Object-based detection of hazards to the European gas pipeline network using SAR images

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Abstract

In this paper the results of a study for a hazard detection system for Europe's extensive high pressure gas mains transmission systems are presented. The system is designed to trace uncontrolled digging, ploughing, excavating activities using draglines or other machinery, construction works and planting of trees near pipelines using remote sensing. The architecture of the system consists of three stages: SAR and optical change detection, change categorisation and change classification. In case of SAR change detection two cases were worked out, one for airborne sensors and one for spaceborne sensors. For the airborne case an average percentage of detection was found of 74 %. For the spaceborne case this figure was 37 %. Results of optical change detection are not fully elaborated yet, but some are shown. Additional reduction of false alarms takes place in the change classification stage. The study is part of the European Commission fifth framework project PRESENSE - Pipeline REmote SENsing for Safety and the Environment.

1 Introduction

The European Commission fifth framework project PRESENSE - Pipeline REmote SENsing for Safety and the Environment (http://www.presense.net) - aims to further improve the safe and secure transmission of gas in Europe's extensive high pressure gas mains transmission systems, by assessing the potential benefits of remote monitoring techniques and processes. Hundreds of incidents are reported each year such as third party interference and soil movement, some of which result in methane releases (a strong greenhouse gas). The ultimate target is a new form of pipeline management system based upon remote satellite surveillance. This would provide pipeline operators with a computer based information system capable of alerting them to potential pipeline damage, in all weather and lighting conditions.
Third party interference of pipelines typically consists of uncontrolled digging, ploughing and excavating activities using draglines or other machinery near pipelines. Also construction works and planting of trees can cause damage to pipelines. Efficient and cost-effective regular monitoring of the European pipeline network unimpeded by weather conditions is therefore a necessity.
This paper presents results of a study for a hazard detection system that focuses on third party interference. The architecture of the system comprises three stages:

- Change detection - detection of changes based on SAR and optical images
- Change categorisation - fusion of SAR and optical changes, categorisation of changes into priorities
- Change classification - classification of categorised changes into hazards (e.g. digger, excavation, tree, etc.)

The hazard detection system is largely implemented in the eCognition software environment [1], which allows efficient object-based detection, fusion and classification. For the SAR imagery a speckle filter and CFAR (Constant False Alarm Rate) detector were added. The combination of these with object-based analysis combines both the detection of small targets by CFAR, and the advanced analyses of the scene using advanced fuzzy and hierarchical classification rules, see Fig 1.

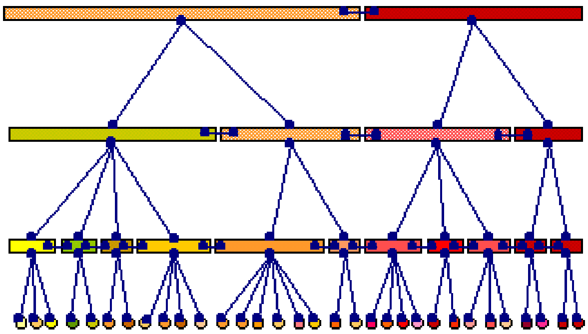

Fig. 1 Hierarchical network of image objects in abstract illustration for classification purposes.

In order to assess the validity of the proposed data handling procedure, high-resolution SAR imagery (0.5

metre), optical imagery (0.8 metre, 11 bands) and LiDAR imagery (1.0 metre) were collected for three test sites in Europe. At these sites several digging devices were deployed. SAR and optical images were collected before and after relocating the devices using the same orbits in order to facilitate the change detection. This was done twice, once in winter and once in summer. We have studied two possible applications one focussing on airborne sensors using the higher resolution data and one focussing on spaceborne sensors, for which the airborne SAR data were degraded to 3.0 metre resolution. An important issue in the detection of hazards is false alarm reduction because false alarms raise the survey costs.

2 Hazard extraction

2.1 Change detection

2.1.1 SAR change detection

The SAR change detection workflow is shown in Fig 2.

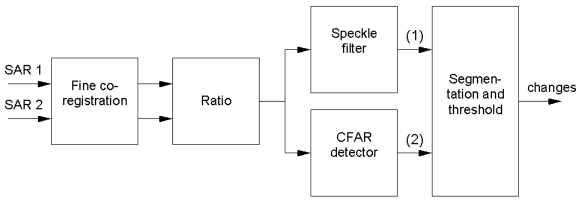

Fig. 2 SAR change detection workflow.

The workflow starts with an automatic FFT-based fine co-registration module which takes care of small geo-referencing errors. The ratio of the images passes a speckle filter and a CFAR detector in parallel. Both are input to the segmentation process in which changed objects are recognised in eCognition. Speckle filtering is applied to reduce the number of false alarms from the segmentation process [2]. A CFAR detector [3] is applied to preserve small changes and prevent them from being swallowed by large objects in the hierarchical segmentation process. Due to the parallel processing of information, the workflow covers distributed changes as ploughed fields (1) and small targets as digging machinery (2). The co-registration module, speckle filter and CFAR detector are implemented in ERDAS Imagine using the Developers Toolkit. Fig 3 shows a result of the workflow.

2.1.2 Optical change detection

The optical change detection flow is also characterised by a parallel approach.
The first approach is that of a post-classification change detection algorithm in which changes are detected based on the results of land cover classification. Changes occur if the land cover between two images is different. Basic land cover classification was applied to the optical data in eCognition. Before classification image objects were created by multiresolution segmentation. An important feature in land cover classification is the normalised difference vegetation index (NDVI) which is an indication of the relative amount of vegetation. GIS data was used to delimit the buildings. Fig 4 shows a land cover result. LiDAR data was added atop to classify shaded areas and to prevent them from generating false alarms.
The second approach is pixel-based and comprises different pre-classification change detection algorithms [4]. The first algorithm calculates the temporal scalar product (TSP), i.e. the cosine of the angle between the vectors that are formed by the 11 channels of two optical images. The second algorithm searches for changes in vegetation by calculating the NDVI. Both TSP and NDVI output are merged into one layer. A third algorithm is statistical and produces a false alarm mask. Changes in those areas are considered as false. Both approaches are used in optical change detection.

Fig. 3 Detected changes from a pair of SAR images of the Borculo test site in the Netherlands (top) showing a relocated shovel near a farm (encircled and bottom). The other detections are due to activities on the farm or are false.

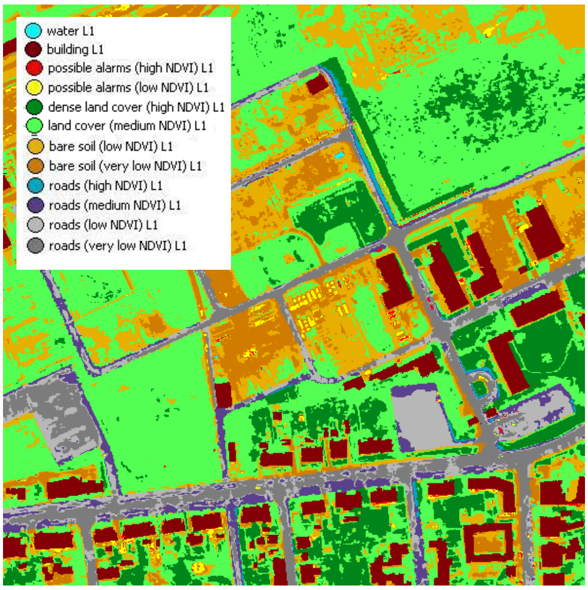

Fig. 4 Basic land cover classification of the Dorsten test site in Germany for the purpose of optical change detection.

2.2 Change categorisation

In the change categorisation the information of all change detection algorithms is fused and categorised into three priorities.

Here the false alarm mask is used to exclude possible false alarms from SAR as well as from the optical images. First, both parallel optical change detection approaches (i.e. post-classification change detection and the TSP/NDVI products) are combined into one layer, leaving only coinciding changes. Changes present in only one of the layers are excluded, reducing the number of false alarms. Second, SAR and optical are combined and given three priorities:

- Highest - coinciding changes
- High - changes in SAR only
- Medium - changes in optical only

The highest priority is given to changes that occur in both SAR and optical at the same time.

2.3 Change classification

Here the priorities of changes are classified into hazards. Due to the resolutions (0.5 - 0.8 metre) this is not an easy task. Therefore classes will not be that specific. The following ten classes are defined:

- Small machine off-road, small excavation
- Small machine on-road, small road-work
- Large machine off-road, large excavation, planted trees
- Large machine on-road, large road-work
- Top-soil work, planted forest
- Logging activities
- Demolished buildings
- Disappeared water
- New water
- Other hazards

The definition of classes is based on a set of advisory guidelines by the IGEM - Institution of Gas Engineers and Managers [5] and what could possibly be detected using remote sensing images. Classification of the objects is based on object size, spectral signature and underlying landcover. The latter is based on GIS data. Fig 5 shows an example of a result.

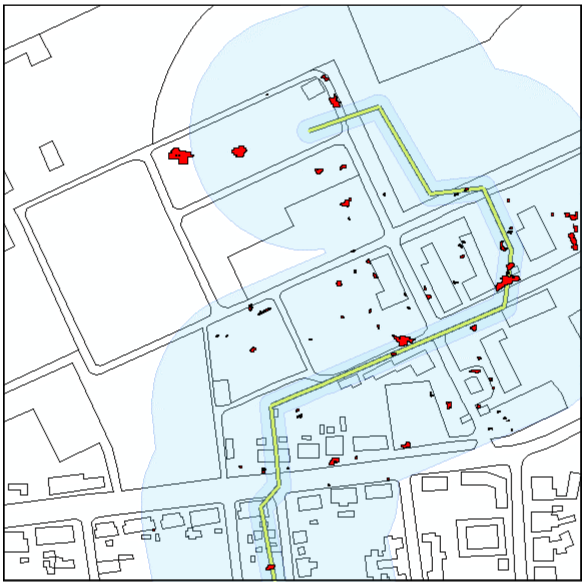

Fig. 5 Classified hazards (red) in the neighbourhood of a gas main (green) in Dorsten. At this site several digging devices were deployed and excavations made.

3 Results

With the hazard detection system, data of the two campaigns (winter and summer) and the three test sites are processed. In case of SAR, the sites were imaged at different track angles and processed at different resolutions (0.5 and 3.0 metre). Table 1 shows the results of the first stage: SAR change detection (section 2.1.1), in winter.

At Borculo eight devices were deployed. The devices include tractors, draglines, a shovel and a water tank. Several devices were deployed close to deciduous trees. The differences in detection are mainly due to differences in track angle (i.e. imaging direction) and therefore masking by trees, even in winter.

At Dorsten nine devices were deployed, two excavations made and a basin flooded. The devices include trucks, cranes, a dragline, a shovel, a tractor and a few small devices. Here all devices were detected except for a private car and the excavations and basin. The reflectivity of them in the direction of the radar, in combination with their size, turned out to be too low. Here no difference was found between the different track angles.

At Marseille two diggers, a truck, a metal plate and two plastic targets were deployed and one excavation made. They were located in the imaged areas of three different sites. The metal plate, the plastic targets and the excavation did not return enough radarwaves to be detected. The other devices were detected once or twice. Because the few objects were divided over the three sites, statistics are not reliable and therefore not given.

The differences between 0.5 and 3.0 metre are significant: the percentage of detected changes is about halved, see also [6] which shows some figures on the numbers of false alarms too.

test site	track	0.5 metre		3.0 metre	
		pass 1	pass 2	pass 1	pass 2
Borculo	005	88	71	50	57
	006	75	57	25	29
	007	63	71	25	14
Dorsten	003	89	67	33	33
	004	78	67	44	33
	008	89	67	56	42
average		74		37	

Table 1 Percentage of detected objects from SAR images during the winter campaign during first and second pass. Changes include relocated digging devices, excavations and flooding.

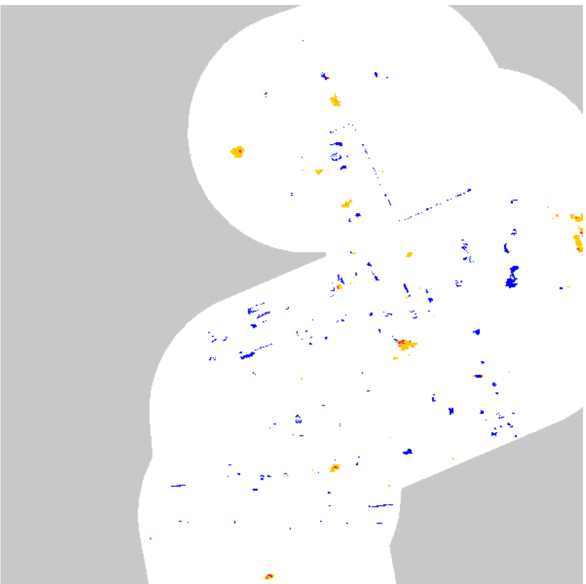

Fig. 6 Categorisation of changes in SAR (orange), changes in optical (blue) and coinciding changes (red) at Dorsten.

For optical change detection not all data is processed yet, except for Dorsten, see also Fig 6. This figure shows that the optical images result in more detected changes than the SAR images. Although some are the result of misregistration, at this point it is difficult to say what the performance of optical change detection is with respect to the number of detected objects and false alarms. Besides, in the final stage (i.e. change classification) additional reduction of false alarms takes place. This will happen for example for very small changes. Fig 6 shows a number of cases in which changes from SAR and optical coincide (i.e. highest priority changes).

4 Conclusions

An architecture to detect hazards that threat the European gas mains network using remote sensing is presented. It consists of three stages: SAR and optical change detection, change categorisation and change classification. In case of SAR change detection two cases were worked out, one for airborne sensors and one for spaceborne sensors. For the airborne case an average percentage of detection was found of 74 %. For the spaceborne case this figure was 37 %. Results of optical change detection are not fully elaborated yet.

5 Literature

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