Pipeline Integrity Management from Space

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ABSTRACT

In Europe the largest cause for failures of transmission gas pipelines are Third Party Interferences (TPI). Currently inspections of pipelines are performed by helicopters, cars and walking along the pipeline route. Recently other systems are introduced which detect possible threats by e.g. sensing pipelines via fibre-optic cables or with acoustic sensors. To these surveying methods for detection of TPI we add surveillance by EO/SAR (Earth Observation/ Synthetic Aperture Radar) satellites with high revisit frequencies. By integrating space based technologies[1] with terrestrial systems we aim (i) to improve regularity and effectiveness of inspection operations, (ii) to increase safety and (iii) to eventually reduce costs for pipeline operators. This is realised by providing a system delivering the following integrated services:

1. Detection of Third Party Interference (TPI), which mostly are threats related to excavation / construction activities and building of settlements near pipelines. These activities are detected through change detection techniques applied to successive EO/SAR satellite images. The system also allows to correlate detected changes via satellites with known third party activities, helicopter reports and results of other surveying methods.

2. Measuring ground elevation movements which are related to erosion, subsidence, and early detection of landslides and sink holes. Monitoring will be performed through Permanent Scatterer Interferometry (InSAR) techniques applied to a stack of EO/SAR satellite images. InSAR techniques can accurately measure slow varying movements with an accuracy of millimetres per year.

3. Guidance via a tablet computer of field operators to the exact field location where threats have been identified and enabling them to record visual evidences (photo's, reports). The exact location of the recordings of visual evidences will be geo-tagged and transmitted in real-time to the central system.

4. Monitoring pipeline health status of the pipeline by measuring in-situ sensors installed along the pipeline infrastructure.

In this paper we focus on results of our technology for detecting TPI based on real life experiments with EO/SAR satellites. The work presented here has been conducted with support of the Netherlands Space Organisation and in partnership with ESA's Integrated Applications Promotion (IAP) programme.

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[1] For example earth observation (SatEO), navigation (SatNav) and communication (SatCom).

INTRODUCTION

In Europe the main cause for failures in high pressure gas transmission pipelines is Third Party Interference (TPI). From Figure 1 it follows that TPI is responsible for almost 50% of all failures. Other important causes are corrosion and ground movements. For the USA (Figure 2) the situation for high pressure gas transmission pipelines is different. Here material failure is the largest cause and TPI the second. Reasons for the difference between Europe and the USA are probably: (i) the older average age and (ii) the condition of the USA pipelines. A strong indication for this are the values for the failure frequency (per 1.000 km x year). The values for Europe, Canada and the USA are:

- Europe : 0.164 (EGIG, 2011[i])
- Canada: 0.170 (CEPA, 2011[ii])
- USA : 0.522 (PHMSA, 2011[iii])

So the failure frequency in the USA is more than 3x the value for Europe. Knowing the total length of gas transmission pipelines (in km) we can calculate the average failures per year:

- Europe : 23 failures (140,117 km)
- Canada: 12 failures (72,000 km)
- USA : 287 failures (550,000 km)

Figure 1: Causes for pipeline failures in Europe (EGIG[i], 2011)

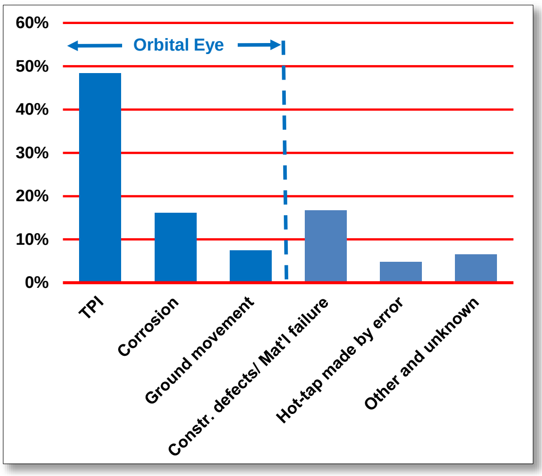
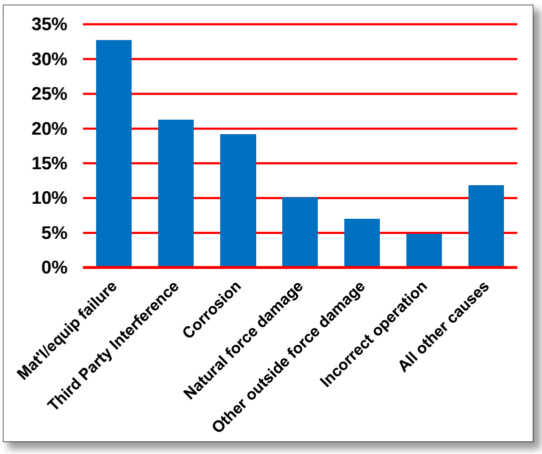
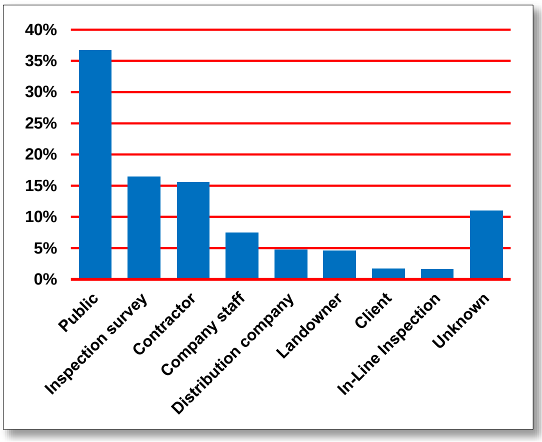


Figure 2: Causes for pipeline failures in USA (PHMSA[iii], 2011)



From the numbers in Figure 1 and 2 we also can calculate for both Europe and the USA the failure frequency specifically caused by TPI. The values (per 1.000 km x year) are: 0.079 for Europe and 0.111 for the USA. So although in the USA TPI is not the largest cause for failures, TPI results in more failures per 1,000 km pipeline than in Europe.

Figure 3: Detection of pipeline failures (EGIG[i], 2011)



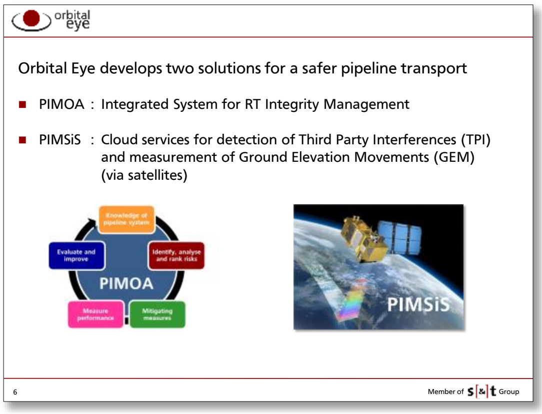
Another important question is who detects failures in high pressure gas transmission pipelines (see Figure 3). By far most of the failures are detected by the public. Since the category ‘landowners’ is also public over 40% of the failures is detected by the public and only 47% by professionals.

So we conclude that with respect to integrity management of transmission pipelines there are two major areas where improvement is urgently required:

1. Surveying methods to detect TPI, to prevent unknown third party activities to become real threats to the integrity of the transmission pipeline.

2. Better methods to monitor the system health of transmission pipeline systems. These methods analyse and process in real-time data from in-situ sensors installed along the pipeline (e.g. P, T, flow, CP, etc.) to early detect or even predict conditions which can result in failures.

Figure 4: Two solutions for a safer pipeline transport



Although we are developing solutions for both areas (see Figure 4) in this paper we focus on presenting a new method for the detection of TPI and the integration of this method with already available information.

PIMSiS: TPI detection using EO/SAR satellites

EO/SAR satellites

EO/SAR satellites are satellites with long range radars mounted and using advanced processing techniques to generate high resolution images. Unlike optical systems that rely on reflected solar radiation or thermal radiation emitted by Earth, radar instruments work independently of light and heat. Radars transmit a beam of radiation in the microwave region of the electromagnetic spectrum. EO/SAR satellites can provide day-and-night imagery of the Earth and in addition, images can also be acquired independent of weather conditions.

PIMSiS - Processing chain

PIMSIS detects TPI by comparing detected events in an EO/SAR reference image with detected events in a new acquired EO/SAR image. For this we did implement a processing chain with the following steps:

1. The construction of a reference image starts by retrieving from the image store of the satellite provider one or more images covering the complete pipeline route to be monitored. The images are pre-processed to correct for differences in terrain elevation and differences in satellite orbits. Then the actual reference image is constructed by cutting a strip around the route of the pipeline to be monitored. Additional the following processing steps are applied to the reference image:
   - Using phase signatures manmade structures are separated from the natural environment.
   - Manmade structures are detected (target detection).

   The reference image can be based on one or more images acquired at a specific date but may also, for a stable area, be based on images acquired at 2 or 3 successive dates (for suppression of noise).

2. When after a revisit by the satellite new images of the pipeline route become available these images are retrieved from the image store of the satellite provider. The same pre-processing and processing steps are applied as described above. Subsequently the detected targets in the new acquired images and in the reference image are compared. Also a second detection algorithm is applied based on the coherence between the new acquired image and the reference image.

3. Than the differences in detected targets (i.e. appearances or disappearances of events) are sent as notifications via a secure internet connection to a pipeline integrity management system at the site of our clients. The notifications have a location and a quality measure, which describes the quality of the detected changes.

4. The new acquired images becomes (part of) the reference image and we continue to step 2 of the processing chain.

The complete PIMSiS processing chain as described above operates in a fully automatic manner, including a number of quality controls to test intermediate results and to optimise specific parameters of the algorithms applied to the data.

Target satellites

For our PIMSiS services we use EO/SAR satellites or constellations of EO/SAR satellites with the following characteristics:

- High revisit frequency.
- Wide swath (i.e. the width of the image).
- Reasonable geographic resolution.

For our PIMSiS services we initially selected as target satellites the constellation of the two ESA Sentinel-1 satellites (Sentinel-1A and -1B) which fulfil these requirements in combination with fast data delivery and free access to data. ESA will launch Sentinel-1A in April 2014 and Sentinel-1B in the second half of 2015.

Currently we are expanding our processing chain from data sourcing from a single EO/SAR platform to data sourcing from multiple, different EO/SAR platforms (including the constellations of TerraSAR-X and COSMO-SkyMed satellites and the RadarSAT-2 satellite). This new processing chain will also allow us to use both ascending and descending orbits of EO/SAR satellites.

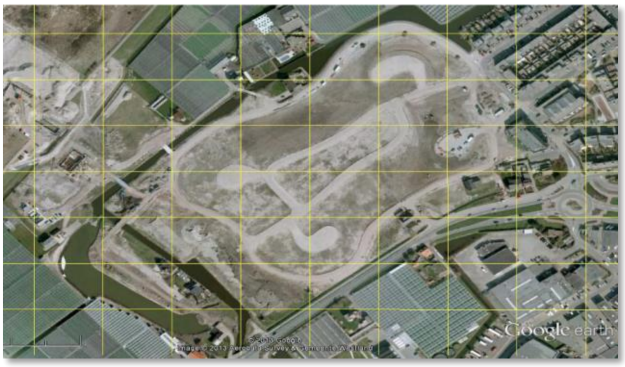
With the new processing chain we can dramatically increase the update frequency of the notifications for Third Party Interferences and also offer a flexibility in resolution and costs for satellite data.

Some results from the development phase

We are developing our PIMSiS technology in a project that started in January 2013. We have access to two test sites close to our offices in Delft (Netherlands). One test site was located in Bleiswijk, east of the Hague and close to the A12 freeway and the other test site was located in Monster, south of The Hague and close to the North Sea shore.

Figure 5: Bleiswijk test site

Figure 6: Monster test site



The Bleiswijk test site is an area planned for industrial development but, due to the financial crisis in 2013, without any building activity. The soil of this test site is peat and clay. The Monster test site is an area for urban development, but for the same reason also without any construction activity. The soil of this test site is sand.

During the development phase we used data acquired in standard mode by the EO/SAR satellite RadarSAT-2. The standard mode of RadarSAT-2 has very similar specifications as the target satellite constellation Sentinel-1.

For every revisit of the RadarSAT-2 satellite we did simulate at these test sites all kind of Third Party Interference events. The acquired satellite images were used to develop and optimise our processing chain. The pictures below are examples of (simulated) TPI events. These photos were taken to document the ground truth required to test our algorithms.

Figure 7: Examples of simulated Third Party Interferences

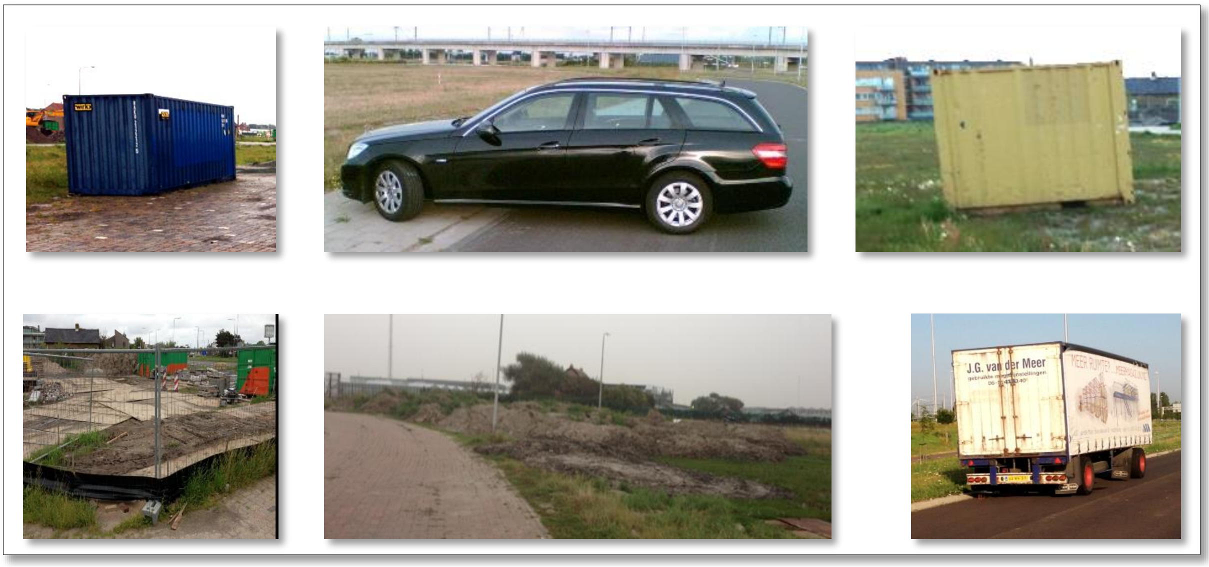
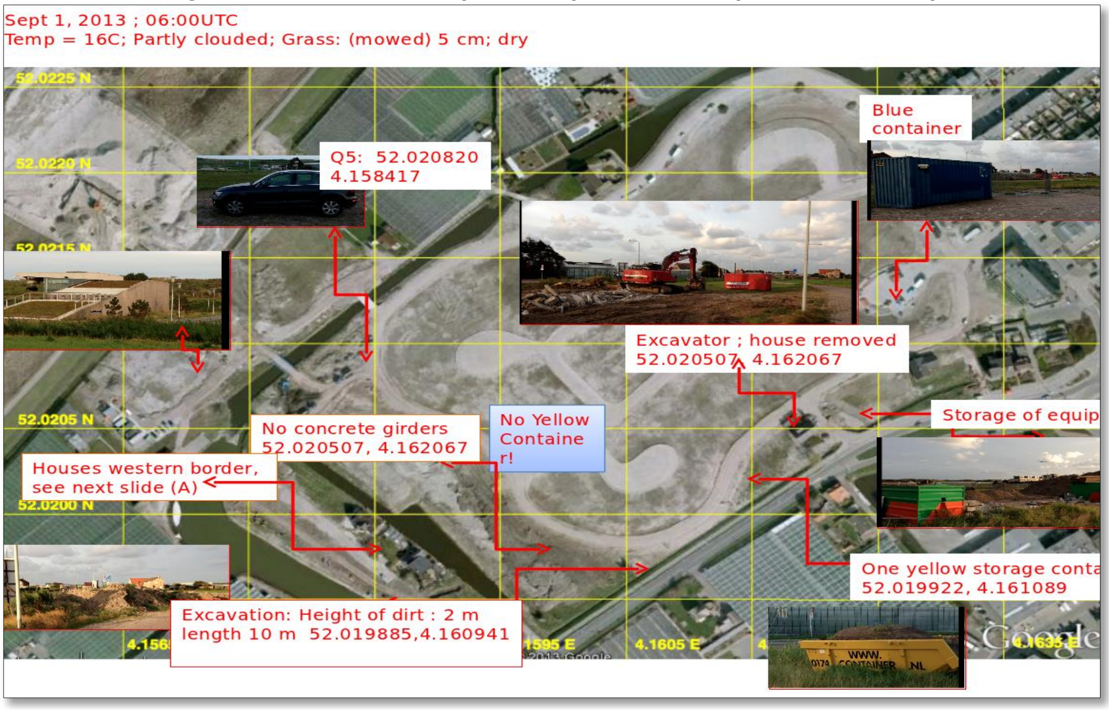


Figure 8 is the ground truth map for the Monster test site for the revisit of the RadarSAT-2 satellite on 1 September 2013.

Figure 8: Ground truth map for 1 September 2013 (Monster test site)



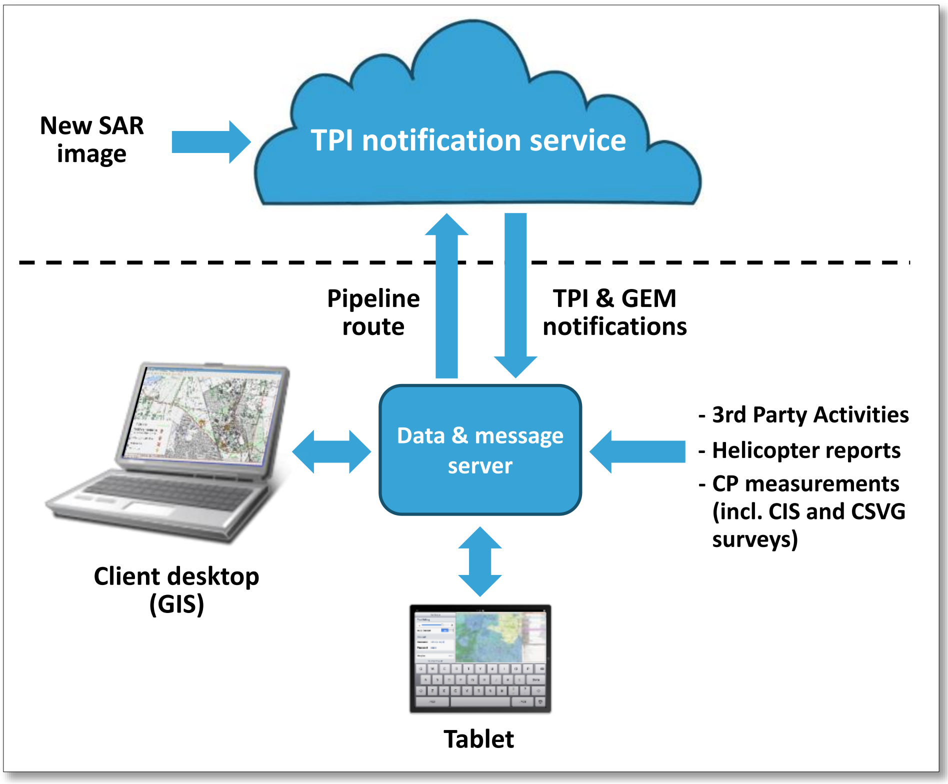
After applying our processing chain we did detect the TPI targets (picture below). The objects are represented by the red pins in the image. By studying successive images we were able to detect changes (i.e. appearing or disappearing of TPI targets). It is to be noted that the PIMSiS processing chain we can separate manmade objects from responses from the natural environment.

Figure 9: Automated target detection for 1 September 2013 (Monster test site)

System approach for the PIMSiS services

With the PIMSiS processing chain we automatically generate Third Party Interference (TPI) notifications for every new revisit of the pipeline route by the EO/SAR satellite. These TPI notifications are via a secured internet connection automatically delivered to either an existing pipeline integrity management system owned by the client or to a system provided by Orbital Eye (Figure 10).

Figure 10: PIMSiS - System overview



Orbital Eye's desktop & tablet system supports a GIS application which can manage the following object and display their locations on a geographic map:

- Pipeline system (as build, inclusive all stations)
- TPI notifications (locations and quality measure)
- Planned 3rd Party Activities (incl. planning info and design documents)
- Helicopter reports
- CP stations and measuring points (incl. CIS and CSVG surveys)
- Pipeline repairs

Information related to each object can be selected in the GIS application, retrieved from the database and displayed on the screen.

Both desktop and tablet computer share the same database, so data integrity is maintained between desktop system and tablet. Both desktop and the tablet allow clients to visually correlate TPI notifications with known 3rd Party Activities, helicopter reports and CP data. The tablet can also be used in the field to support the validate and document TPI notifications and update information to registered planned 3rd Party Activities (including reports, photos and videos).

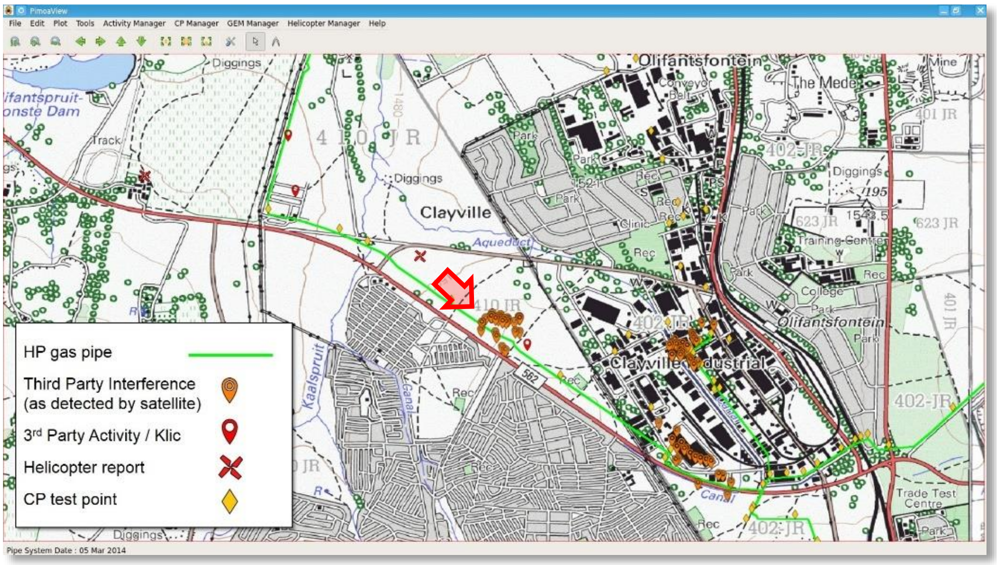
Via a notification inbox users of both desktop and clients are informed when after a revisit of the satellite new TPI notifications arrive.

Planned 3rd Party Activities, helicopter reports, CP data and pipe repair information can be automatically uploaded into the database. A business process is implemented for the processing of applications for planned 3rd Party Activities.

Examples of TPI detection via EO/SAR satellites

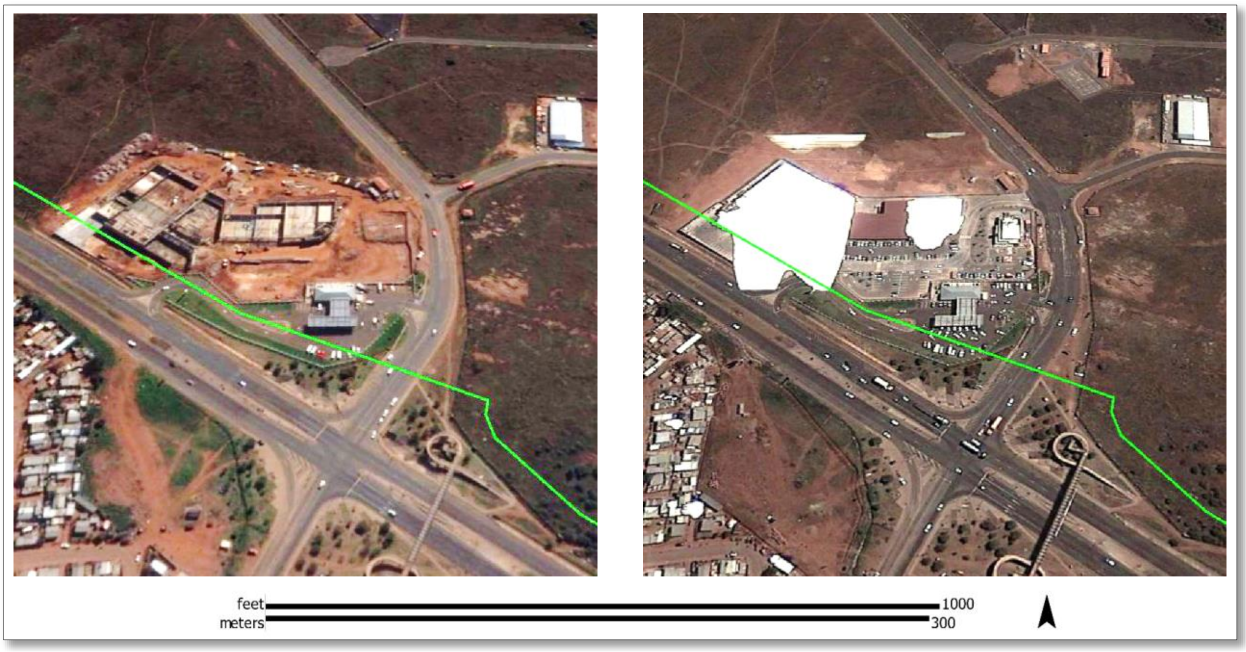
The picture below is a screen shot of the PIMSiS desktop system. Added is a description of the various symbols displayed in the picture. Clearly visible are three

Figure 11: Screenshot of PIMSiS desktop with description of displayed objects



clusters of TPI notifications. These results were part of a blind test, so no prior ground truth information was available. The images used to detect TPI were acquired in July 2013 and December 2013, so with a difference of 5 month. The images are acquired

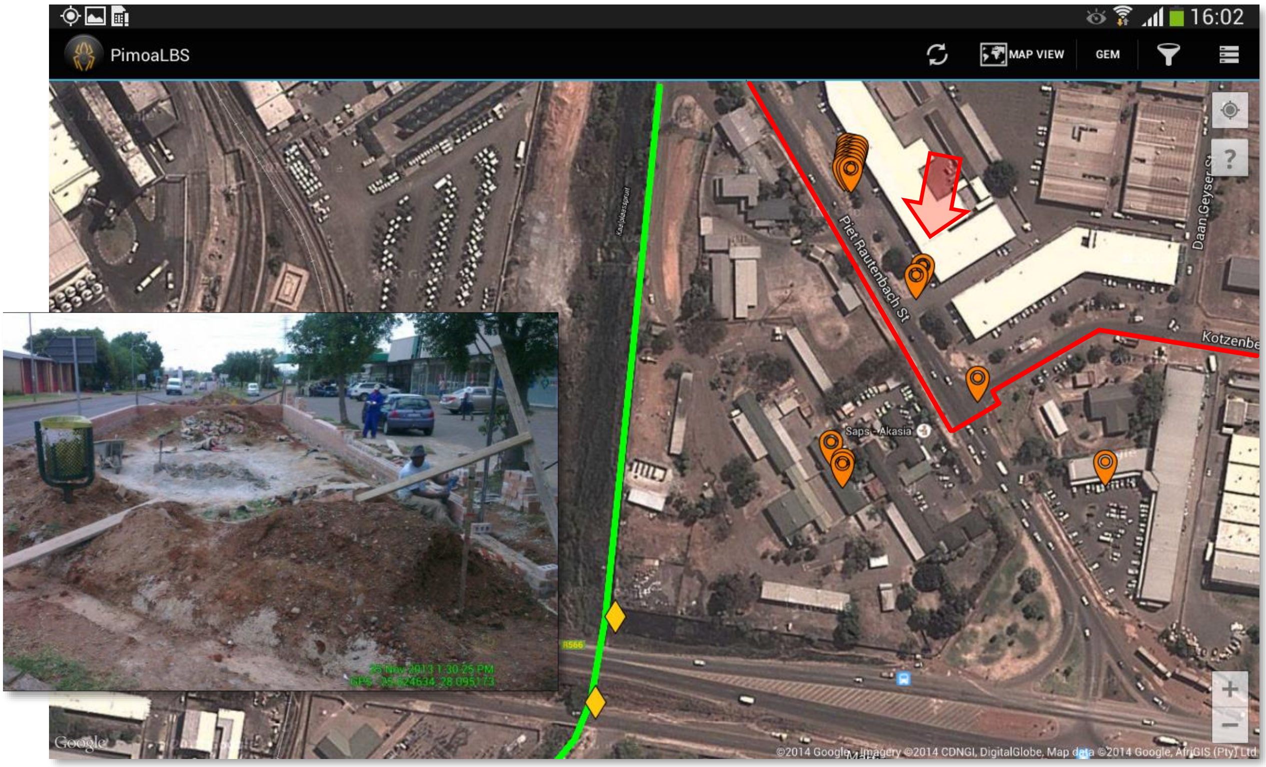
Figure 12: Ground truth at red arrow in Figure 11 (left image 25/4/2013, right image 9/11/2013)



with the TerraSAR-X satellite. For the location with the red arrow we received ground truth information after we presented the results of this experiment to the owner of the gas transmission pipeline. It turned out that during 2013 at this location a shopping mall was built (Figure 12). Please note that for unknown reasons some shops in the right image are blanked.

In Figure 13 a second example is given. For a description of the various symbols, see Figure 12. The red line is a distribution pipeline operated by the owner of the

Figure 13: Screenshot of the tablet computer



transmission pipeline. The images used for the detection of the TPI's were acquired by the TerraSAR-X satellite. Also this experiment was part of the same blind test as described above. The inset of Figure 13 is a photo taken at the location indicated with the red arrow and clearly displays the active construction activity. We visited this site ourselves and were able to verify that also at the other locations along the pipeline route were TPI notifications were detected active construction activities were taken place.

PIMSiS: Current status

The first version of PIMSiS was completed beginning of 2014. This version can only process data of a single SAR platform. After we completed a number of successful tests for surveying a pipeline (see e.g. Figures 11-13) we decided to expand our processing chain from data sourcing from a single SAR platform to data sourcing from multiple, different EO/SAR platforms. This new processing chain will also allow us to use both ascending and descending orbits of EO/SAR satellites.

With the new processing chain we will be able to dramatically increase the update frequency of the Third Party Interference notifications and also offer a flexibility in resolution and costs for satellite data. We expect to complete this development before mid-2014.

An important aspect of the development of PIMSiS is the validation of the technology by operators of high-pressure gas transmission pipelines. Both Sasol Gas (S-A) and Gasunie (NL) agreed to test the system for six months under operational conditions.

During this validation phase together with our partners we will also further improve the method by:

- Clustering of TPI notifications. When you look to the TPI notifications (Figure 11 and 13) in more detail you notice that the notifications are often clustered. We developed several clustering techniques we will test under normal operational conditions.
- Implementation of learning sets. We expect that monitoring of pipeline over a longer period will teach us that some parts of the pipeline rout are more prone for detection of TPI notifications than others. By acquiring and applying learning sets we expect to correct for these differences.
- Quality measures. Each generated TPI notification has a location and a quality measure. We expect to retrieve additional information from the values for these quality measures. Information relevant for e.g. clustering of TPI notifications and for the learning sets.

Conclusion

In this paper we proposed a new method for the detection of Third Party Interferences based on data acquired with EO/SAR satellites.

Notifications of Third Party Interferences are automatically generated after each revisit of the pipeline route by a satellite and sent via a secured Internet connection to a client system. Here these notifications can be correlated with the results of other surveying methods (e.g. helicopter reports, etc.) and other available information (e.g. planned Third Party Activities, etc.). Mutual interpretation of all this information results in more complete, comprehensive and timely knowledge of all external threats to a pipeline system.

Acknowledgement

We specifically acknowledge Sasol Gas and Gasunie for all discussions and input we received during the specification and the development phase of the project.

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[i] 8th report of the European Gas pipeline Incident data Group, EGIG 11.R.0402 (version2), December 2011

[ii] Fact Book 2012, CEPA, October 2012

[iii] http://primis.phmsa.dot.gov