THE EYE

IN THE SKY

Jan Ridder, Sven van Haver and Marcel Kaufmann, Orbital Eye, the Netherlands, explore how the use of radar satellites can assist pipeline operators with pipe inspection and locating potential third-party interferences.

Pipeline operators are responsible for the safe transport of hazardous materials through transmission pipelines. Since pipeline failures can cause severe damage to people, infrastructure, and both the natural and built environment, operators are concerned with monitoring the integrity of their pipelines on a regular, or even continuous, basis. This article discusses the use of radar satellite imagery to provide pipeline operators with a continuous source of information in order to monitor and manage their assets from space.

Failures in transmission pipelines are high impact events. In Europe, most transmission pipelines are buried at a depth of 1 - 1.5 m. The main cause of failures in transmission pipelines is third-party interferences (TPIs). Examples of TPIs for buried pipelines are excavations, deep ploughing, construction

activities, informal settlements and city encroachments. Major TPIs for aboveground pipelines are construction activities, informal settlements, vandalism and city encroachments.

Helicopter surveys

In order to minimise the threats caused by TPIs, pipeline companies survey their pipeline routes regularly, using helicopters as a mitigating measure. The frequency of these surveys depends on the risk profile of the pipeline route. Typically, the helicopters fly at an altitude of 300 ft and a speed of approximately 200 km/h. However, generally, these helicopter surveys have a number of drawbacks. Bad weather conditions can give low visibility or make helicopter flights impossible altogether. Other drawbacks include safety concerns, noise, emissions and the relatively high costs associated with helicopter surveys. As a result, pipeline operators require other information sources, which could replace or reduce their need for helicopter surveys.

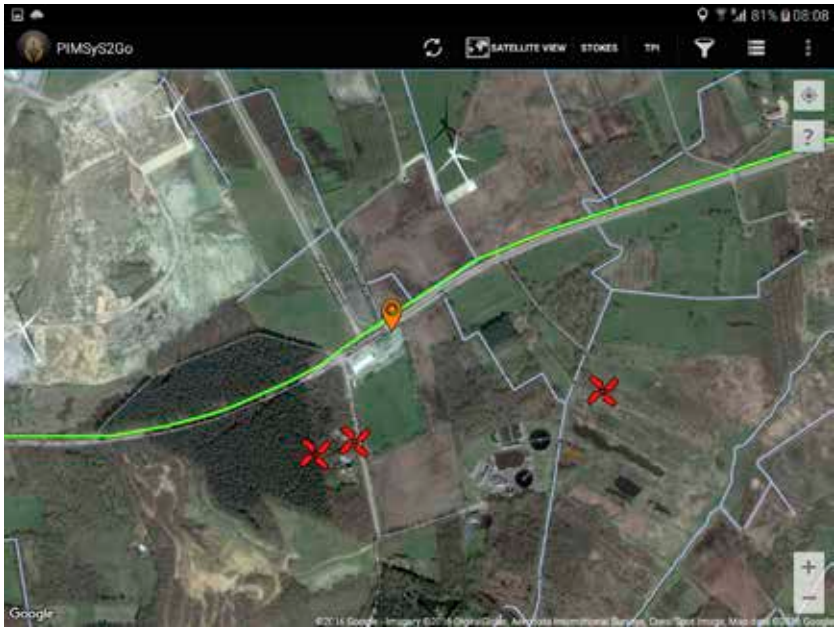

Figure 1. A mobile device using the PIMSyS app that is showing the pipeline route (green line), a TPI notification detected by PIMSyS (orange placeholder) and helicopter reports (red rotor blades).

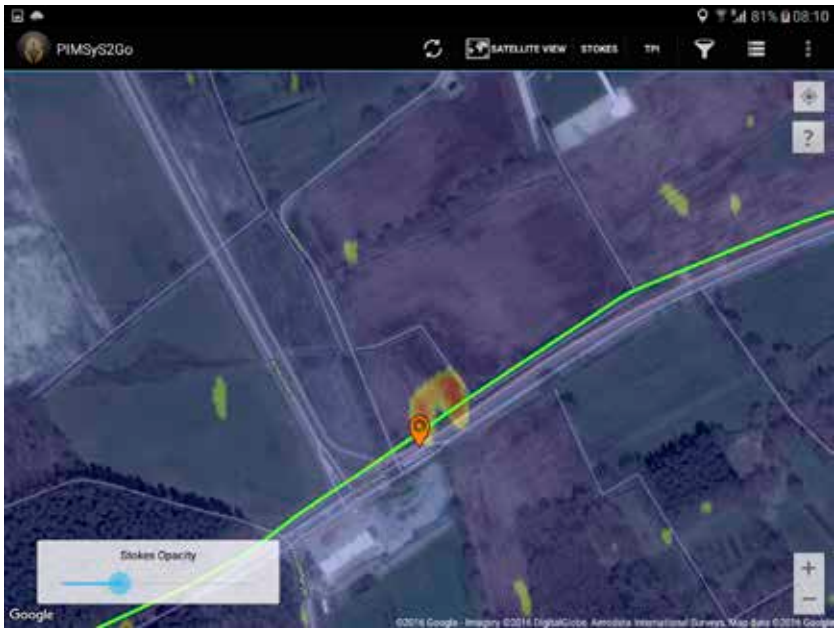

Figure 2. As Figure 1, but with an extra layer displaying the affected area as detected by PIMSyS as a heatmap.

Radar satellites

To detect threats to the integrity of transmission pipelines, a new method that uses data acquired by radar satellites has been developed by Orbital Eye. The service – named PIMSyS – uses images acquired by one of the European Copernicus programme's Earth observation (EO) satellites, named Sentinel-1A.

Radar satellites operate day and night, in all weather conditions and regardless of cloud coverage. A major advantage of Sentinel-1A over commercial radar satellites is that all of the data it acquires is available for free. The satellite orbits the Earth at an altitude of 693 km and has a repeat cycle of 12 days.

Sentinel-1A is part of a constellation of two satellites. The second satellite, Sentinel-1B, became operational in October 2016. Together, the two Sentinels will revisit each place on Earth every six days.

Evidence-based inspection

PIMSyS is deployed to clients as a cloud service. The service supports pipeline operators by providing additional information about possible TPI threats to their pipeline infrastructure. To use PIMSyS, the PIMSyS application must be installed onto a tablet or desktop computer. PIMSyS facilitates evidence-based inspection by supporting the optimisation of scheduling inspections by providing information about the location of potential TPI threats.

Potential threats are identified through coherent change detection based on amplitude and phase information in two radar images of the same area that are acquired successively in time. To avoid false positives, the changes that are observed are then evaluated and filtered according to the probability of being a relevant change

Figure 3. Photo taken by a helicopter of the affected area displayed in Figure 2.

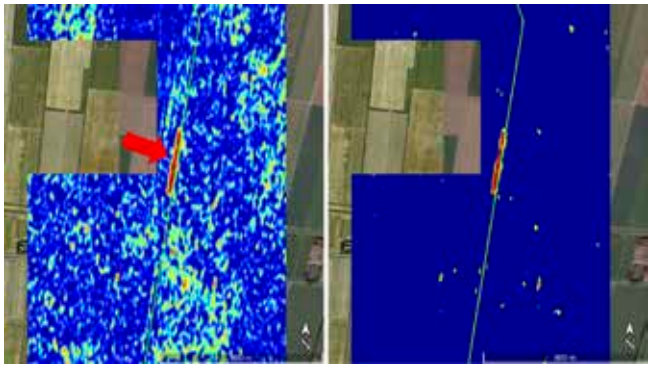

Figure 4. Left: farmland with events related to agricultural activities and other activities near the pipeline (indicated by the red arrow). Right: events related to agricultural activities have been automatically classified and removed.

in reality. PIMSyS can be complementary to or even completely replace current surveying methods.

Figure 1 shows a screenshot of a mobile device with the PIMSyS app. The green line displays the pipeline route. The orange placeholder depicts a TPI threat as detected by PIMSyS. The red rotor blades indicate that for these locations helicopter reports are also available. In Figure 2, the affected area as detected by PIMSyS is displayed as a heatmap. Finally, Figure 3 is a photograph taken from one of the helicopter reports.

A cloud service

PIMSyS is offered to clients as a cloud service. Part of this cloud service, but hidden for clients, is a fully automated processing chain for radar data from Sentinel-1 and other satellites. The chain automatically detects new satellite images available for areas with monitored pipeline systems. The images are automatically downloaded and processed such that TPI reports are generated by comparing the images acquired for the same area. The TPI reports that are not in the vicinity of the pipeline are filtered out to reduce storage and transfer. All remaining TPI reports are sent to the PIMSyS server, which is part of the cloud infrastructure.

The PIMSyS server supports the display of geographic maps, locations of pipeline systems (including valves, CP objects and stations), detected TPI reports, helicopter reports, planned third-party activity reports and vehicle investigation reports. All of this information can be further combined with information about landowners and municipalities. Additionally, the PIMSyS server supports business processes for the management of the reports.

To access this information and execute the workflows of the business processes, pipeline operators only have to connect the PIMSyS app on their mobile device or desktop computer to the PIMSyS cloud environment.

Validation project

PIMSyS was validated during an eight month project executed along with a pipeline operator. During this project, the identified threats were compared to the results of helicopter surveys. The validation project was executed in 2014 - 2015 in an area measuring 30 km by 50 km in the Netherlands. The original plan was to utilise Sentinel-1 data for this project. However, Sentinel-1 was not yet operational at this time. Therefore, a commercial satellite, TerraSAR-X, was used instead. The total length of the pipeline route monitored during the project was approximately 238 km, with a total pipeline length of approximately 366 km as some routes contained more than one pipeline. For the eight month period, six satellite images were available. These were acquired at intervals varying from 22 to 66 days.

For this time period, all reports of helicopter surveys (with a surveying frequency of once per three weeks) were

also provided by the pipeline operator. Moreover, a list of all locations in the vicinity of the pipeline route (within 50 m) where third-party excavation activities were planned and approved was made available.

The pipeline company selected four locations where they had planned activities during the validation project. For these four locations, the detected changes showed a perfect match with the actual start and end dates of the activities. However, the locations represented no more than approximately 1 - 2 km of the total pipeline route. For that reason, a statistical analysis was made for the entire validation period and the total project area. This analysis proved a strong correlation between the results and other activities executed by the pipeline company for the extension and maintenance of their pipeline system.

Correlation with planned TPIs

For approximately 90 km of pipeline route, the correlation was investigated between detected TPI threats, the results of the helicopter surveys and planned third-party excavation activities. In the Netherlands, planned third-party excavations are registered through a central mandatory system known as KLIC. During the validation project, the helicopter and PIMSyS detected events at 152 unique locations. For 80 of the 152 locations (53%) there was information available via a helicopter report and for 134 of 152 locations (88%) information was available via PIMSyS. Table 1 shows the number of locations for which a certain combination of data sources was available. For example, only 4.6% of the 152 locations were covered by all available information sources. In 7.2% of the locations, a helicopter report matched a KLIC registration (the sum of the number of locations in rows 'Helicopter + Satellites + KLIC' and 'Helicopter + KLIC' in Table 1).

Similarly, the correlation between KLIC and PIMSyS was 23.7%. One of the reasons for the relatively low correlation is that most third-party excavation registrations are active for only a short period of time (of up to two weeks) while the surveying frequency is once every three weeks for helicopters and 22 to 66 days for the satellite images available for this study.

Table 1. Distribution of TPI events for the 152 locations

TPI detected by	Helicopter: number of locations	Percentage of locations (%)	PIMSyS: number of locations	Percentage of locations (%)
Helicopter + PIMSyS + KLIC	7	4.6	7	4.6
Helicopter + PIMSyS	55	36.2	55	36.2
Helicopter + KLIC	4	2.6	-	-
PIMSyS + KLIC	-	-	29	19.1
Helicopter	14	9.2	-	-
PIMSyS	-	-	43	28.3
TOTAL	**80**	**52.6**	**134**	**88.2**

Further interpretation

There are 14 helicopter reports for locations that were not detected by PIMSyS. Analysis of these 14 reports showed that 10 reports were related to short-lived events that most likely both started and ended in the period between two satellite images. In addition, two helicopter reports showed no activity (false alarms) and two showed longer-lived activities that were not detected with PIMSyS. Of the 43 locations that were only reported by PIMSyS, 33 were related to a major pipeline extension activity that was executed by the pipeline company. The helicopter did not report these events, even though the helicopter observer is instructed to report also the activities of the pipeline company itself.

In conclusion, the correlation between the KLIC-registration and PIMSyS was approximately three times higher than the helicopter reports. Furthermore, 88% of all locations were detected in total. This demonstrates that PIMSyS was reliable and provided the pipeline operators with a valuable source of additional information for monitoring and managing their pipelines.

New developments

PIMSyS has been offered to the market since October 2015 and it is 100% OPEX-based. Currently, PIMSyS monitors over 3000 km pipeline route on a commercial basis. However, Orbital Eye expects this number to grow to over 15 000 km in the near future.

Since PIMSyS is a new, disruptive technology, there is still room for further improvement. For example, Orbital Eye is executing research and development that is aimed at a more refined automatic classification of detected TPIs, to further reduce false alarms.

In the Netherlands, transmission pipelines are frequently buried in farmland. PIMSyS detects agricultural activities, such as ploughing and harvesting. Pipeline operators have told Orbital Eye that they would appreciate PIMSyS to detect events like ploughing and harvesting, as heavy equipment moves over their pipelines, causing an elevated risk. However, since operators cannot prevent farming, they have requested that Orbital Eye automatically classifies these events as agricultural. Recently, Orbital Eye has developed a technology that is capable of conducting this automatic classification.

The image on the left of Figure 4 visualises the location of the buried pipeline (green line) and events detected by PIMSyS. These events are caused by agricultural activities and other activities close to the pipeline (indicated by the red arrow). In the image on the right of Figure 4, these agricultural activities have been automatic classified and removed from the image. This leaves events related to other activities close to the pipe and related to activities at the yards of individual farm houses showing.