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Space Assets for Pipeline Integrity Management (PIMS)

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Pipeline integrity management systems (PIMS) are a key concept in the gas and pipeline industry that aims to ensure that pipeline systems are safe and full-time operational. It addresses infrastructure design & construction, inspection & maintenance, management and documentation. Space Assets for PIMS is a feasibility study of the European Space Agency's Integrated Application Promotion program. Its objective is to investigate and define services that provide added value to PIMS-related activities by integration of multiple space assets, i.e. Earth Observation (EO), Satellite Navigation and Satellite Communication.

The application of PIMS has been particularly successful in steadily reducing the number of incidents in pipeline operation, due to e.g. accidental third party intervention, sabotage, corrosion or landslides. Nevertheless, pipeline monitoring as performed today remains costly and therefore incomprehensive. Significant improvement can still be achieved by more ubiquitous use of Geographical Information Systems (GIS), such as PIMOA, and other innovations.

S&T together with EuroPIMS are about to conclude the PIMS Space Assets feasibility study. Involved users are the gas pipeline operators SASOL (South Africa) and GasUnie (The Netherlands). These users have expressed, as a primary need, their interest in a cost reduction of pipeline inspections (surveys) and a more frequent and comprehensive monitoring of various threats to the pipeline integrity. In particular, third party interference has to be better avoided, especially in South Africa. The study has next addressed the added value, feasibility, viability and sustainability of novel services based on integration of multiple space assets into PIMS activities. For example satellite images (SAR, hyperspectral, optical) can be used to detect large industrial vehicles or areas where landslides occur or subsidence takes place. In remote areas the pipeline could be equipped with sensor networks that transmit in-situ measurements via satellite communication to a central data processing facility, where the data is then checked for signs of corrosion and other anomalies. Finally satellite navigation can improve the georeferencing of pipelines and the measurements, overcoming the drawbacks in using traditional station coordinates or paper drawings of the pipeline.

The study has so far resulted in a PIMS service design that integrates the PIMS PIMOA software suit with a multi-source and wide area network of sensors. The sensor suite comprises EO imagery instruments (optical & radar) for observing the surrounding conditions of the pipeline, in-situ sensors measuring basic pipeline data, and a communication network to transmit all data into a centralised database for further analysis and processing. The development of a pre-operational service together with the involved users is foreseen as a next step.

<u>I. PIMSIS AND ESA'S INTEGRATED APPLICATIONS PROGRAMME</u>

<u>I.1 ESA and IAP (ARTES 20)</u>

The Pipeline Integrity Management Service In Space (PIMSIS) is a Feasibility Study of the Integrated Applications Program (IAP) of the European Space Agency (ESA).

ESA's Agenda 2011 contains a key objective: "*Development and Promotion of integrated applications (space & non-space) and integration of security in the European Space Policy. New concepts, new capabilities and a new culture have to be developed in order to respond to a multitude of needs from users who are not yet familiar with space systems*." Responding to this objective are the Integrated Applications Programme (IAP), also known as ESA's ARTES 20 element (user-driven applications), as well as the ARTES 3-4 Telecommunications Applications element (product-driven applications). These elements are dedicated to development, implementation and pilot operations, utilising not only Telecommunications satellites, but also combining the use of different types of space assets, including Earth Observation and Navigation, as well as Human Spaceflight technologies.

The overall goal of the IAP program is the *"the development of operational services for a wide range of users through the combination of different systems"*. The goal is to incubate sustainable services to the benefit of society that obtain their added value from the innovative integration of existing terrestrial technologies with space assets, such as Telecommunications, Earth Observation, Navigation, and Human Spaceflight technologies. "*Sustainable*" means here: triggered by, responsive to and sustained by real user demand, while taking into account financial (e.g. commercial) and non-financial (e.g. environmental, legal, adoptability) constraints. The provision of commercial *services* (rather than of mere products) is seen as a key outcome - one that offers flexibility and increases sustainability of demand, supply, and indirectly, up the value chain, also of space assets. In this way, "our satellites help to do better the daily work of society".

Such services are to be incubated through two steps or levels of ESA IAP activities:

1. Basic activities, which aim at generating, assessing and studying ideas for projects. Feasibility Studies provide the preparatory framework to identify, analyse and define new potentially sustainable activities.

2. Demonstration activities which aim at demonstration of the ideas generated in the first element.

IAP activities cover a wide range of themes, including Health, Transport, Energy, Development, Safety, Environment, Agriculture and Fisheries.

<u>I.2 Space for Energy and Safety</u>

PIMSIS is an example of an IAP activity under the theme "Space for Energy". Typical Space for Energy activities make use of the space assets Earth Observation, Satellite Navigation and Satellite Communication (Figure 1), for example in the context of:

- In-situ measurements & remote communication
- Nowcasting/forecasting (based on e.g. weather) of environmental conditions necessary for power plant production generation (e.g. from alternative energy sources such as water, sun wind, etc.)
- Land subsidence / structural integrity monitoring of power grids and other infrastructure
- Third party interference monitoring

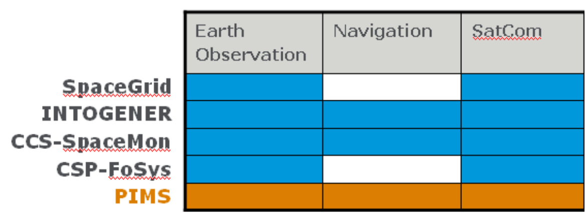


Figure 1. Space for Energy projects of IAP and the involved space assets.

SpaceGrid is focused on the monitoring of safe corridors built around power lines. These corridors try to avoid interferences caused by e.g. building or vegetation with the power lines. These monitoring is currently done over 43000 Km of power lines in Italy, using chage and subsidence detection

INTOGENER (INTegration of EO data and GNSS-R for ENERgy Applications) support hydropower plant operation in the Andean mountains of Chile by performing large area water level prediction. Water level is monitored using GNSS-R (reflected signal). Earth Observation SAR (snow height) and Optical/IR (temperature) data is integrated with water flow models in order to make the required predictions. Satellite communications are used to transmit in-situ collected data to the data processing centre, far away from the mountains.

CCS-SpaceMon (Carbon Capture & Storage) investigates the usability of multitemporal SAR for the geomechanical monitoring of carbon subsurface storage sites. Calibration and confirmation is performed using differential GNSS. Satellite Communications are used for data communication and remote monitoring.

CSP-FoSyS is a Concentrated Solar Power Forecast System. Nowcasting/Forecasting of environmental conditions is used as input for the estimation of solar parabolic-through power plants electricity output as well as for optimised maintenance planning. It is based on Earth Observation data (meteo) and in-situ measurements, involving again Satellite Communications for data provisioning.

I.3 The PIMSIS Study

The objective of the PIMS Feasibility Study is the assessment of the technical and economic feasibility of the utilisation of space assets (Earth Observation, SatNav, SatCom) in a pipeline integrity monitoring service, seamlessly integrating in real-time data from terrestrial and space-based sources, increasing the monitoring performance and reducing operational cost and hazard.

The users involved in the PIMSIS study are GasUnie (NL) and Sasol Gas (SA)

The study team consists of:

- Science & Technology B.V. (S&T) (NL, prime) with experience in remote sensing data products and processing
- EuroPims B.V. (NL, subcontractor) with expertise in the operation of oil and gas pipelines and associated facilities (Shell, Gasunie, Sasol, Gaz de France NL, Total EP NL, Geoplin SL)

This consortium is already active in Pipeline Monitoring Management and has developed a PIMS software environment (PIMOA). PIMS International, the intended future service provider, has been founded in 2010 as a joint venture between S&T and EuroPims.

The study includes the following elements:

1. *User requirements definition*, analysing present and future legislation and relying on the inputs from the participating pipeline operators the user requirements will be refined and captured;
2. *State-of-the-art analysis and identification*, identifying and analysing current terrestrial and space technologies; identification of cost-efficient technologies and technology gaps;
3. *System and service definition:* system and service specifications will regard functional, performance, interface and environmental aspects; reliable health and alarm indicators will be defined; the system and related service architecture will be defined in consultation with the users;
4. *Proof of concept:* not foreseen in the study due to budget constraints;
5. *Viability analysis:* a comprehensive economic and non-economic viability analysis will be carried out, paying special attention to cost-efficient services and the alignment of the activity with the legislation;
6. *Implementation Roadmap:* the overall technical and economic feasibility will be assessed; a comprehensive roadmap for the further implementation and its associated services will be drawn, as well as the preparation of a potential demonstration project;

If concluded positively, it shall be followed by a demonstration project in South Africa/Mozambique (Sasol) and/or in the Netherlands (GasUnie) in which all elements of the full service will be prototyped and run in pre-operational manner.

III. PIPELINE INTEGRITY MONITORING

III.1 Background

Based on The World Fact Book, the total length of pipelines (gas, oil, and refined products combined) is about 1.8 million kilometres. The European gas transmission network is about 225,000 km in length; it includes over 100 cross-border points and a similar amount of underground storage facilities. The growth of the pipeline systems is fuelled by the increased dependency on imports and demand for renewable sources (bio-methane).

The collection of pipeline safety data is growing in significance as interest of responsible authorities for safe gas transmission strengthens. Large operators typically spend several million Euros each year to monitor their pipes. The total cost for monitoring remote segments of pipelines is roughly estimated to exceed 100 million Euros per year. This monitoring effort pays off. Although the network is growing, the incident rate has decreased from about 0.9 per 1000 km/y in 1970 to the current value of 0.37 per 1000 km/y. It has been argued however that pipeline integrity issues can have a significant impact on energy price, even by tens of percentage points.

Gas and oil pipeline integrity is a serious safety concern. Over 50% of pipeline failures are the result of third party intervention. This intervention may be by accident (digging works) or from purposeful attempts to interfere with or scavenge the gas or oil flow. Corrosion and ground movements are other common causes of incidents. Failures interrupt or affect the supply and in addition can lead to casualties, impact on the environment, and damage the image of the stakeholders. Dramatic examples include one of the largest non-nuclear explosions in history along the Trans-Siberian Pipeline in 1982, and the petroleum pipeline explosion at Jesse in the Niger Delta in 1998 that killed 1200 villagers, some of whom were scavenging gasoline.

In most countries periodic inspections of natural gas pipelines are required by national legislation. Currently, traditional pipeline inspection methods are used based on helicopter inspections with a cost of approximately 1,000 Euro/km. Other pipeline costs include maintenance (e.g. corrosion, valve failures), safety risks and downtime.

The pipeline operators are supported by so-called Pipeline Integrity Maintenance Systems (PIMS) that provide support in the administration, planning, analyses of inspection data and risk analysis activities related to pipeline integrity. These PIMSs are usually applications making use of the data of a Geographic Information System (GIS).

There are several products on the market varying from just GIS-systems for presentation of the pipeline on the map up to highly sophisticated tools used to analyse inspection data, carry out risk assessments and to support the pipeline operator in the development of his Integrity Management Plan.

It is expected that the integration of space assets in such pipeline monitoring systems is able to detect problems easier and earlier, thereby reducing efforts, downtime, and cost.

The proposed activity for a pipeline integrity monitoring system concentrates on a subset of the pipeline system, i.e. the gas/oil pipelines that are difficult or impossible to access, that are located in remote areas, and that do not have a reliable data infrastructure. A conservative estimate of the percentage of pipelines that fulfil above criteria is 5% (corresponding to 90,000km).

III.2 Sustainability aspects for a PIMS service based on space assets

In Europe, pipeline safety standards are derived from ISO and CEN standards. They are more and more often imposed by national legislation regulations which in turn follow the European Gas Directives of 1998, 2003 and others. The European Standard EN 1594 for natural gas pipeline monitoring covers all relevant technical safety aspects concerning the design, construction, operation and maintenance of transmission gas systems. PIMS and safety management are detailed by the supportive normative documents. In summary, there is a well-defined legal basis for improvement of the current monitoring practises.

With an inspection cost of approximately 1,000 Euro/km/year by helicopter, the targeted pipeline network of about 90,000 km represents a market value of about 90 million Euros per year which is considered sufficiently attractive to investigate this subject.

However, the economic viability will be impacted by the cost of the satellite data. A first survey indicates that the offered satellite data are not directly compatible with the inspection requirements which ask only for a small area strip around the pipeline. Image resolution and timeliness are also issues, that may be partly countered by integration with an in-pipe / near-pipe sensor grid combined with e.g. a Satcom SCADA network – of course at additional cost. Therefore, a viability analysis will be performed that pays special attention to the economic part.

IV. PIMSIS INTERMEDIATE RESULTS

IV.1 The users and the threats they experience

Stakeholders in the addressed field are (high pressure) pipeline operators, regulators, pipeline integrity management consults. From these stakeholders, two oil/gas companies are involved in the activity, GasUnie (NL) and Sasol Gas (SA).

GasUnie produces natural gas at ~100.10^9 m^3/year and is the main gas-pipeline operator in the Netherlands with a network of 12.000 km pipeline. It is also a gas-pipeline operator in Germany (3.000 km pipeline). Furthermore it is a shareholder / operator of major international pipes such as the Balgzand Bacton Line (BBL) between Netherlands and England, and Nordstream (Russia – Germany).

In the Netherlands a reporting system is implemented (KLIC), that makes it mandatory to centrally register any intended excavation work. Albeit at a much lower rate, in this densely populated country, incidents that cause pipeline damage continue to occur however (Figure 2). Ground cover over pipelines (including submerged ones) sometimes reduces due to erosion or agricultural activity, leaving the pipelines much more vulnerable. Also light damage can lead to gas leakage as a result of corrosion. The monitoring of the dense Dutch pipeline network therefore remains a necessity.

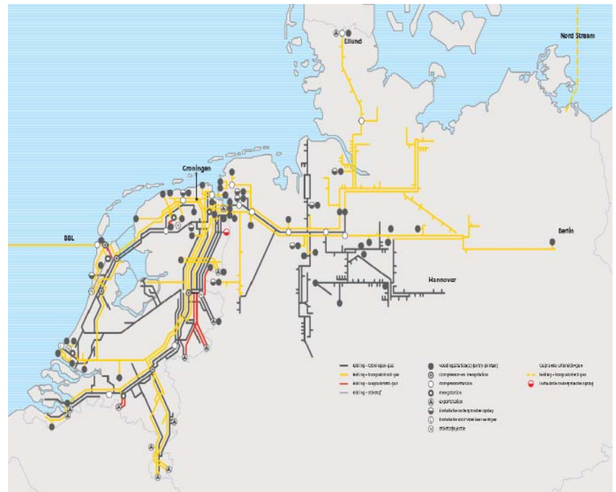
Figure 2. Pipeline coating damage due to excavation.

Sasol Gas operates and maintains own natural gas and methane rich gas pipelines in South Africa and Mozambique (~1200 km). It is contracted to operate and maintain the Mozambique to South Africa gas transmission pipeline including 1 compressor station located in Komatipoort (~865 km), as well as to maintain 6 other petrochemical pipelines (~600 km). Finally, the National Energy regulator of South Africa (NERSA) has Licensed Sasol Gas to operate the pipe gas transmission, distribution and trading business.

Sasol Gas assets may be underground (pipelines, valves) and aboveground (customer metering stations, pressure reduction stations, scraper stations, solar energy systems etc.).

Major threats to Sasol Gas assets include but are not limited to the following:

- external interference - unintentional damage to underground assets e.g. 3rd party contractors erecting underground utilities
- sabotage/theft on critical assets – solar energy units, electrical cabling.
- sabotage/theft on cellular assets – cellular SIM cards (Subscriber Identity Module) used in remote communication have been stolen on numerous occasions.
- ecological – soil erosion, landslides and earthquakes e.g. in western Gauteng a historic number of earth tremors has been reported via USGS and SACGS.
- encroachment – formal and informal developments e.g. informal housing erected near pipelines.
- gas leaks – from underground and aboveground



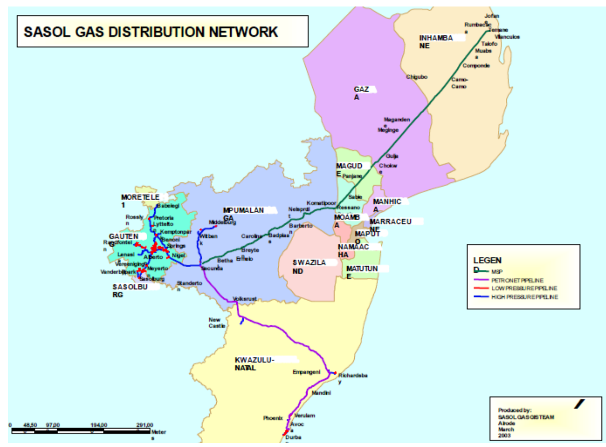


Figure 3. Pipeline networks of GasUnie in The Netherlands and Germany (top) and Sasol Gas in South Africa and Mozambique (bottom).

IV.1 Current PIMS operations and the user needs

Until recently, there were no legal requirements regarding the integrity and risk management of pipelines - inspections were not prescribed. Both in Europe and the US however operators are now requested to have a comprehensive integrated Pipeline Integrity Management System (PIMS) in place, encompassing aspects of engineering, operation, inspection, maintenance, communication etc. The monitoring tasks include inspection to check for any leak or damage of the pipeline, and that there is no danger to the pipeline integrity from nearby construction or ground movement activities, the so-called third-party interference. Many operators are currently looking into new technologies to effectively meet the monitoring requirements and to deal safely with the expected increase in gas consumption. This is a challenge: on the one hand the market demands for gas provision increase and require even more guarantees for the supply of gas at a competitive cost, on the other hand the resources for maintaining and operating the transmission facilities need to be limited more and more for cost reasons.

One of the passive protection mechanisms used by the pipeline operators is placing the pipelines subsurface with sufficient ground cover to protect the pipeline form ground excavating activities (minimum about 80-100 cm). Having the pipes below ground however, makes monitoring threats and damage much less trivial.

The use of helicopters or fixed-wing aircrafts is currently often regarded as the most effective way of detecting third-party interference. Inspection frequency is typically 2 weeks, even if such frequency may not be sufficient. Besides the high operations cost, the use of helicopters introduces additional hazards as they need to operate at an altitude which is lower than normal operations.

A second pillar for reducing risk of pipeline damage is corrosion protection of the pipeline system. This is realized by impressed current, making the pipeline the cathode of an electrochemical cell. It is of great importance that it is verified that the Cathodic Protection (CP) operates as intended. The CP—installation, and other installations close to the pipelines (valves, flow meters, pressure meters, etc) need a secure and dependable data link to send the data to the control centre, which processes these data to assess the health of the installations. In remote areas it is difficult and expensive to maintain this data link but even developed and more densely populated countries (like The Netherlands) still rely on manual inspection (incl. by in-situ electric potential measurements) and data collection of these installations which are considered expensive and do not deliver real-time data. The exact location of corrosion in a buried pipe is difficult to establish at great precision, given that the measurements are indirect and measurement points are limited to about a few km intervals typically. More direct and continuous in-line measurements from within the pipe ("pig-run") are exceedingly expensive and therefore are performed only once every number of years.

Finally, IT systems form a vital part of the overall management of the network to provide auditable results. Pipeline operators require vast amounts of data in order to manage the everyday activities related to pipeline integrity: a PIMS provides the best way to store data and solve the problem of data transparency. With this information available the operator can analyse the relationship between the different facts and figures and make appropriate decisions related to pipeline inspections, repair plans and preventive measures. An example of such a system is PIMOA, developed by S&T in collaboration with EuroPims (Figure 4).

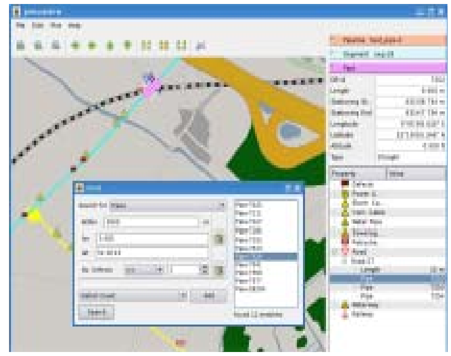


Figure 4. Screenshot of PIMOA software for PIMS.

Following in-depth discussions with the involved users (Sasol Gas and Gasunie), taking into account current operational scenarios, tools and methodologies in use, operator needs and requirements have thus been formulated. In-line intrusive activities need to be discovered earlier to reduce system downtime. A Right-Of-Way (ROW) zone of about 10-100 m around the pipeline is to be monitored for third party intervention. Landslides or other threats to the integrity should be monitored and appropriate warning signals released. Helicopter operations should be reduced to minimize cost and hazard. Measurements and observations should be more precise and geo-tagged, as it still happens that the wrong pipeline segment is excavated after failure reports. The monitoring must be adequate, secure, regular, cost-effective, and importantly, it should not generate false alarms.

With the recent availability of a range of technologies, data sources and software systems, and the ambition of many operators to upgrade their monitoring systems, a strong need exists for seamlessly real-time integrated services, managed through a PIMS.

Three major service functions have been categorized as particularly interesting for the users:

- The detection of third-party interference.
- The monitoring of the ground cover and changes in it (e.g. due to erosion, land slides)
- A reliable data link of pipeline equipment to a central processing facility.

IV.2 Previous studies and technological heritage

Preparatory studies on the use of space assets have recently been performed which indicate that there is a need and that the available technology is about to reach the required performance.

The FP5 project PRESENSE (Pipeline REmote SENsing for Safety and the Environment)[1] (completed in 2004) assessed the potential of remote sensing techniques for PIMS including technology to automatically find potential targets which might compromise pipeline security. It produced algorithms, a prototype information system and a successful concept demonstration. PRESENSE identified that for a commercially viable system satellite capabilities needed to be improved and extended, and data must be available at lower cost.

The ESA activity PIPEMON[2] (completed in 2006) included pre-commercial trials to introduce Earth Observation services to the pipeline industry. Results from the PIPEMON test sites identified that there is strong interest by pipeline operators regarding InSAR applications, particularly supported by distributed corner reflectors.

On the industrial side, the pipeline operator Sasol has performed an internal study on the use of satellite communications and believes that the inclusion of Satcom systems can bring operational advantages. GAZPROM started development of a small dedicated satellite, PIMSpace.

So far however, remote pipelines have traditionally been maintained by a technician going to a site to take readings and make adjustments. On his return, this data is integrated off-line in the control centre. Bi-weekly inspections are also made from low-flying helicopters. To improve coverage and lower the cost, wireless communication devices are now being deployed, and the supervisory control and data acquisition systems (SCADA) are being extended with configuration item control/ enterprise resource planning tools (ERP) and GIS applications for pipelines.

Novel techniques were developed under the European GERG8 committee and include optical waveguides or fibre-optic systems installed alongside pipelines to detect vibrations and temperature abnormalities. Microphones can be used to monitor the gas flow at distances up to 15 km. Advanced UV/IR spectroscopic laser systems (differential absorption LIDAR) and infrared sensors have been developed that can be used to detect gas leaks (methane) remotely. They are capable of detecting gas clouds from helicopters which are equipped with D-GNSS and fly at an altitude of 100 m and with a speed of up to 90 km/hr.

IV.1 The proposed solution

The proposed solution is to provide the user with a service delivering information that will greatly enhance the decision process of the integrity management officers. The major idea is to combine and fuse data coming from different origin in order to at least

1. detect third-party interference as soon as possible,
2. monitor the ground cover, and
3. obtain system-health relation information about the equipment related to the pipeline.

Nevertheless, the *combination* of data –coming from different information sources– provides a very promising concept. Figure 5 depicts such a decision-support system where the information of various information sources are combined and processed to support the integrity-related activities.

Various space assets are being considered. EO data (optical and SAR at 0.5-1 m resolution from a variety of commercial providers) will be used to detect third-party interference by performing change-detection between a current picture and a set of historical pictures of the same area. A major advantage over current practise is that an objective and comprehensive (full coverage) semi-automated analysis can be made in this way. Satellite communication will be used to establish a reliable link between the various in-situ sensors and a central (Supervisory Control And Data Acquisition) SCADA system.

There are limiting factors to what space assets can realistically provide in terms of monitoring:

- limited revisit time of satellites (in order of tens of days) – this can to some extent be resolved to the level of weeks (close to current monitoring practise) by invoking multiple suppliers.
- still high cost for high resolution imagery (0.5-1 m), especially when taking into account that the typical minimal scene size (square of 50 km^2) exceeds by orders of magnitude the required narrow path around a pipeline. As a result, imaging a pipeline network from space has comparable cost to that from a helicopter (yet not lower).
- Resolution from a helicopter remains significantly better to distinguish submeter details that may be important for a trained eye to distinguish potential threats from what would essentially be false alarms.

For this reason it is not yet feasible to replace current methodology of helicopter inspection completely. Rather, a staggered approach is being considered:

1. low-cost low-resolution data is used to identify potential threat areas
2. high-resolution data is requested to analyze those areas in more detail
3. the high-resolution data is analyzed, and combined with or checked against recent and/or historical ground measurements and reference imagery.
4. change detection identifies spots to be investigated
5. targeted helicopter inspection and, subsequently, possible in-situ investigations are requested.

In order to monitor the changes in ground-cover InSAR techniques will be used[3] (low-res with Envisat, Sentinel-1 or in some cases hi-res with commercial systems), exploiting the phase-difference present between current and a set of historical SAR images. For the threat that can be identified in this way (erosion/landslides), currently only very limited terrestrial monitoring is in place, therefore the case for this service is more straightforward.

In this system concept, the data of the various information sources are combined within the PIMOA system, such that the link between the ingested data is primarily linked by their geographic parameters. That is, in PIMOA it will be possible to link features of the ingested data using the geographic position. In such a way, it will be possible to determine whether a feature in an earth observation image is close to a pipeline. With possible third-party interferences detected, one can optimize the inspection cost and coverage by optimizing the helicopter flights. Also, if some idiosyncratic value in the inspection data (pigrun, CP-values) is noticed (indicating, e.g., a possible damage of the protective layer of the pipelines) –to explain the damage- the historical record of SAR images is analyzed to identify whether in the past a possibly related interference was detected by the system.

Figure 5 shows a number of possible information sources that will feed the decision-support system. Figure 5 is, however, not intended to be exhaustive; it shall be possible to ingest other information sources as well. For example, we have identified SAR as the main source for space-born images, but other images (such as optical) shall be possible as well. Also, the information sources that are present in Figure 5 need not be present in a real-life implementation of the decision-support system. Besides data coming from EO-sensors or transported using satellite communication, the system will also be able to ingest data from earth-bound sensor systems, such as a seismic measurement network.

All these data sources combined together with the (geographical) information available of the pipeline infrastructure will deliver a comprehensive view of the possible threats for the pipeline integrity. For example, inspection of the SAR images may indicate a change close to the pipeline indicating major ground excavating activities. During ingestion of the data, the system will check for a wide range of possible threats and will inform the pipeline integrity officer. The officer will be able to further analyze these warnings e.g. by inspection of historical data. The outcome of these analyses should then result in optimized (flight) inspection schedules to warrant integrity of the pipeline infrastructure. This optimization is likely to include more targeted flights (skipping large parts of the infrastructure) and higher flight speeds (shorter flights) and may involve semi-automated imaging from the helicopter.

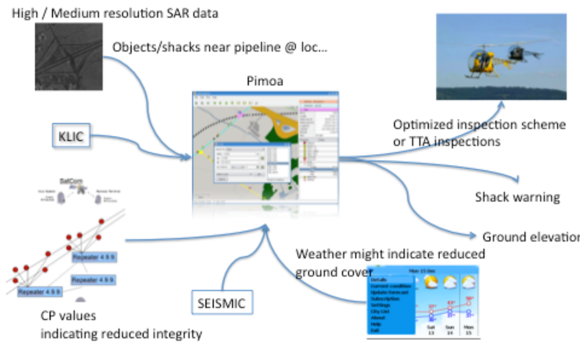


Figure 5 Decision support system to create better situational awareness related to pipeline integrity

IV.1 The added value of space assets

The involvement of space assets is expected to provide added value to a future Pipeline Integrity Monitoring System:

- *Earth Observation:* Remote sensing technologies combined with proper feature extraction algorithms can provide relevant information for many of the critical pipeline monitoring needs. Third party interference can be detected indirectly through change in position of surface features related to excavation practises over successively obtained images. Such images may in principle originate from a wide variety of sensors, such as SAR, optical, thermal and LIDAR, but from satellites, SAR and optical (VNIR) are the more suitable candidates. SAR is more expensive, less widely available and somewhat lower in resolution, but insensitive to cloud cover or time of day (day/night). Subsidence of the ground and landslides can typically be observed from space using SAR interferometry. Gas leakage has been observed in proof of concept demonstrations directly using aerial spectrometers and indirectly from space (IKONOS) through their effects on vegetation, although both type of measurements have been found to be ambiguous and are not likely to be sufficiently reliable to be cost-effective. Overall however, integration of space based remote sensing with terrestrial techniques as opposed to purely aerial tracing of the pipelines may offer lower cost and provide greater continuity and better spatial context;
- *Satellite Navigation:* High integrity and more accurate positioning data by augmented GPS (such as by EGNOS) allows to more unambiguously identify fault and digging locations (for pipeline

visual inspection or repair) and stay-out zones (for third parties). GPS-sourced time tags and guidance by augmented GPS (such as by EGNOS) could help to provide more effective in-situ manual measurements on buried (invisible) pipelines. For monitoring of the Cathodic Protection, precisely timed coordinated measurements (at 0.01 s absolute accuracy) need to be made along the pipe. Also investigators typically need to trace the underground (invisible) pipe accurately above ground for continuous measurements.

Some technological opportunities for differential navigation (D-GNSS) technologies have been identified, however it should be noted that no needs for these have been expressed so far by the users:

- Aerial or helicopter based observations, which are more suited for detailed investigations and leakage detection due to their higher resolution and much smaller target distance, may be accurately geo-tagged using D-GNSS systems and precise data on sensor pointing to allow for automated processing and easy integration into a GIS environment.

- D-GNSS applications could be a suitable technique for monitoring of pipeline motion in critical areas.

- *Satellite Communications:* Supporting a secure, seamless and real-time integration of data, Satcom can provide the communication link for existing pipeline infrastructure and the collection of data from a local WiFi enabled sensor networks. This can be achieved by the implementation of a SCADA network with e.g. VSAT terminals connected to the control centre.

V. CONCLUSON

Earlier research (PIPEMON, PRESENSE), has suggested that space assets are relevant tools for pipeline integrity monitoring (PIMS). Nevertheless, no space assets are currently being exploited. Considering steadily increasing performance of space infrastructure, ESA IAP has started the PIMSIS study.

In PIMSIS, operational scenarios and needs for enhancements in pipeline integrity monitoring systems have been obtained from two major, and distinct, pipeline operators (Sasol Gas and Gasunie), who have taken the role of (potential) users. Three major service functions have been categorized as particularly interesting for these users:

- The detection of third-party interference.
- The monitoring of the ground cover and changes in it (e.g. due to erosion, land slides)
- A reliable data link of pipeline equipment to a central processing facility.

A commercial service provision scheme is currently being developed that integrates terrestrial technologies (helicopter inspections, Cathodic Protection in-situ monitoring and PIMS software) with space assets (optical and SAR earth observation data at 30 m down to 0.5 m resolution, SatCom, GNSS). The expectation is that this service can optimize, rather than replace, the current PIMS methodologies. A full replacement of helicopter inspection flights has been found to be not (yet) possible. However, certain threats, such as ground cover erosion are very hard and costly to regularly monitor with current terrestrial means, while space assets provide good opportunities. Also, at the moment, corrosion monitoring is currently hardly integrated with aerial inspections. The PIMSIS service package would combine these strengths to provide higher reliability at the same or lower cost.

The detailed design and commercial viability are the next steps to be performed.

If concluded positively, it shall be followed in the 2012 timeframe by a demonstration project in South Africa/Mozambique (Sasol) and/or in the Netherlands (GasUnie) in which all elements of the full service will be prototyped and tested.

REFERENCES

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