipeline monitoring with UAVs is an elaborate and carefully balanced workflow. Otherwise a multitude of inaccuracies are passed on from stage to stage making detailed preprocessing and image information extraction impossible.

The major elements of automated aerial monitoring pipelines with UAVs are represented globally in Figure 2.

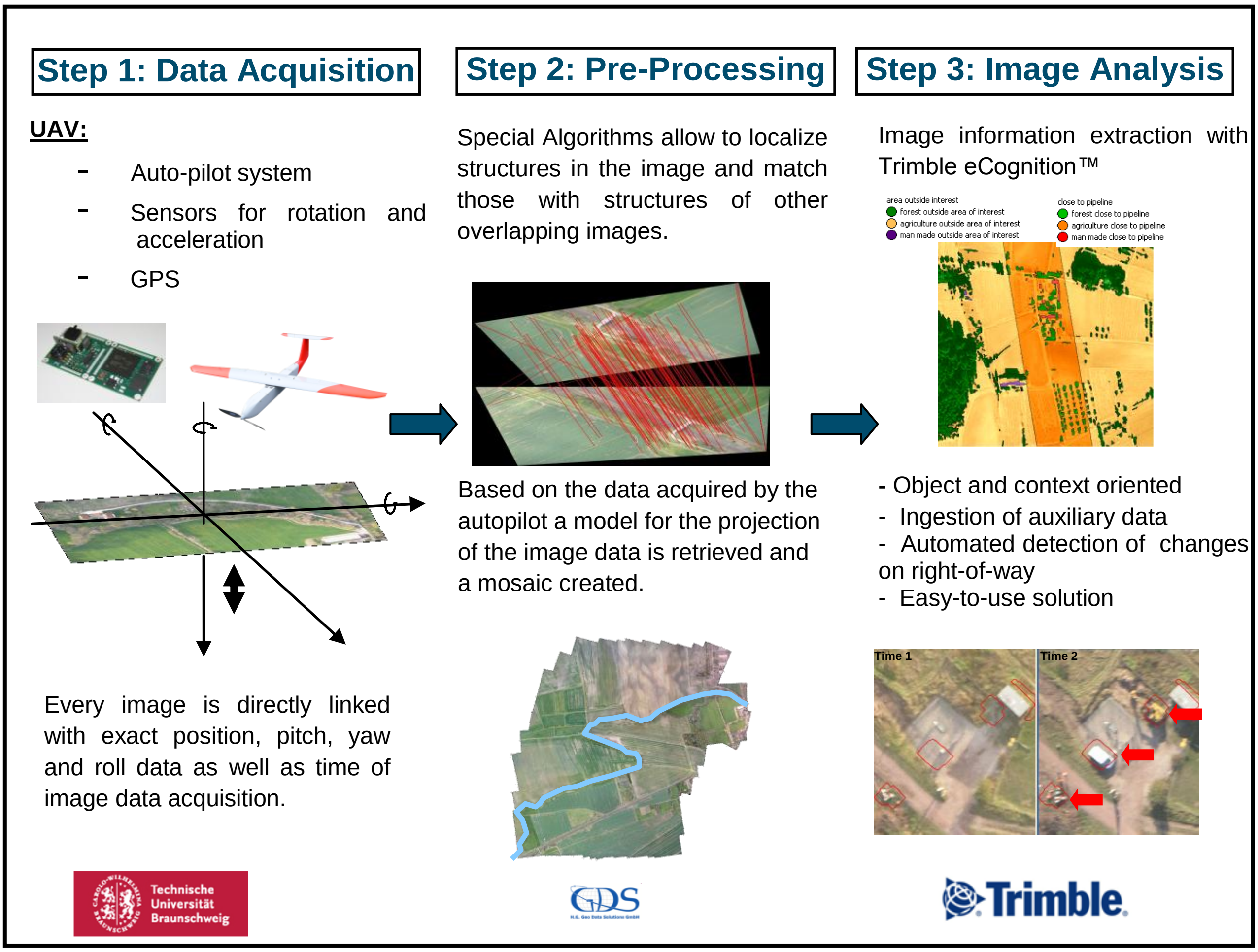

Figure 2: Process workflow and steps

2.2 Step 1 – Data acquisition with UAVs

Collecting images starts with choosing the right UAV with regard to size, costs, payload, range, etc. and adapting an adequate camera. An autopilot which allows the programming of the flight route and precise GPS positioning are crucial. Every image is directly linked with exact position, pitch, yaw and roll data as well as precise time of image data acquisition. All this information is handed over to the next stage and determines the accuracy of the image pre-processing.

2.3 Step 2 - Image Pre-processing: image assembly and georeferencing

In this step the raw images acquired on the UAV platform are re-positioned pixel by pixel and endued with coordinates. This allows comparison with other image data and maps as well as a precise location of relevant changes, respectively risks to the pipeline.

Special algorithms allow to localise structures in the image and match those with structures of other overlapping images. The structures may be twisted, tilted, have different scales or have different radiometric parameters. Based on the data acquired by the autopilot a model for the projection of the image data is then retrieved.

The final outcome of the stage is a geo-referenced mosaic of images covering the pipeline corridor/right-of way for the required section of the pipeline. The image mosaic can consist of thousands of single images.

The geometric accuracy of the image is crucial for the next step – image information extraction. If images of subsequent data acquisition campaigns do not fit properly onto each other the consequence will be a high number of false alarms.

2.4 Step 3 - Image Information Extraction 1, 2, 3)

The last step in the overall workflow is to identify objects near the pipeline that might represent a potential threat.

Trimble eCognition™ is the basis for any image information extraction in the project. It is an object and context oriented analysis software, in which pixels are grouped to objects. Consequently the basis for detection and classification is much broader as it does not only refer to colour and texture as in pixel-based classification methods but uses the form of objects, their size, neighbourhood and distance to other objects in addition.

The software allows a description of objects in a macro language called CNL ("Cognition Network Language" - e.g. a house is mostly rectangular, has a shadow, might be surrounded by green and has other houses in a certain distance, furthermore it might be close to a street and there is a connection between the house and the road).

The developed application focuses on finding all changes / risks even with the risk of creating false alarms. In the current state of development, all relevant detected changes / risks have to be reviewed by an operator on ground. It is important to keep the rate of not-detected changes / risks close to zero. In the future, the involvement of the operator has to be decreased to ensure acceptance.

2.5 Solution Modules for Image Analysis

The change detection sequence is part of a solution looking for activities along a pipeline corridor potentially threatening the pipeline.

The overall solution will comprise the derivation of a base map from aerial orthophotos or other sources of information, potential threat detection and verification on multitemporal UAV image stacks (by plausibility checks and base map comparison) and the decrease / elimination of false alarms. Results will be exported, optimized for operator driven refinement. For operator driven threat verification, GUI and functionality for efficient alarm verification will be provided. As an end product, thumbnail reports, maps, and statistics of threats will be delivered to the pipeline operator.

The solution is looking for objects of interest pointing at the above-mentioned activities. These could be construction equipment/machinery, usually metallic, sized at least 2 m x 1 m, cars, tractors, and other vehicles, longitudinal structures with a length of some 5 m and diameters of 0.2 m and above, deep vehicle tracks, waterlogged surfaces (as indicators for excavations filled with water), new shrubs and trees with a top diameter of 0.2 m and above, temporary deposition of materials and agricultural products as well as new buildings and roads.

Until now, gas transmission pipelines were overflown in Nancy/France, operated by GRTgaz (subsidiary of GDF SUEZ), and Zaragoza/Spain, operated by Enagas.

2.6 First results of full image processing workflow

- **Workflow for Image Information Extraction**

The flowchart in Figure 3 illustrates the workflow within the Trimble solution covering step 3.

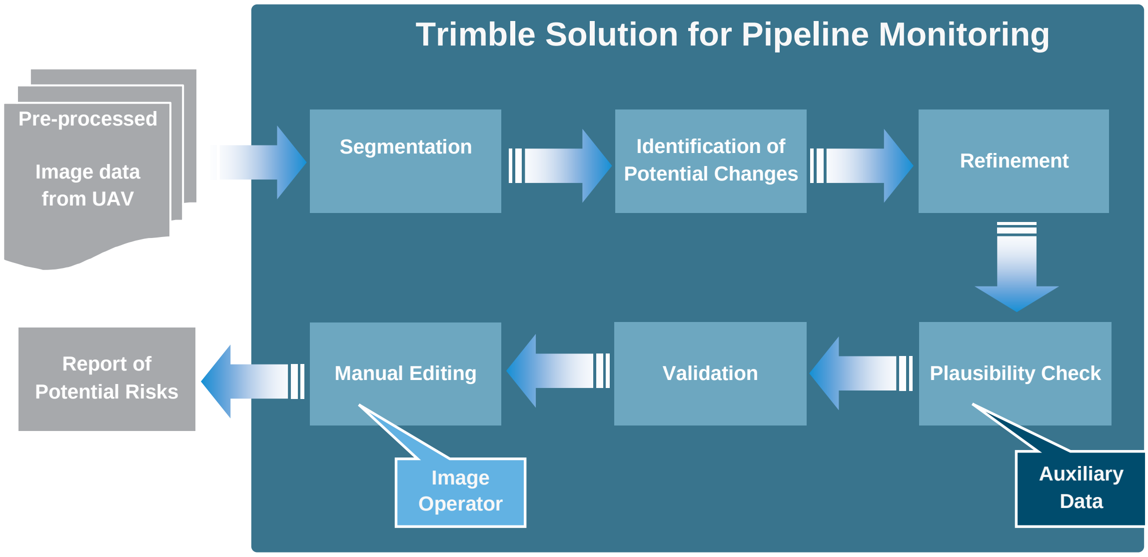

Figure 3: Workflow for step 3 - image information extraction

- **Example Change Detection**

In the following example, two images of the same site (France), taken at time 1 and time 2 are compared and the Trimble change detection analysis is performed. The digging machine was identified as a potential threat with a different position at the two points in time.

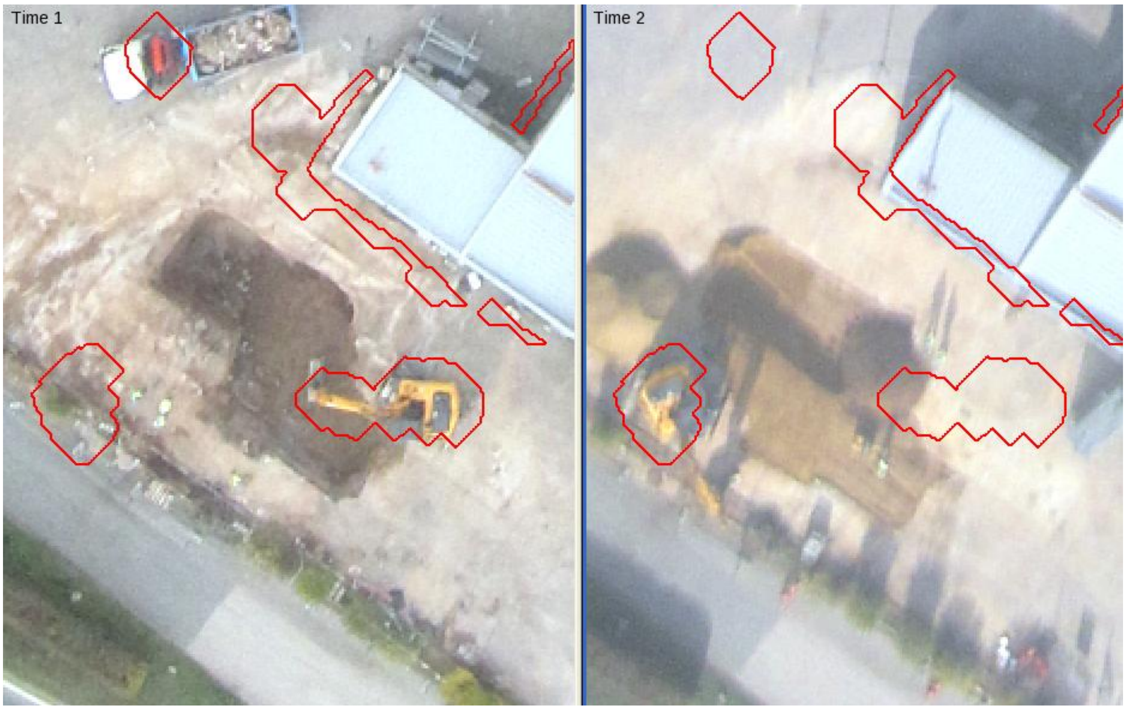

Figure 4: Example for Change Detection

3. HOW TO DEAL WITH THE EMERGING RISK DIMENSION

This risk is emerging because the commercial use of this automated aerial surveillance technology is new, and no experience is available with it. As mentioned in section 1, the emerging risk dimension is considered here according to the iNTegRisk emerging risk management framework: Technology, Human, Organisational and Communication, and Regulatory.

While a physical UAV failure may lead to consequences, these are not so severe, and mitigation measures can be set up. The inefficiency in fulfilling the surveillance task might have more severe consequences if a harmful aggression is not prevented by it, so other prevention measures have to be more efficient. These different aspects are identified as emerging risks listed below:

- Physical UAV failure & loss of control (ERI 1),
- Image / Data collection failure (ERI 2),
- Automated image processing inefficiency (ERI 3),
- Civil aviation acceptance (ERI 4),
- General public acceptance (ERI 5),
- Automated industrial surveillance improves pipeline risk management (ERI 6).

ERIs 2 and 3 are focused on relating system performance with its capability of reducing risk to pipelines.

ERIs 4 and 5 address specifically governance and communication issues that go beyond the coverage in ERI 1, and that are aimed at quite different stakeholders, civil aviation regulators for ERI 4, and other stakeholders for ERI 5, that’s why they are treated separately.

Finally, ERI 6 integrates the emerging technology in the mature risk management framework of transmission pipelines concerning the prevention of external interference.

We describe below the current status of the investigations for the different emerging risk issues. The first three ones need specific failure event trees and key performance indicators that are under construction as the technical objects evolve themselves.

3.1 Physical UAV failure & loss of control

The emerging risk issues due to UAV operation are of two types: critical failure, which implies potential severe consequences, and mission failure, which does not impose the direct risk of damage or injury and still leaves the option of repeating the mission. This ERI 1 covers the critical failure scenarios.

The ERI 1 of critical UAV failure implies its crash on the ground or its collision with aircraft, or with a high-rise obstacle.

A simple mitigation option is the recovery of the UAV by parachute (Flight Termination System) in an unpredictable area along the flight corridor. This parachute system can itself fail and lead to a UAV crash.

While a crash of manned aircaft with all its consequences is widely accepted due to the very low probability, this issue has to be addressed independently for UAV operations due to the significant differences in operational procedures, probabilities of failure and severity of consequences.

The emerging risk aspect is related mainly to the fact that the technology is new, and is planned to be deployed above public and private properties, so has a potential impact over tens of kilometers over a relatively short time, ~ 1-2 h.

Scenarios that can lead to physical UAV failure or loss of control are identified on the event tree below.

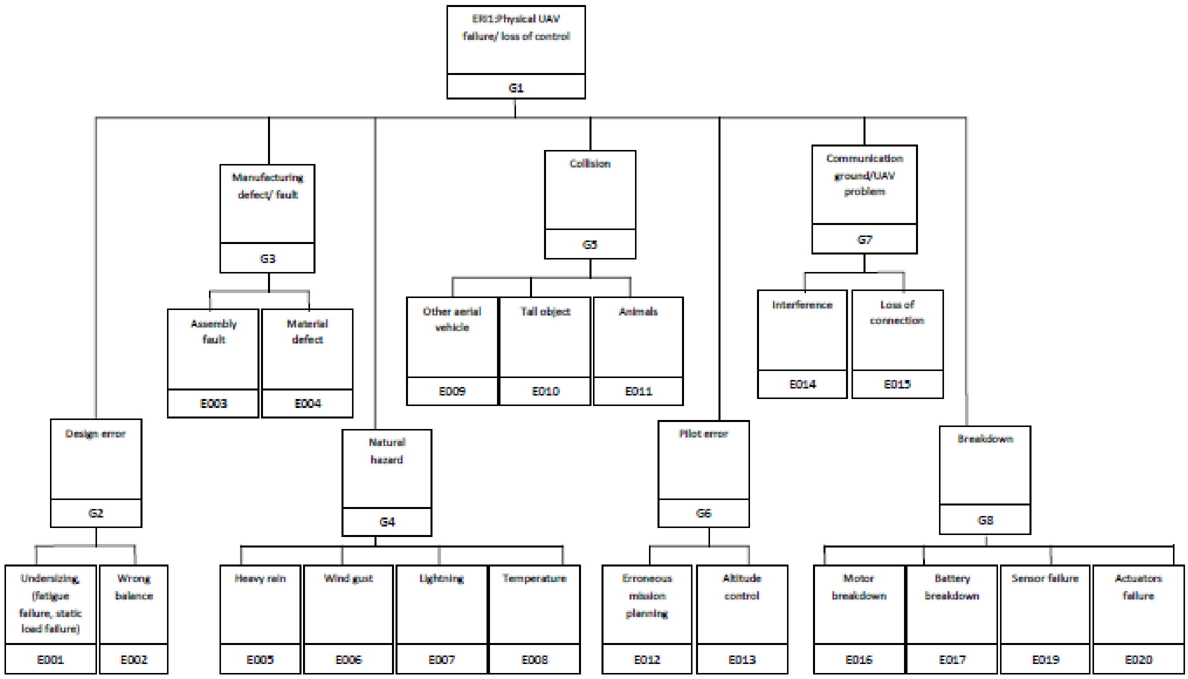

Figure 5: Failure scenarios for Physical UAV failure / Loss of control

In the absence of a systematic and specific study of consequences of an UAV crash, the most basic approach is to note that damage is created in a crash due to kinetic energy dissipation. Therefore an order of magnitude comparison can provide a rough estimate, as shown in the Table 1 below for a typical surveillance plane, a Cessna 150 two seater, and the mini UAV Carolo 200 used in iNTegRisk.

Parameter	Cessna 150	Carolo 200
m (kg)	730	6
V (km/h)	200	55
Ek (kJ)	1126,5	0,7

Table 1: Kinetic energy dissipation comparison between Cessna 150 and mini UAV

The ratio of kinetic energy dissipated in a crash for a UAV vs. a surveillance aircraft is $6.2*10^{-4}$, in other words, there are more than three orders of magnitude between the energy dissipated by the UAV crash and that for a light plane, and we can start with the assumption of consequences scaling linearly with this ratio.

Moreover, the different test campaigns that were already performed over several hundreds of kilometres in the project are a first step to show that aerial surveillance of transmission pipelines with UAVs can be controlled and secured, provided among others that a different bandwidth is chosen for the RC link than those used for GSM and for Digital Broadcasting.

3.2 Image / Data collection failure

As the acquisition of high quality images that can be analyzed on potential threats for the pipeline is the critical step within the workflow, the emerging risks have to be tackled carefully.

Mainly technical issues referring to the camera can lead to images that cannot be used and make a whole mission obsolete. Also human failure in handling the camera and its settings might lead to bad images.

The automated pre-processing algorithms have to be able to tackle all kinds of different situations - therefore their development is crucial and an appropriate test phase is inevitable.

Last not least every flight mission is dependent on the weather conditions - therefore fog and clouds might make a planned flight impossible or reduce the image quality tremendously whereas a full snow cover might cause that threats cannot be detected at all.

Figure 6: Example of image georeferencing and assembling

The following pre-assessment identifies scenario which can lead to a lack of image or bad quality images:

- Data acquisition failure, due to:
  - camera failure (sensor distorsion, color, etc.)
  - bad camera setup (radiometry, contrast, brightness)
  - sampling rate too low
  - data storage failure (insufficient memory space, memory crash, etc.)

- Bad weather conditions:
  - fog
  - clouds

- Not updated / wrong flight parameters:
  - altitude too low or too high
  - too high roll/pitch angle (incorrect ground coverage)
  - too fast speed compared with sampling rate
  - unintended aircraft movement (blurry image)

3.3 Automated image processing efficiency

The key image processing step, change detection, identification and location can be characterised by key performance indicators typical of 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 needs to be kept low, only qualified threats require reporting
- False positive alarms can cause trouble, but are not dangerous
- False negative alarms – i.e. not recognizing a possible threat - can be real hazards
- Recurrent alarms have to be avoided, which makes the reliability of change detection – i.e. the comparison between new and former observations – even more important.

A section of the images taken in Nancy (France) in October 2009 has been used to develop the automated change detection analysis tool described above and to assess its accuracy.

Tables 2 and 3 show the results before and after a user (which may be the pipeline operator) has manually approved the detected changes.

The object verification tool is still under development; therefore the type of threat (excavation machine, etc.) cannot be listed yet.

Nb. Real Targets	Nb. of false positives (false alarm)	Nb. of false negatives (missed)	Nb. of true negatives	Nb. of true positives (hits)	Total Nb. Negatives	Total Nb. Positives	**POD**	**POFA**
18	247	1	62	17	309	18	**94%**	**93%**

Table 2: Threat detection performance before manual editing

Nb. Real Targets	Nb. of false positives (false alarm)	Nb. of false negatives (missed)	Nb. of true negatives	Nb. of true positives (hits)	Total Nb. Negatives	Total Nb. Positives	**POD**	**POFA**
18	1	2	3	16	4	18	**89%**	**6%**

Table 3: Threat detection performance after manual editing

The current version of the prototype shows a high level of detection, but is rather prone to false alarms. If manual checks are currently necessary, future improvements should decrease this requirement.

3.4 Civil aviation acceptance

Civil Aviation Authorities are generally conservative when asked to allow the use of new technologies in the airspace. UAVs represent a certain risk in this strongly regulated environment due to issues related to both safety and security.

This situation is supported by the fact that in an emergency case (risk or collision or accident), a person can decide how to proceed and to guide the plane. However, for an UAV with an automatic control system, there is not chance to decide how to proceed in case of an imminent collision against a building or another flying object.

Beyond these facts, acceptance criteria applied in each country by Civil Aviation Authorities may differ. In some countries Authorities may be relatively restrictive, others have plans to regulate UAV use in the near future, while for others a UAV, like a ultralight plane or a radio controlled model plane, is not “aviation” and for this reason there is a lack of regulation.

The current situation in Germany, Spain and France raises two types of risk issues:

- Technical: how to proceed with technology development to guarantee the successful achievement of the flight mission without risk to third parties.
- Regulation: the positions of Civil Aviation Authorities concerning commercial UAV use for civil applications may be a clear risk to their large scale deployment. Some

countries can decide to follow a very conservative approach, which means that the use of UAVs will be almost impossible there.

In France, a working group was created in 2011 at the initiative of the Civil Aviation Authorities to discuss with stakeholders about regulation evolutions.

3.5 General public acceptance

The use of UAVs for industrial infrastructure surveillance has been studied under the scope of its social acceptability. On the basis of bibliographical analyses and stakeholders interviews, major obstacles that may threaten the development of this UAV application were identified.

The main obstacles identified are juridical, technological and social.

The juridical ones are related to:

- the lack of a technical risk acceptability matrix dedicated to UAVs;
- the lack of insurance mechanisms to cover third parties damages;
- The segregation of airspaces for UAV applications.

The technological challenges identified are:

- the development of reliable and efficient sense and avoid systems;
- gathering of reliability data;
- protection of remote control frequency bands;
- development of sense and avoid systems;
- Third party information about existing segregated airspace.

Regarding the social dimensions, the following obstacles have been identified:

- Images confidentiality
- Noise
- An adequate information of populations

4. CONCLUSION AND FURTHER WORK

Thanks to the test campaigns in France and Spain, an existing light UAV has shown its ability to fly autonomously over pipeline routes in stretches of the order of 20 to 40 km. It collected images with a consumer camera that are geo-referenced, and for which the flight attitude of the UAV is known.

Preprocessing algorithms for stitching the images together to form a mosaic and correct them for the actual position of the plane have been developed and used.

A change detection algorithm was developed based on the eCognition software, and this resulted in a high probability of detection on the flight that was analysed. In automatic mode, the threat identification part is not yet satisfactory, and as a back fall manual identification was introduced. Yet to achieve practical use, human involvement has to be minimised, so future work is directed towards this aim.

In addition, the acceptability of this emerging technology has started to be assessed for different stakeholders, and a method to evaluate the expected and unexpected effects of changing the surveillance approach has been outlined. Its practical use will be part of the future work.

REFERENCES

1. U. Benz, P. Hofmann, G. Willhauck, I. Lingenfelder, M. Heynen. Multi-resolution, object-oriented fuzzy analysis of remote sensing data for GIS-ready information. Trimble. Munich, Germany; in journal ISPRS Journal of Photogrammetry & Remote Sensing 58 (2004) 239– 258.

2. M. Baatz, C. Hoffmann, G. Willhauck. Progressing from object-based to object-oriented image analysis", Trimble. Munich, Germany in book Object-Based Image Analysis: Spatial Concepts for Knowledge-Driven Remote Sensing Applications (T. Blaschke, S. Lang, G. Hay; Springer, 2008).

3. eCognition Developer 8.0.1 User Guide", Document Version 1.2.1, 2010.

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