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Pipeline Technology Journal

Remote Sensing

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Michel Pinet
Head of Network Monitoring

GRTgaz

In France, the company operates more than 32,500 km of buried transportation pipelines. These structures cover most of the French territory and are subject to regular monitoring and inspection, as part of our maintenance programs, to ensure their operational safety.

Some of these pipelines cross areas that can be hard to access or where field operators could be exposed to safety hazards should data collection be required. GRTgaz's commitment to safety is paramount and hence the company started exploring alternatives to automatize certain maintenance operations. In addition, the company was looking to improve the reliability and repeatability of its data collection and processing in order to leverage historical information.

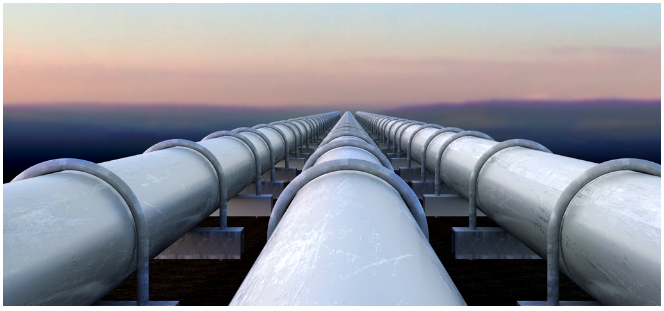
River crossings were rapidly identified as being amongst the most complicated environments to operate in given the logistical constraints involved, with the need for divers and supporting equipment, and the risk to operators, as above-water activity can be present. GRTgaz promotes and uses automatic remote technologies, such as magnetic inspections via UAV or multi-beam bathymetric via ROV, to perform high-precision digital twins for depth of cover assessment or bending strain assessments.

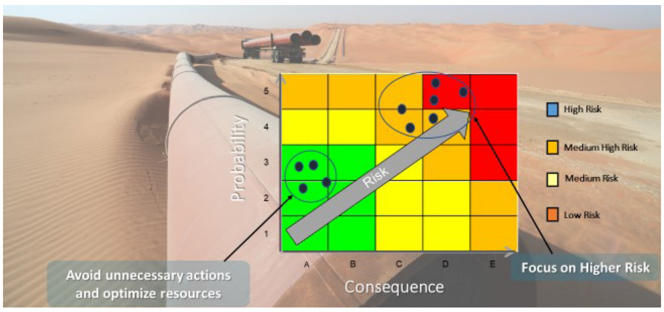
This issue of the Pipeline Technology Journal, with its focus on "Remote Sensing", presents a comprehensive overview on the following pages.

Sincerely,

Michel Pinet
Head of Network Monitoring
GRTgaz

This Issue's
COMPLETE CONTENT





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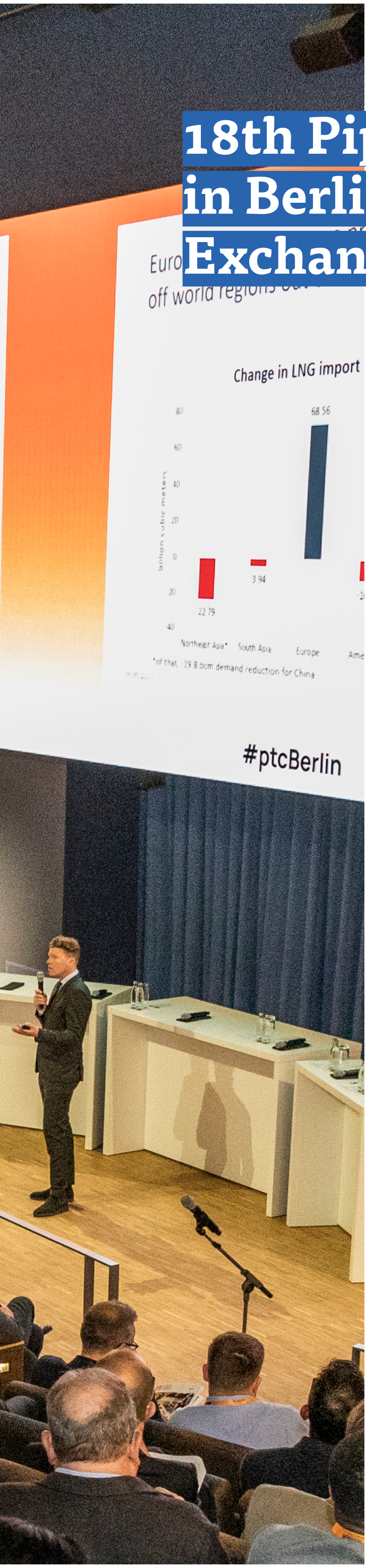


18th Pipeline Technology Conference in Berlin, Promoting Global Exchange and Collaboration

With 1,000 participants from around the world, the 18th Pipeline Technology Conference (ptc) has been larger and more international than ever before: for the first time, the Full-Event-Ticket, which included the seminar program on Monday, was completely sold out.

The flagship global conference & exhibition took place from 8 - 11 May 2023 in Berlin, attracting 82 exhibiting companies and participants from 58 different countries. 83 pipeline operating companies sent delegations to Berlin, and one out of three participants in the capital city came from a pipeline operator.

ptc 2023 explored a range of pivotal topics for the international pipeline industry. The conference started with a keynote speech on "Energy security, decarbonization, and the clean transition: Implications for policy and infrastructure" examining international energy policies. Subsequently, key sessions focused on regional developments in the booming African pipeline market, the decarbonization of the pipeline industry, the impact of climate adaptation and geohazards on pipeline infrastructure, the future of CO2 transportation, and perspectives for the pipeline market in the United States, Europe, and Southeast Asia.

Read the full article here:

https://www.pipeline-journal.net/news/18th-pipeline-technology-conference-berlin-promoting-global-exchange-and-collaboration

Read more pipeline news:
www.pipeline-journal.net

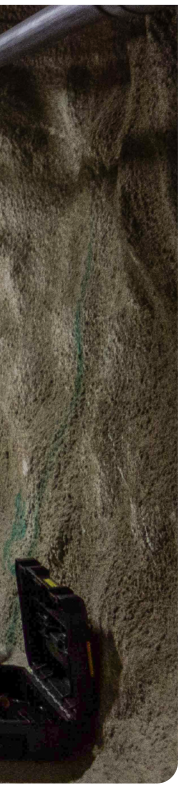
Winner Entries of the 2023

more information at
www.pipeline-conference.com/photo-contest

Winner Photo

This photo was taken at the beginning of the pull back process of the HDD. The DN700 pipeline with a length of 800 meters was laid under the Schelde for the water-link water company in the city of Antwerp.

Marc Huysmans, water-link



Runner-Up Photo

Tunnel near Obergesteln (Valais, Switzerland) | Flow measurement of natural gas on a 48‘‘ transport pipeline

Guido Jary, FLEXIM GmbH

Interview with YPI Early Achievement Award winner Ana Paula Gomes

How does it feel to receive such recognition from your peers in the pipeline industry?

I am truly honored for being selected for the YPI Early Achievement Award from my peers in the pipeline industry. It's motivating to receive recognition at this stage of my career. This award reinforces my dedication to the pipeline industry and encourages me to continue striving for excellence in my work. I'm incredibly grateful for the support of my colleagues and mentors, and I look forward to contributing even more to our industry's growth and success in the future.

Could you tell us about your background and how you became involved in the pipeline industry?

I think I came naturally from my interest in the Oil&Gas field; it launched me towards my Petroleum Engineering degree. From there it all evolved naturally from my undergraduate research work with gas pipelines.

Given your current role as a Business Developer at Enivibes, could you discuss significant milestones or turning points in your career that have led you to this point of expertise?

My Master of Science degree at the Politecnico di Torino in Italy in Petroleum Engineering program gave me many opportunities to start my career and I chose to join the Italian company Enivibes (formerly known as SolAres).

My first role in the company as a Research Engineer gave me a chance to understand deeply how our e-vpms® technologies work and to focus on developing more accurate leak detection systems for gas pipelines.However, I've always been intrigued by the inner workings of businesses after a product launch. This fascination, coupled with my technical proficiency, naturally steered me towards the field of business development.

Can you share any notable projects or initiatives you've worked on that have had a significant impact on the pipeline industry?

I would say that our [Enivibes] research work leak detection systems for gas pipelines is of great impact to the pipeline industry of today.

In your experience, what are some of the key challenges that the pipeline industry faces today?

We find ourselves in a particular moment where ensuring the safety and security of pipeline assets, whether they're new constructions or aging structures, holds paramount importance in sustaining our way of life. The increasing apprehension to uphold their safety arises from the potential risks posed by pipeline failures, whether arising intentionally or accidentally, which invariably affect both the surrounding communities and the environment.

What role do you believe young professionals can play in shaping the future of the pipeline industry?

I think change is important now more than ever to focus on environmental consequences and cyber security to name a few. We need a workforce that aligns with those principles, so I would say that this is the role of the younger professionals in the industry is to bring that fresh perspective and propel the transformation we need.

Could you share any personal goals or aspirations you have set for yourself within your career and how do you plan to achieve them?

I've recently reached a career milestone by securing a promotion as a business developer within my company, a goal I've long aspired to attain. I'm now eager to embark on endeavors that will enhance my proficiency in this newfound business facet of my journey—though I'm still in the process of clarifying my direction. At present, I'm in the contemplative phase, assessing which MBA program would offer the most advantageous growth opportunities.

Apart from your professional pursuits, what are some of your hobbies or interests that bring you joy and help you maintain a healthy work-life balance?

I consider myself fortunate to have had the opportunity to travel extensively, and I'm particularly grateful for the time I've spent living in Italy, one of the world's most extraordinary countries. Italy has breathtaking locations, and it's a joy to note that many of these places are just a short train ride away. As a result, my husband and I consistently explore new destinations during our weekends. In the winter, I find enjoy many winter sports, including skiing and snowshoe hikes. During the summer months, I'm drawn to hiking and have also discovered a newfound passion for via ferratas – a thrilling summer activity that has quickly become a personal favorite.

Finally, how do you see the future of the pipeline industry evolving, and what role do you envision for yourself in shaping that future?

I think my company, Enivibes, is in the forefront of solving many issues in the industry regarding pipeline integrity. My intention is to be part of that change by leveraging my new position to enable my company and colleagues to enact this change.

From left to right: Ana Paula Gomes, James Leigh (representing the award sponsor Penleigh International), Dennis Fandrich, Kshama Roy (© 2023 Ralph Thiele / EITEP).

Interview with YPI Emerging Young Pipeline Professional Award winner Vinooth Rajendran

Winning this Award is a significant achievement. Can you share with us how you felt when you received the news and what it means to you?

I was expecting an email in March 2023. However, I did not receive any emails, so I assumed I was not selected for this award. Unexpectedly, I came across the award announcement email in the morning of mid-April 2023. I felt surprised and very happy, and I immediately sent an email to my PhD supervisor to seek approval for the further process. This award means a lot to me; as a PhD student, it motivates me to continue innovating in the pipeline industry.

Could you provide an overview of your work or research focus and the potential impact it can have on the pipeline industry?

I am currently working on a research project titled 'Nanowire-based Hybrid Sensors at Pipe-Insulation Interface for Corrosion Under Insulation (CUI) Monitoring and Analysis'. The objective of this research is to design a sensor array that combines acoustic emission, humidity, temperature, and pH sensors to effectively monitor the entire pipeline interface conditions. The overall outcome of this research is expected to have a significant impact on the pipeline monitoring industry, particularly in the effective monitoring and early prediction of failure locations in corrosion under insulation conditions.

What motivates and inspires you to continue pursuing a career in research and academia?

Continuous learning of new skills, acquiring subject knowledge, and working towards the development of new technologies to solve real industrial problems.

What are the key challenges you have faced in your research journey so far, and how have you managed to overcome them?

As part of my research work, I have encountered some challenges. One particular challenge is maximizing the sensor monitoring range in pipeline monitoring. Based on the advanced materials research, I have devised a plan to utilize a nanowire layer to enhance electron transmission and expand the sensor monitoring range. I am currently working on this, and I am hopeful of achieving positive results.

As an emerging professional in the pipeline industry, what do you believe are the most pressing issues or trends that need to be addressed? How do you plan to contribute to their resolution?

As a PhD student with a focus on interface corrosion monitoring. I can see, identifying failure locations and monitoring multilayer structural interface conditions are significant issues. For instance, issues like corrosion under insulation and the degradation of reinforced steel have led to major accidents and substantial financial losses. These aspects require thorough monitoring and analysis.

Beyond your technical skills and research expertise, what other qualities or attributes do you think have contributed to your success as an emerging young professional in the pipeline industry?

Beyond my research work, my vision for the future of the pipeline industry, and my collaborations with industry professionals, help me gain insights into the genuine needs of both present and future industries. Furthermore, my industrial experience has deepened my understanding of industrial problems and has enabled me to find advanced solutions for them.

As a PhD Research student, what lessons have you learned throughout your journey that have significantly impacted your personal and professional growth?

My PhD journey has significantly supported my personal and professional growth. Continuously working will help you achieve outstanding results.

Apart from your professional pursuits, what are some of your hobbies or interests that bring you joy and help you maintain a healthy work-life balance?

Outside of my PhD life, I enjoy taking long walks or jogs to get fresh air and explore beautiful places. Additionally, I have a passion for cooking. I prepare various dishes based on my mood, and I find a lot of enjoyment in doing so.

Vinooth Rajendran with Cindy Dirkx representing the award sponsor Dirkx PM&S (© 2023 Ralph Thiele / EITEP)

Managing the Threat of Hard Spots in Gas Transmission Pipelines

K. TRAN, S. SLATER > ROSEN USA

Abstract

Hard spots are a type of threat many operators are managing as part of their integrity management plan. Hard spots are areas on the pipeline that are more susceptible to cracking or could pose an integrity concern in combination with other threats. The United States gas transmission regulation, 49 CFR 192.3, defines a hard spot as "an area on steel pipe material with a minimum dimension greater than two inches (50.8 mm) in any direction and hardness greater than or equal to Rockwell 35 HRC (Brinell 327 HB or Vickers 345 HV10)".

1. In-line inspection (ILI) focused on hard spots

The first in-line inspection (ILI) focused on hard spots was performed in 1968. Since then, there was little focus on development of the ILI service. This changed in 2019, when visibility of incidents and changing regulation led to an increase in the number of inspections performed, development of in-ditch assessment processes and broader industry collaboration on how to detect and manage hard spot threats. This has propelled the industry towards a renewed focus and understanding of what hard spots are, how they can be assessed and how they can be managed. A schematic timeline is shown in Figure 1, which includes come of the key development moments in recent history.

2. ROSEN's solution

ROSEN's solution for detecting, classifying and sizing hard spots is RoMat Dual MaGnetization (DMG). This approach is based on magnetic flux (MFL) and Internal Eddy Current (IEC) technology. Hardness anomalies demonstrate different metallurgical properties, specifically magnetic permeability, compared to the surrounding metal. Combining high field MFL with low field MFL enables accurate and precise hardness anomaly detection and classification. The MFL-A technology saturates the pipe to overcome the difference in magnetic permeability of different material states. Adding a second magnetization unit with similar design but lower magnetization level detects material change. Comparing the flux leakage amplitudes on the different magnetization levels provides the ability to classify hardness anomalies or other material change from metal loss defects such as corrosion. The technology set up is shown in Figure 2.

Hardness anomalies are material changes that can take many physical forms depending on a combination of variables such as steel chemistry, steel manufacturing processes and specific thermal cycles. They can have different microstructures, different morphologies in terms of shape, and different hardness profiles, all of which can influence the ILI signal characteristics. Through several ILI campaigns with various operators, and an adaptive and agile service approach, three types of hardness anomalies are currently being identified using the RoMAT DMG approach. Each results in distinct signal characteristics in the ILI data. The three types of anomalies are shown in Table 1.

According to available incident reports, hard spot failures are mainly associated with some form of cracking. One of the current ideas shared by the industry is that hydrogen generated from high levels of cathodic protection at coating discontinuities, permeates the hard spots and leads to crack origination. In the presence of high hardness, especially martensitic microstructure, the risks of hydrogen based cracking increases.

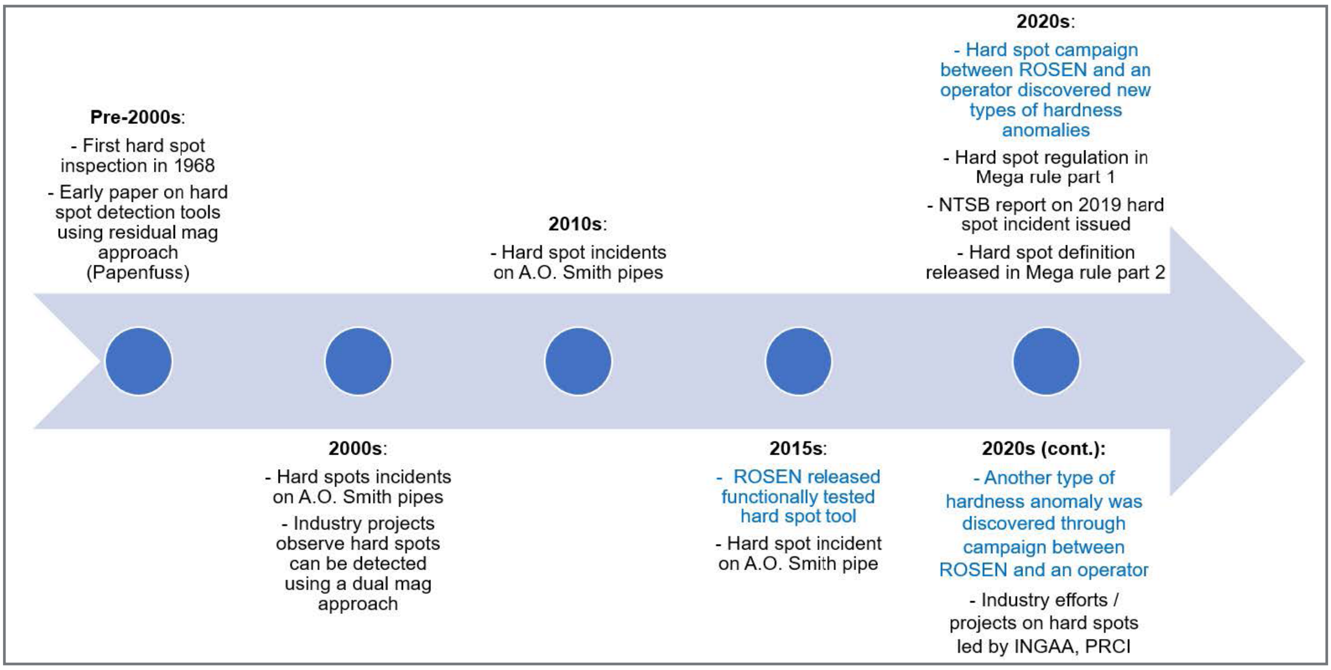


Figure 1: Industry and ROSEN timeline of key events related to hard spots

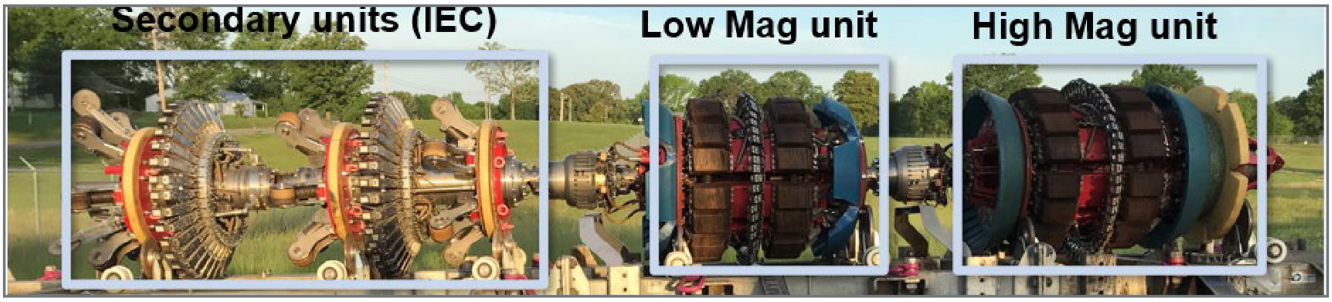


Figure 2: RoMat DMG Hard spot ILI tool with RoCorr IEC

Validation data collected to date, confirms that hardness values up to 400 HB can be present.

Hardness anomalies are generally created during plate/pipe manufacturing or construction. It follows that they have likely survived mill acceptance pressure tests and commissioning pressure tests. Hardness anomalies could therefore be considered stable unless they begin to interact with another threat or change in operational conditions, which creates a time-dependency. Hence, when managing the threat of hard spots, it is critical to consider all available information, including but not limited to hardness, material properties, cathodic potential, soil properties, coating integrity and other threats within the vicinity of the hardness anomalies.

The RoMAT DMG service provides the locations, lengths, widths and hardness values (when applicable) for known types of hardness anomalies. The reported anomalies can be aligned with pipe records and other data sets to obtain a comprehensive picture of asset integrity. Using the combined data sets, anomalies can be prioritized by Operators for a response, so that appropriate decisions are made. In the near future, it is anticipated that the US Pipeline and Hazardous Materials Safety Administration will provide updated guidance on how to assess and manage the threat of hard spots. RoMat DMG will play a part in the process to meet regulatory requirements and maintain public safety.

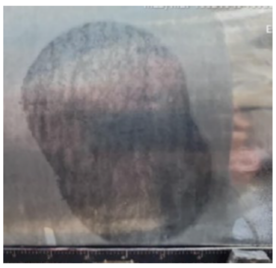
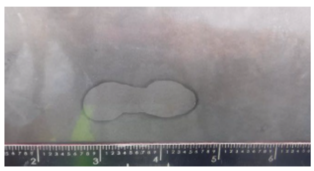
	Type 1	Type 2	Type 3
Description	A hardness anomaly that is typically circumferential in nature. These hardness anomalies tend to be a mixed microstructure and the increased hardness is typically apparent only on one surface.	A hardness anomaly that tends to be a mixed microstructure with martensite and are typically through-wall.	A hardness anomaly that typically has a mixed microstructure with martensite and the increased hardness is apparent only on one surface. Type 3 anomalies can sometimes be identified as a welded repair.
Max. validated hardness to date (HB)	320	400	370
Pipes types the anomaly types have been found on to date	A.O. Smith EFW, Bethlehem DSAW	A.O. Smith EFW, Bethlehem DSAW, Consolidated Western DSAW, Mannesmann DSAW, National Tube DSAW, Kaiser DSAW	A.O. Smith EFW, Bethlehem DSAW, Consolidated Western DSAW, Mannesmann DSAW, National Tube DSAW.
Etching			

Table 1: Description of known hardness anomalies

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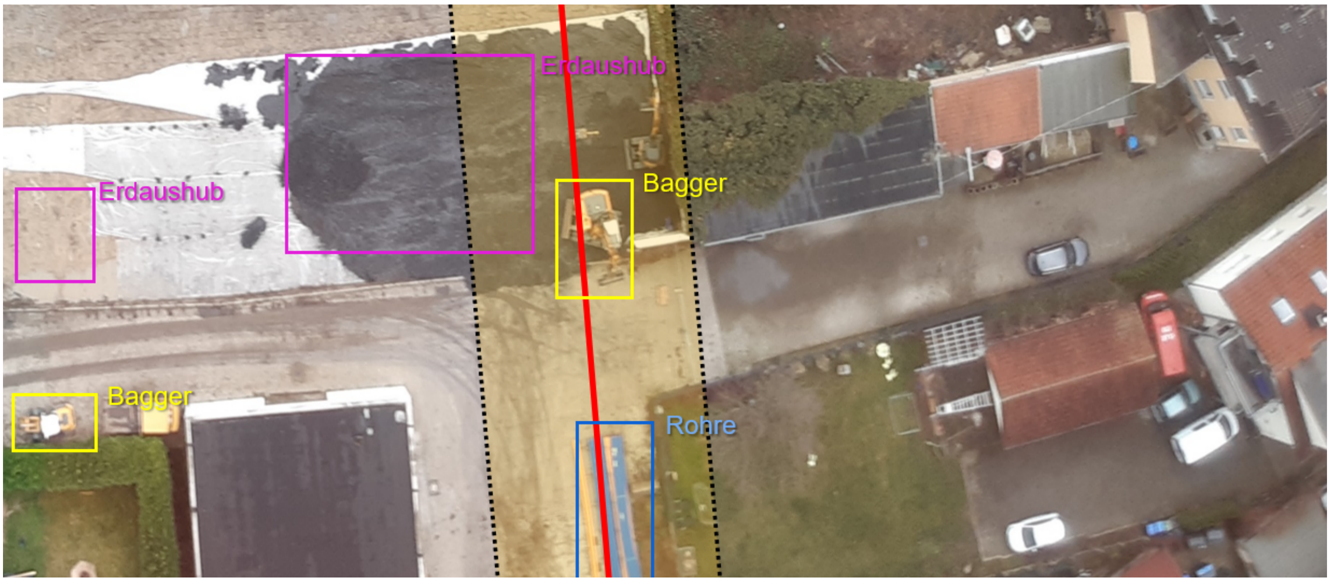

Digitalization of Pipeline Monitoring with Drones and AI at Thyssengas

A. MÜLLER, D. SCHMIDT >THYSSENGAS GMBH

Abstract

Pipeline operators are obliged to regularly monitor their pipeline grid for potential third-party interferences (TPI). They need a reliable, cost-effective method to acquire and analyze aerial images of their pipeline in an automated process. This paper presents the concept of AIMI (Airborne Intelligent Monitoring of Infrastructures), a project initiated 2020 at Thyssengas.

Until now, pipeline inspection is performed by helicopters. The events, reported by the co-pilot, are often unspecific and located inaccurately, which make the inspection at the ground more time consuming. Helicopters are increasingly perceived as a nuisance to people and the environment because of their noise and CO2 emissions. Thyssengas, in cooperation with Open Grid Europe is working on a system that combines drone-, sensor-, and AI technologies to solve those issues.

The aim is to provide an end-to-end service that enables a pipeline monitoring process, which can be adapted to the requirements of infrastructure network operators.

1. Introduction

Pipeline monitoring is an essential part of the pipeline safety concept, aiming to detect potential risks to the integrity of the pipeline at an early stage. Visual inspection of the pipeline network is typically performed through periodic helicopter flights, where an observer - seated next to the pilot - takes georeferenced notes on potential risks and reports them daily to the TSO's operational department.

In Germany the methodology for pipeline monitoring is determined by the regulations of the German Association for Gas and Water (DVGW). These regulations require that the current state-of-the-art technology be considered in the monitoring methodology, necessitating periodic adjustments. Autonomous unmanned aerial platforms (drones) and Artificial Intelligence (AI) are available as technologies for digitalizing the predominantly analog process, making the monitoring process more intelligent, secure, and environmentally friendly.

So far, visual pipeline inspection has been carried out by a human observer who flies over the pipelines as a co-pilot in a helicopter. This process will be digitized by AIMI (Airborne Intelligent Monitoring of Infrastructures) in the future. The human observation capacity will be replaced by digital cameras, sensors, and AI-based image analysis. The AI can identify over 30 different object classes, such as excavators, wood stacks, earth mounds, construction fences, etc. Highly accurate positioning and orientation sensors allow for precise localization of pipeline hazards detected by the AI. The goal is to achieve at least the same level of accuracy as the current helicopter flights, without having to deal with factors such as fatigue or distractions of a human.

Thyssengas utilizes these key technologies to develop the end-to-end pipeline monitoring service AIMI in cooperation with Open Grid Europe (OGE). This involves capturing digital aerial images of the entire pipeline network, which are then georeferenced and analyzed using AI in a highly automated process.

By improving the positional accuracy of notifications and providing orthophotos for each identified event, the workload of the operational personnel responsible for tracking the notifications will be reduced, resulting in available capacity within the company and reducing the overall costs of mandatory pipeline monitoring, as well as noise and CO_2 emissions.

In the coming paragraphs, we present the concept of our work in progress based on these modules and refer to some of the top questions about pipeline monitoring, automation and digitalization.

2. The AIMI end-to-end service

The AIMI service is based on the integration of three modules: flight platforms, sensors, and data analysis, all incorporated into the pipeline monitoring workflow.

The combination of these modules into a closed workflow where infrastructure data (as digital vector files) are the input and detected risks (as qualified reports) are the output is shown in figure 1.

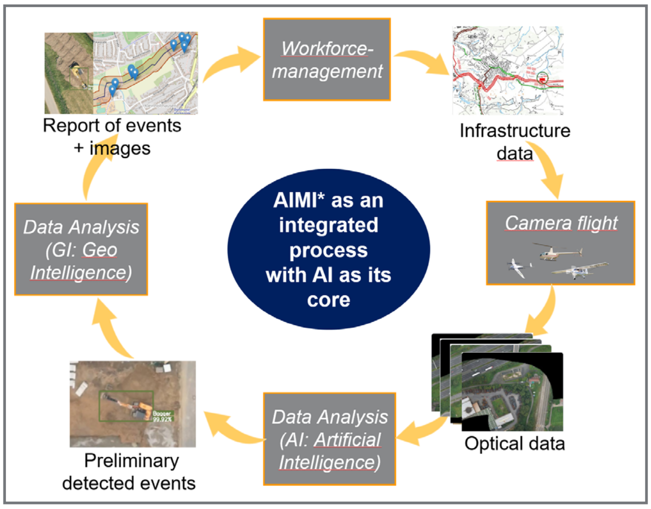

Figure 1: The AIMI services as the center of the pipeline monitoring workflow.

2.1 Input: Network Data

The input for the workflow is the linear infrastructure that needs to be monitored. In a digital sense that means vector data e.g. KML- or SHAPE-files. Each part of the infrastructure can be presented by two vector-files: The infrastructure location and the flight path for the monitoring aircraft platform.

2.2 Module 1: Flight Platforms

The System utilizes up-to-date aerial images, captured using various flight platforms (drones, small aircraft, helicopters, zeppelins, satellites). The choice of platform depends on criteria such as flight range,

Figure 2: A VTOL drone at its hangar

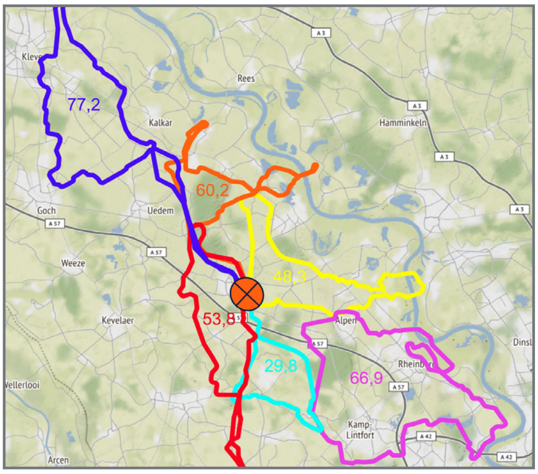

Figure 3: Six drone routes of the demonstrator

cost-effectiveness, approval feasibility, automation, and emissions, considering the specific route of the pipeline.

The use of drones promises the highest degree of automation and emission reduction. The range of drones primarily depends on their design. Fixed wing or VTOL (Vertical Take-Off and Landing) drones are more suitable than multi-copter systems due to their greater flight range. However, even among fixed-wing drones, there are significant differences. Small and lightweight models can cover up to 100 km with lower costs and relatively simple handling. On the other hand, large models with wingspans of over 3 meters, some powered by fuel cells, can fly up to 700 km without intermediate landings. Besides range, logistical requirements must also be considered to achieve efficient monitoring of extensive infrastructure networks.

Today, the biggest obstacle to the widespread use of drones is the approval for Beyond Visual Line of Sight (BVLOS) operations, which refers to flying "beyond the visual range of the drone pilot." Europe-wide regulations need to be adhered to ensure safe flight operations. On the other hand, compared to manned flight platforms, most drones, which are usually electrically powered, excel in terms of noise and CO2 emissions, as well as automation potential. However, most drones have limited range compared to manned flight platforms, requiring ground infrastructure along the network.

This can be handled by mobile personnel who provide support for the drones on the ground (e.g., battery charging or replacement, damage inspection, data storage) or through a fully automated and remotely observed hangar solution that requires minimal on-site personnel for occasional maintenance.

Thyssengas runs a 320 km drone-hangar demonstrator on a 320 km long part of its pipeline network. On a weekly base the VTOL drone autonomously conducts six separated flights making thousands of photos of the area on both sides of the pipeline location.

After each flight the drone lands at the hangar box, uploads the captured data to the cloud storage, reloads its battery, and is ready again to start for the next flight. The whole operation is supervised by a remote pilot at an office fare away from the hangar location.

Although the potential of autonomous flight systems is tremendous, it will likely take some time before drones can cover complete pipeline networks. Therefore, manned flight platforms are currently integrated into the workflow as a bridging technology. Small aircraft and helicopters offer an economical and reliable alternative as they do not require specific flight permits if they do not pass through restricted airspace.

Another platform option is satellites, which continuously capture image and radar data of the Earth's surface. Unfortunately, due to weather-related availability limitations and the still inadequate pixel resolution of satellite images, they currently do not meet the high-quality requirements of the service. However, considering the rapidly evolving number and technical capabilities of earth observation satellites, the use of satellite images in the system can be expected within a few years.

Figure 4: Example of image resolutions. Left 50cm p. Pixel (GSD), right 5cm GSD, taken by manned aircraft.

2.3 Module 2: Sensors

Accurate localization of observations is crucial for quick detection during on-site inspections. This requires proper georectification and georeferencing of each individual aerial image. It is necessary to record the precise camera position and orientation for each image at the time of capture. A system consisting of a precise Global Navigation Satellite System (GNSS) in conjunction with a high-precision Inertial Measurement Unit (IMU) has been selected. The system is connected to the camera and records the precise data at the time of capture. To ensure consistent overlap of individual images and correct alignment, the camera is mounted on a two-axis gyro-stabilized gimbal.

2.4 Module 3: Data Analysis

The AIMI service provides detailed notifications of potential pipeline hazards within a few hours after a flyover.

To ensure this, a fully automated data processing pipeline has been developed. Initially, the captured data from the flyover platform is transferred to an internet-accessible file storage. Once a new flyover dataset is stored there, the upload to the AIMI cloud automatically begins. In the next step, each image is transformed into a small aerial map based on its position and orientation information. This allows assigning a unique geographic coordinate to each pixel of the image. Next, AI-based image analysis takes place, detecting the desired objects. Currently, the AI is trained with several thousands of aerial images to detect over 30 different objects such as excavators, bulldozers, cranes, etc. Each detection serves as an indication of potential construction activities or problematic material storage. The particular challenge in this processing step is to detect very small objects that are relatively rare within very large images in a short amount of time. Once the system detects an object, it captures the object type and geo-coordinates for each single detection. The detections provided by

Figure 5: Map-based presentation of AI detections on the aerial image

the AI are then validated using Geo-Information (GI). Distance operators are used to eliminate duplicate notifications or detections that occur in "safe" areas. Such areas could be for example sales areas of construction vehicle dealers, in order to minimize the number of relevant notifications. Additional geodata can be used to verify the plausibility of the notifications before they are provided as a list, including aerial image, geo-coordinate, and notification type, to the operational personnel responsible for on-site inspections. Since all information is available digitally, the integration into existing workforce management systems can also be realized. We train the AI in parallel with the results of regular helicopter flights, enabling us to constantly evaluate and improve the quality of detections and the overall system performance. In order to use the process in compliance with the DVGW regulations, the quality and reliability of the generated reports must be at least equivalent to those of human observer observations in helicopters. Initial evaluations suggest that the quality of AI observations may even exceed that of human observations.

2.5 Output: Qualified events plus corresponding orthophotos for GIS and WFM

In the non-digital process of pipeline monitoring by a human observer flying in a helicopter, the decision on whether an observation is newsworthy is made within seconds by the observer at the moment he sees the situation live. Thus, the decision is in the hands of the flight service provider. In the case of the digital version of pipeline monitoring, this decision-making authority lies with the operations employee responsible for the respective pipeline section. Compared to the helicopter spotter, the employee does not have time pressure when evaluating the situation on the computer screen (based on the current aerial photograph). Additionally, he also receives the notifications about indicators for potential pipeline hazards as suggestions from the AI on which he has to decide to further investigate or not.

3. Discussion

With the described system we assume to significantly reduce emissions (depending on the chosen platform) and operating costs. But until the system can be deployed fully operational, there are still hurdles to overcome.

One issue to solve is the regulatory framework in Germany represented by the DVGW rulebook. It determines that the aircraft deployed for the monitoring has to be equipped in a way that allows it, in case of the recognition of an instant risk for the pipeline, to immediately intervene (DVGW 466-1 (A)). That means that the aircraft needs to have the ability to land where ever it is necessary. Technically this limits the applicable aircrafts to helicopter. But even in rural regions there are several factors to fit until the helicopter can land outside airfields. Moreover, the chance to detect an instant risk at the very moment it happen is very low at monthly or two-weekly sequential flights.

Another point is, that the rulebook doesn´t consider AI for monitoring pipelines today. We train the AI parallel to the regular helicopter flights. This allows us to constantly evaluate and improve the quality of the risks detection and the overall system performance. Before an AI can be used exclusively and be incorporated into the regulatory framework, the quality and reliability of the generated reports need to be comparable to the observations of a human spotter.

The security of third-party personal rights is another regulatory issue. While digital cameras today have a

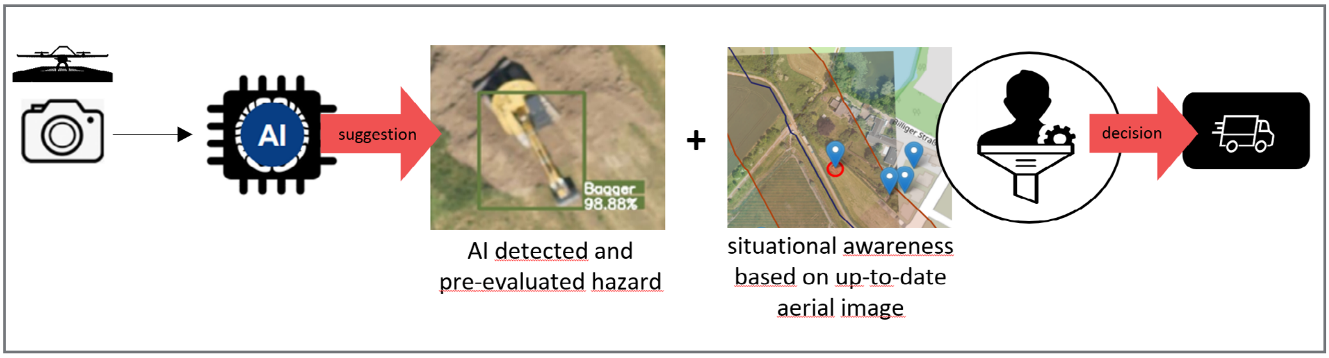

Figure 6: End-to-end process of the digitalized pipeline monitoring process

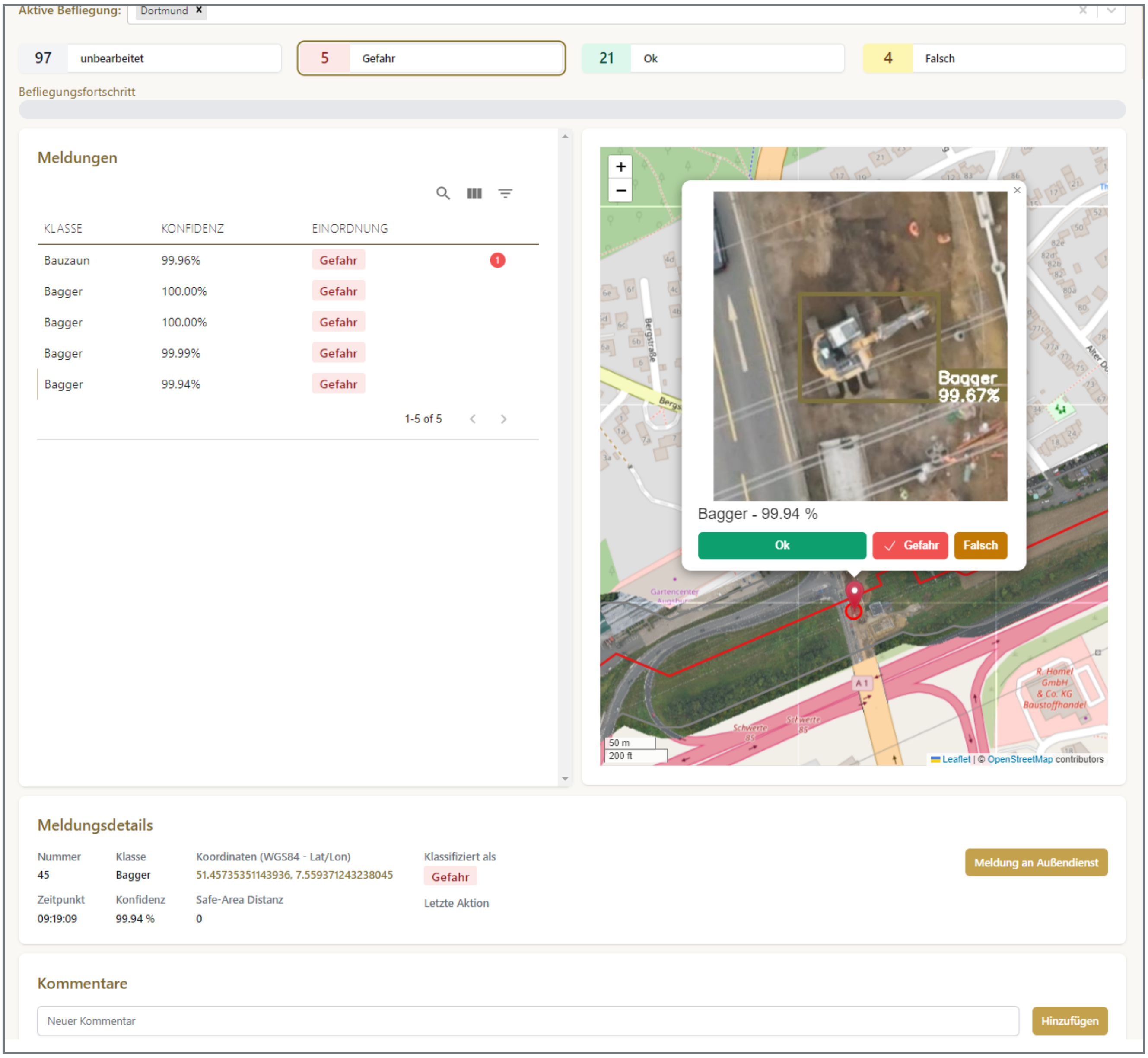

Figure 7: Example display of detected events in the AIMI user frontend.

resolution that would allow ground sample distances of far below one centimeter, such a high resolution will cause, next to the huge data volume, questions concerning personal rights. The data would allow to identify persons by AI as well as to read information such as number plates. We train our system that it works with datasets of 3-7cm GSD (ground sample distance). Using such a relatively low resolutions makes a later cutting out of personal data during the preprocessing unnecessarily and saves storage volume (s. fig. 4). The principle here is: The image resolution has to be as low as possible and as high as necessary.

The monitoring flights generate a data volume of about 0.5 GB of image data per Km pipeline observation, which is about 50 GB for one single 100 Km flight and more than 2 TB for the complete Thyssengas pipeline network (4.400 km). The communication, storage and analysis of such an amount of data is a challenge and requires a powerful and scalable IT infrastructure. Today the greatest challenge is the data transfer from the camera inside the aerial platform to the cloud storage. A fast mobile internet connection is needed in order to send the data already during the flights, because the analysis results are required already few hours after the images were taken. This time criticality also requires the complete integration of the analysis results (hazard reports) into the companies' business processes, which has to be realized for every user individually.

Figure 8: Example of detectability of persons on a 5 cm resolution image

There are still legal issues to be addressed: (I.) Liability of an AI driven system, and (II.) permit to fly drones for the pipeline specific monitoring scenario. The question of responsibility for decisions which an AI has taken (e.g. if the system does not detect a harm, which leads to an incident), finally can't be answered today. Will the user of an AI software be responsible or the developer of the software? Legal regulations will come but are still in early discussions on the European level.

Since the beginning of 2022 also the regulations for flying drones are no longer under national law but unified under European law and have to be applied to real world applications in the coming years. The pipeline monitoring application comes with the following challenges: (I.) Flying beyond visual line of sight (BVLOS) is mandatory, (II.) flights have to strictly follow the pipeline routes without the opportunity of deviations, which means that flights need to be done over every possible type of land use, and (III.) flights need to be done at every possible day of the year. Using also manned aircrafts, this drone specific issues are no burden for AIMI.

4. Conclusion and outlook

The process of visual pipeline inspection carried out by a human observer in a helicopter will be digitized through our system. Replacing human observation with digital cameras, sensors, and AI-based image analysis enables:

- Increased safety through learning AI
- Improved environmental friendliness through emission reduction
- Increased efficiency and effectiveness of on-site inspections

Continuous quality management ensures consistently high reliability of the system. The up-to-date aerial images provided by AIMI help reduce the need for on-site inspections. Should the operational personnel decide to conduct an on-site inspection, the geo-information provided by the system helps locate the exact spot without time-consuming searches. Aerial images also aid in verifying disturbances to pipeline operations, such as disruptive material storage, with precise spatial accuracy. They also assist in deciding on and planning any necessary actions, whether internal or in collaboration with the respective construction companies, and later verifying their implementation.

What is next? The data pipeline is in place, and the AI operating within it needs continuous development to achieve maximum detection quality. As part of our agile development project, we already offer interested companies the opportunity to test the potential of the system through a regionally restricted feasibility study on their own pipelines. We expect valuable expert feedback from this, in addition to further training opportunities for the AI, which will help integrate the process even better into existing workflows and systems. In the long term, we plan to not only use AIMI internally but also offer it as an end-to-end service to other TSOs and infrastructure operators.

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Process Analytics secures the Quality of CO2 Pipeline Management

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Abstract

CO2 is a fundamental building block in the global decarbonization process. In order to successfully develop the individual processes for the separation of CO2 in the coming years, a reliable transport network, for example via pipelines, is a key issue.

Here, process analytics plays an important role here to efficiently monitor and control the primarily innovative sustainable processes. This increases the plant yields, optimizes energy costs and ensures product specifications.

The objective of this paper is to present and discuss solution sets for online analytics such as process chromatography or spectroscopy for CO2 product quality by means of typical measuring tasks. The presentation elaborates the capabilities to simplify and standardize the analytical solution for some representative application examples including the impact on life cycle management.

1. The valueof Carbon Capture in Decarbonization

Global decarbonization efforts are increasingly relevant across all industries. Refineries are migrating to "green" energy parks and are placing the production processes of fuels on a new bio-based platform.

In addition, for a smooth decarbonization transition the development of an efficient future Carbon Capture and Storage (CCS) infrastructure is mandatory to allow the transport of captured CO2 from emitters to safe storage sites. CCS also makes it possible to address emissions from existing plants and is a flexible instrument for a stable energy supply. In the long run it enables negative emissions from power generation when combined with bioenergy. Here of course, special regulations and quality specifications need to be taken into consideration.

Nevertheless, it is a balancing act with opportunities along traditional and new paths.

2. Process Analyzers support a high-quality product

Process analytics plays an important role also for decarbonization markets to efficiently monitor and control the primarily innovative sustainable processes. This increases the plant yields, optimizes energy costs and ensures product specifications. As part of process management, process analytics helps to ensure that processes are as economically efficient as possible (as shown in picture 1). The amortization period is often under one year. The illustration shows a typical optimizing sequence. A setpoint (SP) must be determined to ensure that the maximum impurity level (A) as per the design specification is not achieved. Without process analyzer support, the product purity is fluctuating due to missing information of individual component concentrations of the impurity. Optimized process monitoring using e.g., process gas chromatographs (process GC) enable the operator to use a setpoint much closer to the design specification without risks. People in charge know exactly what happens in the process and most probably the fluctuation is lower. The result is economical plant operation, high product quality, and increased throughput. Process GCs make a valuable contribution for process optimization.

3. CO_2 Pipeline Management

Carbon dioxide (CO2) emissions into the atmosphere must be reduced. Unfortunately, this cannot be done overnight. Industry continues to produce large amounts of CO2, even though it is making great efforts to become more climate friendly. This raises the question of what to do with the CO2? Possible options are to use it for other purposes (e.g., in the beverage industry, for Enhanced Oil Recovery -EOR, or as raw material for chemical processes) or to store it safely for a long time (e.g., in large and empty former hydrocarbon reservoirs, mainly offshore) to keep the CO2 out of the atmosphere permanently. To transport the gas to the final destination pipelines are required.

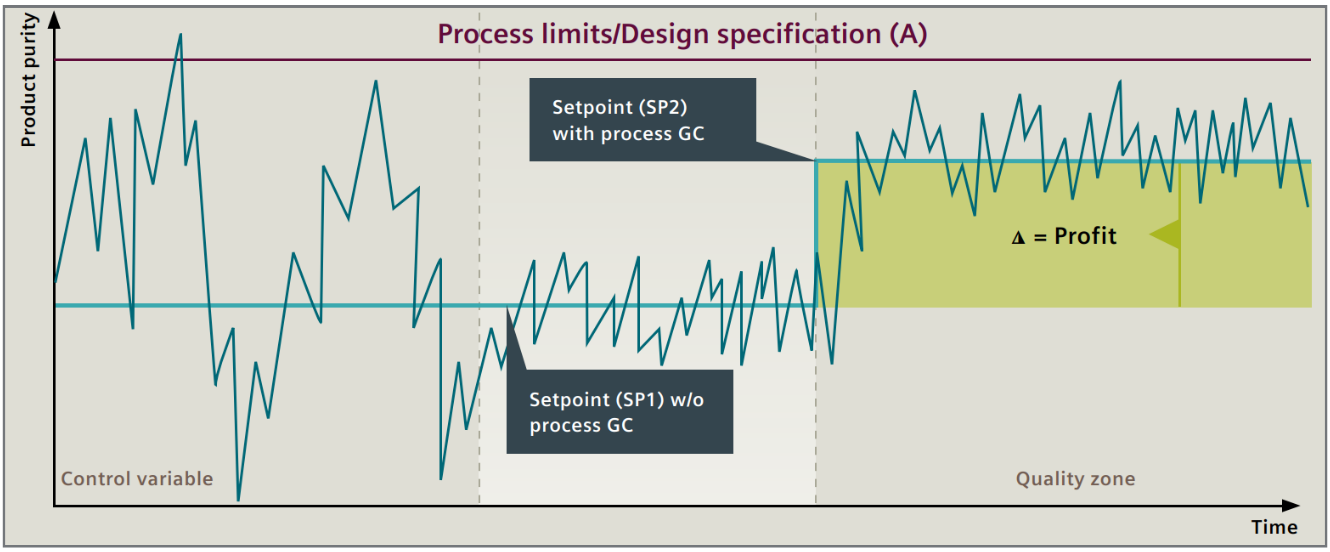

Figure 1: Process efficiency improvement by using process analyzers

3.1 Carbon Capture and Storage Major Technology Steps

CO2 has been captured from industrial process streams for many years. Proven capture technologies such as pre-, post-combustion or oxyfuel processes are available.

The post-combustion process is explained here as an example: When separating CO2 from the off gas after combustion, a chemical is utilized to extract and separate it from the other flue gases. A proven technology since decades is e.g., the amine absorption process. In the first stage, the flue gas comes into contact with the amine fluid. The CO2 is bonded in the liquid. The absorption liquid (amine / water mixture) is transported to a stripper column where the CO2 is separated at higher temperature from the amine fluid which is reused. After a further treatment step by dehydration the pure CO2 is compressed to be ready for pipeline transport.

3.2 Process Analytics in Carbon Capture Facilities

In CO2 capture, various gases must be measured in order to make the process as optimal as possible in terms of energy and capture efficiency. In addition, the flue gas that is released into the atmosphere must be clean in order to comply with environmental regulations. Further processing also requires the removal

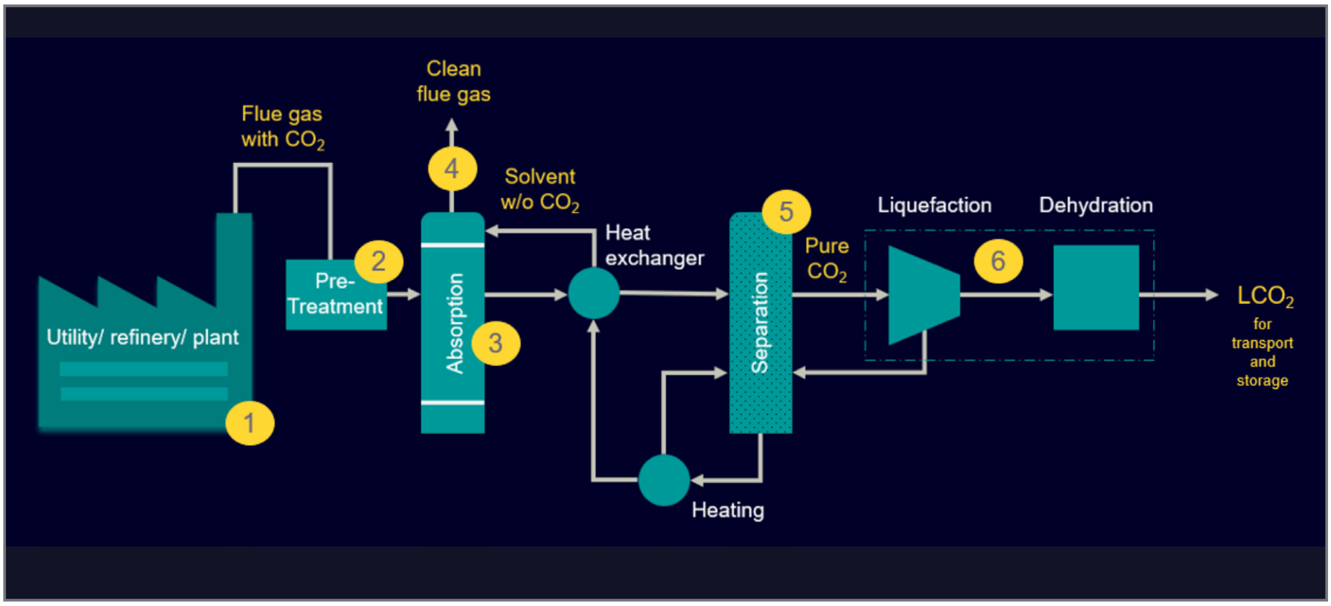

Figure 2: Measuring points for Process Analytics in the Carbon Capture Post-Combustion Process

	Measuring Point	Measuring Task	Measuring Components	Typical online analyzer
1	Boiler (Flue gas with CO_2)	Combustion control	CO_2, O_2	IR
2	Flue gas pre-treatment	Treatment optimization	SOx, CO_2, NO, NO_2	IR
3	CO_2 Absorption	Treatment optimization	SOx, CO_2, NO, NO_2, Amines	IR
4	Stack (Clean flue gas)	Emission monitoring	CO, CO_2, NOx, SO_2, O_2	IR
5	CO_2 separation (Stripper)	CO_2 quality monitoring	O_2, H_2, H_2O, Amines (traces, impurities)	GC, IR
6.1	Dehydration/ Deoxygenation	CO_2 quality control	H_2O, O_2	IR, moisture analyzers
6.2	CO_2 compression	CO_2 quality control	CO_2, H_2O, H_2, Ar, CO, H_2S, COS, C_{2+} , mercaptans, alcohols	GC, (IR)

Table 1: Typical measuring points and recommended analyzers

of trace gases (e.g., N2, O2, NOx, SOx, H2S) to a minimum level and the complete drying of the CO2. All this is monitored continuously by online analytics. Finally, after the combined purification and liquefaction, the quality of the CO2 has to be controlled again to meet CO2 specifications for further transport e.g., via pipeline in liquefied form (LCO2) at approx. 20 bar or higher and for final usage.

Across the entire value chain, various measuring points for process analyzers by using different analytical technologies can be identified and are illustrated in Figure 2.

For flue gas monitoring at the boiler up to CO2 capture as well as emission monitoring at the stack, continuous gas analyzers based on the principle of IR spectroscopy have been proven in use. Process GCs are used primarily for trace analysis in the downstream process streams like the CO2 separation and CO2 quality control. These measuring instruments can reliably determine a large number of individual components down to the low ppm range, even with complex gas mixtures. Therefore, they contribute to a secure and reliable CO2 transport by analyzing the critical CO2 fluid constituents down to trace concentration levels as referred to relevant standards, e.g., ISO27913:2016.

Figure 3: Process gas chromatograph with double oven technology and densification options

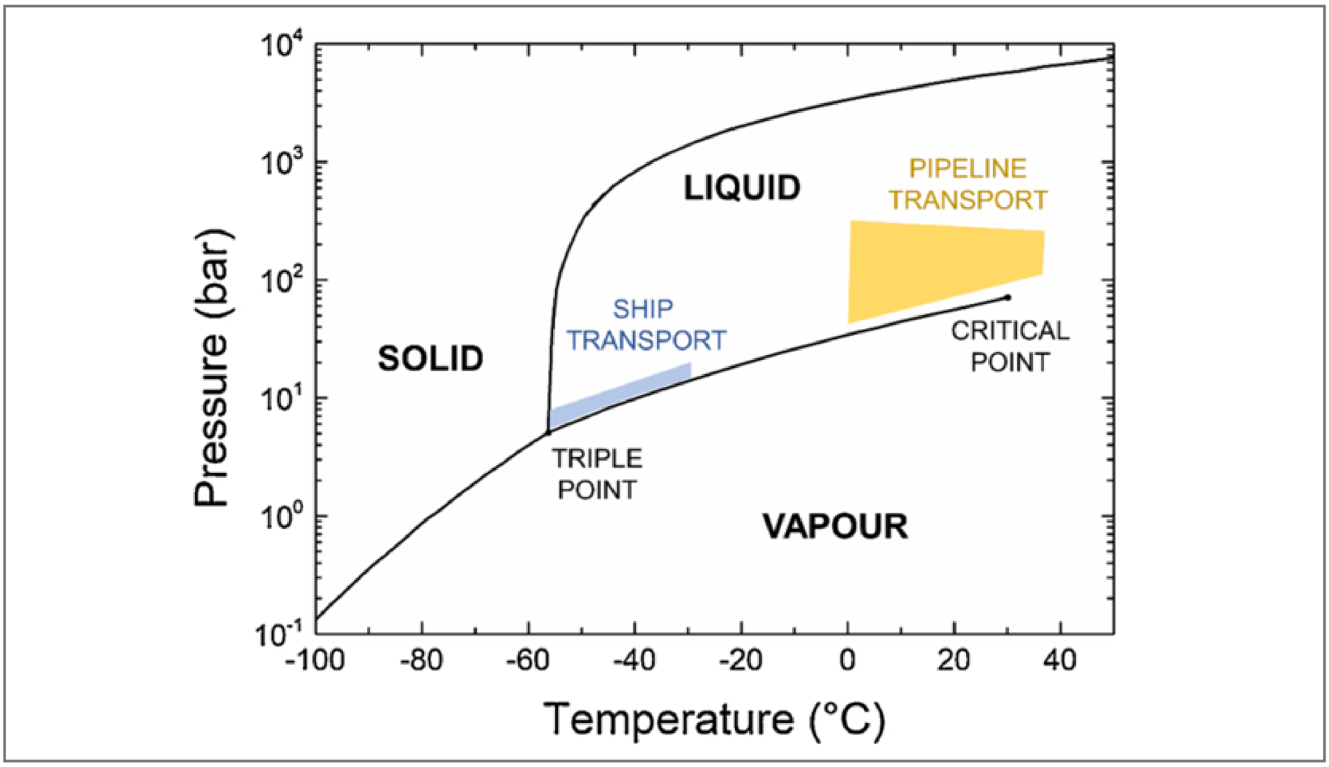

Figure 4: Typical phase diagram of CO2 [4]

The Siemens MAXUM Ed. II process gas chromatograph has been already established for decades in the process industry to analyze reliably and precisely multiple product matrices in different concentration values. Flexible detection technologies such as TCD (thermal conductivity), FID (flame ionization) and FPD (flame photometric) in combination with suitable injection and separation techniques guarantee the determination of high concentration levels as well as low ppm levels for many CO2 trace species.

CO2 quality monitoring by means of process analytics is specifically mandatory since the presence of impurities in the CO2 stream can alter the phase diagram depending on the concentrations, can create dual phase regions or requires higher pressure which increases the risk that the process is getting economically unfeasible for liquefied CO2 transport.

Furthermore, the shape of the CO2 phase diagram is differing depending on the used carbon capture technology since different impurities (e.g., hydrogen, nitrogen, argon, oxygen) can be found. That's the reason why standardization activities are ongoing to specify quality gates in accordance with international regulations.

4. Conclusion

The CO2 economy is a key market for the global decarbonization activities. Product quality plays an important role to develop those sustainable products successfully. To secure the quality of CO2 pipeline management it is recommended to integrate process analytics into the network. Hereby, application flexibility is mandatory when adapting technical equipment to sustainable processes such as carbon capture economy. This also applies to process analytics. A superior analyzer performance needs to be provided by using convincing and solution oriented analytical concepts. Gas chromatographs play here an important role due to their high flexibility and reliability.

Sustainability must become a matter of course and this is much more successful with process analytics.

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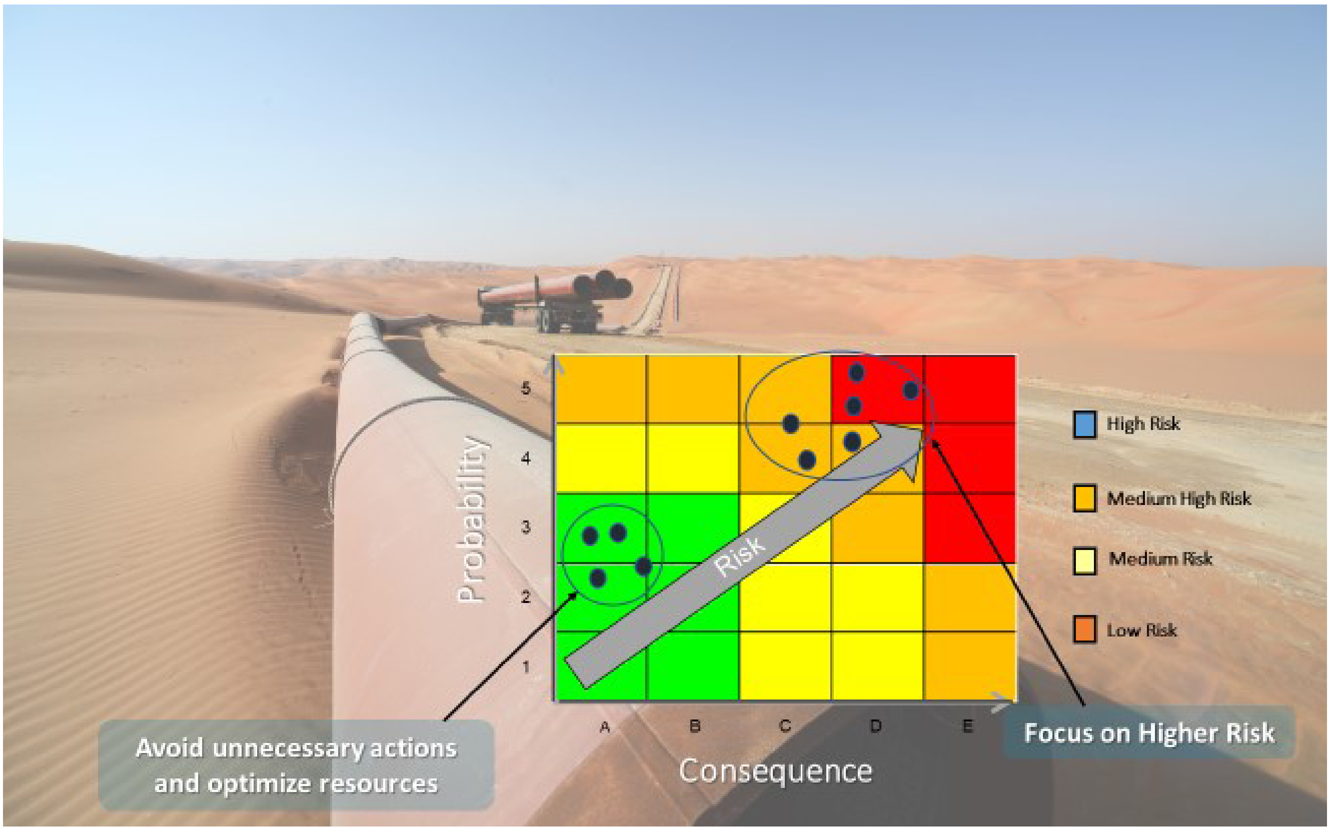

Development of a Semi-quantitative Risk Assessment Approach for Pipelines

R. AL HAJRI, M. AL BAHLI, H. AL HAMDAN, N. DAKWAR > SAUDI ARAMCO

Abstract

Pipelines are typically designed using different practices and codes than in-plant piping. While Risk-based Inspection (RBI) quantitative methodologies have evolved and been applied for in-plant piping, e.g. API RP 581, limited methodology framework has been specified and widely used for pipelines, in a similar approach.

Alternatively, for pipelines, the concept of risk assessment combined with an integrity management system has been widely adopted by the industry. In this work, a semi-quantitative risk assessment methodology is devised and showcased to allow for systematic and repetitive application.

To increase repeatability of application and relative-based analysis of risk for each pipeline segment, criteria have been devised for five (5) pipeline threats of failure and three (3) factors for consequence of failure, using a 5x5 risk matrix. The threats of failure and consequence factors include examples of projected metal loss, failure pressure, Cathodic Protection performance, inventory volumes, population density and other factors.

1. Introduction

In oil and gas industry, pipelines are used to facilitate as a network of transporting feedstock and product hydrocarbon fluids among oil and gas processing facilities. As they traverse long distances and cross country areas with relatively less population densities, they are typically handled using different sets of design and construction practices than oil and gas facilities which relatively have higher population density and higher risk of failure. An instance of such practices is the use of ASME B31G or DNVGL-RP-F101 [1 and 2] as fitness-for-service evaluation for internal and external corrosion. Such evaluation utilizes principles of fracture mechanics to calculate and estimate failure pressure to avoid fracture failures in pipelines.

This is particularly applied as majority of oil and gas pipeline operators do not incorporate corrosion allowance in design. On the other hand, several risk assessment methodologies, including Risk-based Inspection (RBI), have been devised to maintain the integrity of plant piping and equipment within oil and gas facilities. Instances include API RP 580, API RP 581, and ASME PCC-3 [3 - 5]. API RP 580 and ASME PCC-3 for instance elaborate on the general recommended framework for establishing an RBI program and principles that are to be followed to establish an RBI methodology. An industrial example of an RBI methodology is included in API RP 581 which can represent an RBI with a quantitative analysis approach. API RP 581 has been adopted by several international oil and gas plant operators. However, API RP 581 is only applicable to plant piping and equipment and therefore excludes pipelines.

Several users have conducted RBI to pipelines by different and diverse approaches. Perumal conducted an RBI assessment on a hydrocarbon condensate pipeline that had impurities of CO_2 and H_2S activating the susceptibility to wet CO_2 and H_2S combined corrosion, and sulfide stress corrosion cracking (SSCC) and utilized a qualitative analysis approach [6]. Zhang et al. conducted an RBI assessment to gas pipeline compressor station with CO_2 sweet corrosion probability and utilized API RP 581 quantitative analysis approach [7]. However, in essence, API RP 581 quantitative analysis that has been used may not be accurate as the dispersion calculation is affected by that onshore pipelines are typically buried and offshore pipeline are typically at subsea level, which impact the consequence dispersion calculations. Selvik et al. studied the current risk-based inspection of API RP 581 and introduced the concept of adding factors when calculating risk [8]. These include sensitivity and uncertainty factors, as assessment input data sources can yield different levels of uncertainty, thereby affecting risk value.

Despite there are general guidelines to establish an RBI assessment for pipelines, there is no RBI methodology adopted in industrial standardization societies for pipelines, e.g. API, ASME, ISO, NACE, etc, and basically there are no or limited recommended practices or publications similar to API RP 581. However, for pipelines, instead of RBI, risk assessment is considered part of a general integrity management program and framework. Such management program encloses elements that are illustrated in Figure 1. The intent of this work is to discuss and elaborate on a semi-quantitative risk assessment approach established and applied for possible precise and repeatable use by oil and gas pipeline operators.

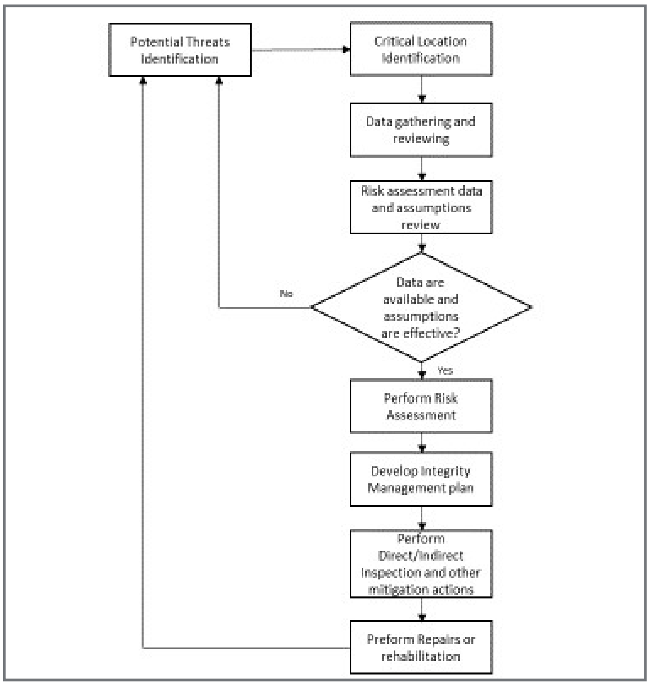

Figure 1: Typical elements of integrity management program used for managing pipeline integrity

2. Establishing Pipeline Risk Assessment Method: A Case Study

This section discusses a case study of establishing a semi-quantitative risk assessment method that may readily be applied to onshore and offshore pipelines.

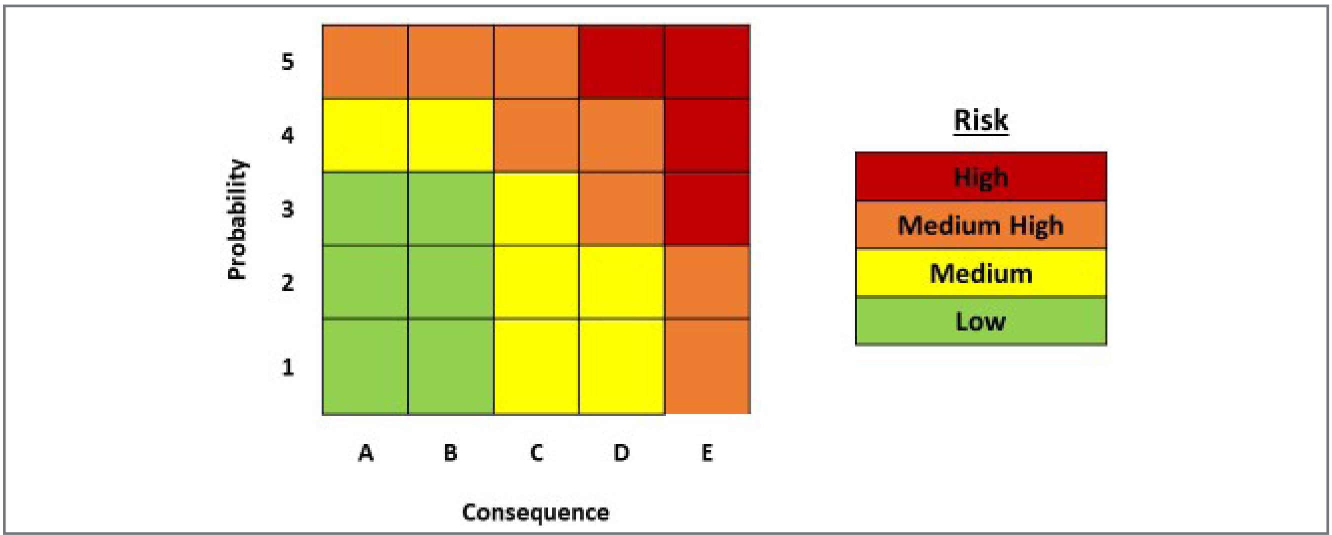

Figure 2: 5-5 risk matrix used for pipeline semi-quantitative risk assessment

This method utilizes the concept of relative risk ranking and its bases are literature review and compiled experience of pipeline threats of failure. The risk assessment discussed here uses a 5-5 risk matrix shown in Figure 2. The probability is demonstrated in the abscissa and is divided into five levels, where 1 corresponds to the lowest probability and 5 to the greatest. The consequence part is demonstrated in the ordinate with A indicating least consequence of failure and E indicating greatest. The risk categories are low, medium, medium high and high.

2.1 Inventory grouping:

In this risk assessment method, the first step is to designate inventory groups. At the discretion of the pipeline operator, an inventory group may represent a pipeline portion surrounded by remotely controlled isolation valves. Each pipeline inventory group represents a separate component that is to be individually risk assessed.

2.2 Probability of Failure Selection:

Probability of Failure (PoF) covers the following pipeline failure threats where each threat is evaluated independently and designated a probability level to help designate a risk level for an inventory group. Other threats, e.g. potential and status of mechanical damages, may be considered at the discretion of the operator.

I. Projected metal loss and corrosion rate:

In this threat, projected metal loss, failure pressure and corrosion rate are evaluated. For this threat, the risk assessment method uses the criteria in Table 1. As illustrated in Table 1, the PoF is a function of corrosion

PoF	PoF Level 1	PoF Level 2	PoF Level 3	PoF Level 4	PoF Level 5
Projected Metal Loss	Metal Loss ≤ 10%	Metal Loss ≤ 20%	20% < Metal Loss ≤ 40%	40% < Metal Loss ≤ 60%	Metal Loss > 60%
Projected ERF	[0-0.2]	(0.2-0.4]	(0.4-0.6]	(0.6-0.8]	(0.8-1.0]
Corrosion Rate (CR), mpy	< 3 mpy	3 ≤ CR < 6 mpy	6 ≤ CR < 9 mpy	9 ≤ CR < 15 mpy	CR ≥ 15 mpy

Table 1: Projected metal loss and corrosion rate PoF criteria

PoF	PoF Level 1	PoF Level 2	PoF Level 3	PoF Level 4	PoF Level 5
Average StE Potential, mV	≤ -1100	-1000≥ Potential > -1100	-900 ≥Potential > -1000	-850 ≥ Potential > -900	Potential > -850
% of Distance with Inadequate StE Potential	0%	1-5%	6-10%	10-15%	>15%

Table 2: Ineffectiveness of CP PoF criteria

rate, projected metal loss and projected estimated repair factor (ERF). ERF here is defined as the ratio of maximum operating pressure to the failure pressure and the projection is towards next integrity assessment date. The highest level by any of these criteria can be considered when setting the PoF level for this threat of failure.

II. Ineffectiveness in Cathodic Protection system:

This threat considers the protection level made by Cathodic Protection (CP) system to pipeline inventory groups. The PoF for this threat can be defined by using the criteria illustrated in Table 2.

As can be seen, the PoF is a function of average structure-to-electrolyte (StE) potential level realized in the inventory group and percentage of pipeline inventory group distance with StE less than required. In Table 2, -1100mV is arbitrarily set as an example of required threshold protection level for onshore pipelines with rectifier or DC power energized. The highest PoF level by any of these criteria can be considered when setting the PoF level.

III. Hydrogen Induced Cracking (HIC) and Stress Oriented HIC (SOHIC):

In essence, if the pipeline material of construction is carbon or low alloy steel, not meeting ISO 15156 or not coated or clad with corrosion resistance alloy (e.g. stainless steel, nickel alloy, etc), and the pipeline fluid contains water/moisture and H_2S, then the pipeline should be evaluated for susceptibility to Hydrogen Induced Cracking (HIC) and Stress Oriented Hydrogen Induced Cracking (SOHIC) [17]. For this threat, Table 3 can be used for PoF ranking.

The PoF ranking relies on the susceptibility to cracking level (i.e. None, Low, Medium and High) defined by Table 9.3 of API RP581, edition 3, Part 2 [4]. API RP 581 has set the rules to define acceptable scheme for classifying susceptibility to HIC and SOHIC. Such susceptibility classification is aligned with literature and has been used by many users [17-24].

IV. Internal Stress Corrosion Cracking:

The internal Stress Corrosion Cracking (SCC) threat in this risk assessment method covers Sulfide Stress Cracking (SSC), alkaline carbonate SCC (ACSCC), and Chloride SCC (CSCC). Typically, these types of SCC are not applicable to the wide spectrum of pipelines in the oil and gas industry.

If the pipeline material of construction is carbon or low alloy steel and the process fluid contains water/moisture and H_2S in any concentration, then the pipeline should be evaluated for susceptibility to SSC. Similarly, the pipeline should be considered for evaluation for susceptibility to ACSCC, if the pipeline material of construction is carbon or low alloy steel and the process fluid contains alkaline water at $pH > 7.5$. Lastly, the pipeline should be considered for evaluation for susceptibility to CSCC if the pipeline is made of or clad with austenitic stainless steel and the pipeline is exposed or potentially exposed to water or moisture containing chlorides, considering upsets and hydrostatic test water, and operating at a temperature above 38°C.

PoF	PoF Level 1	PoF Level 2	PoF Level 3	PoF Level 4	PoF Level 5
API RP 581 Susceptibility Level	Not susceptible		Low	Moderate	High

Table 3: HIC, SOHIC and internal SCC PoF Criteria

PoF	PoF Level 1	PoF Level 2	PoF Level 3	PoF Level 4	PoF Level 5
MAOP, %SMYS			< 40	40 ≤ MAOP < 50	≥ 50
Operating Pressure, % SMYS			< 30	30 ≤ Operating Pressure < 40	≥ 40
Operating Temperature, °C			< 30	30 ≤ Temperature < 40	≥ 40
Length of Pipeline Segment Downstream of Pump/Compressor Station, km			> 50	32 < Segment Distance ≤ 50	≤32
StE Potential, mV					-790 ≥ Potential > -600

Table 4: External SCC PoF criteria

For internal SCC, Table 3 can be used for PoF ranking. The PoF ranking is a function of susceptibility to cracking level (None, Low, Medium and High) that is reflected in Table 8.3 of API RP 581, edition 3, Part 2 for SSC, Table 10.2 of API RP581, edition 3, Part 2 for ACSCC, and Table 12.2 of API-581, edition 3, Part 2, for CSCC. Similarly, such susceptibility classification is aligned with literature [22, 23, 25-27].

IV. External Stress Corrosion Cracking:

Historically, external Stress Corrosion Cracking (SCC) have occurred in onshore buried pipelines in the forms of near-neutral and high pH SCC. According to cracking surveys and studies in literature, high pH SCC is prone to carbon steel pipelines with metal temperatures above 32°C, soil pH higher than 9 and pipe potentials in the range of -600 to 750mV using $Cu/CuSO_4$ reference electrode. Typically, such form of SCC has been most reported within the first 32km downstream of a pipeline facility, e.g. compressor station for transmission pipelines. Near neutral pH SCC on the other hand is relatively independent of pipeline temperature. It is prone to pipeline areas where potential is at the unprotection level (i.e. –760 mV to –790 mV using $Cu/CuSO_4$ reference electrode), and pH of soil between 5.5 to 7.5. Both forms of SCC did not occur in an effectively applied coating system made of Fusion Bonded Epoxy (FBE). Typically, both SCC forms occur when the applied stress level exceeds 60% of the specified minimum yield strength (SMYS). [10 and 13]

Therefore, in this assessment method, if the pipeline is buried and onshore, its material of construction is carbon or low alloy steel, its external coating system is other than fusion boned epoxy (FBE), and operating stress level is greater than 40% of SMYS, then the pipeline should be evaluated for susceptibility to external SCC. Table 4 can used for PoF ranking which is a function of maximum operating pressure (MAOP), operating pressure, operating temperature, pipeline potential and distance from pipeline facility, e.g. pump or compressor station.

2.3 Consequence of Failure Selection:

To determine the consequence of failure (CoF), the following criteria can be evaluated in which a consequence level can be designated. Other criteria may be recommended to be established such as transportation redundancy and production interruption impact by a pipeline shutdown.

I. Inventory volume:

The first and most important CoF criterion is inventory volume of an inventory group. One intuitive approach is to consider the fact that the larger the inventory volume the greater CoF is. To determine Inventory Volume CoF level, Table 5 for instance may be followed. In Table 5, the inventory group with largest inventory volume is identified and its inventory volume is denoted as Vmax. The inventory group with largest inventory volume is placed in CoF level E. Based on Vmax, CoF level for the remainder of inventory groups is defined based volume ratio to Vmax as shown in Table 5.

II. Location classification and population density:

Location classification and population density is intuitive criterion that is followed in a pipeline risk assessment. This is due to the fact that pipeline inventory groups with higher population density have higher failure consequence. In this risk assessment, Table 5 can also be followed. The location classes in Table 5 are defined by ASME B31.8 section 840.2 which is a function of number of buildings for human occupancies close to a pipeline inventory group [15].

III. Potential of secondary failures:

Potential of secondary failures is typically applicable to onshore single and multi-phase pipelines containing gas. For the potential of secondary failure, Table 5 may also be used to set CoF level which utilizes the number of adjacent pipelines within a lateral distance of 10 m in each side.

2.4 Risk ranking for inventory groups:

When PoF and CoF analyses are completed for each susceptible threat and consequence factor, the worst-case scenario PoF and CoF category may be assigned for each inventory group to develop the risk level in Figure 2.

As an alternative approach, when pipeline-to-pipeline risk ranking is performed, pipeline total inventory volume may be calculated instead of inventory group volume. The pipeline with highest inventory volume is alternatively identified and denoted as Vmax. To consider the environmental impact of offshore pipelines, a factor of 1.5, for instance, may be multiplied to the

CoF Factor	CoF Level A	CoF Level B	CoF Level C	CoF Level D	CoF Level E
Inventory Volume	0 – 0.2Vmax	0.21Vmax – 0.4Vmax	0.41Vmax – 0.6Vmax	0.61Vmax – 0.8Vmax	0.81Vmax – Vmax
Location Class	Location Class 1		Location Class 2	Location Class 3	Location Class 4
No. of Adjacent Pipelines			1	2	≥ 3

Table 5: Inventory volume, location classification and potential of secondary failure CoF criteria

inventory volume for offshore pipelines. In some situations, cost may be preferred instead of inventory volume. This particularly applicable if the oil and gas pipeline operator has a network of pipelines with different transported fluid streams. To move with this alternative, the cost per unit volume should be obtained which can be multiplied to each pipeline or inventory group volume, for the purpose of obtaining an additional financial consequence measure.

3. Application of Risk Assessment:

Upon establishment, the risk assessment methodology has been piloted and applied for more than 400 pipelines and has led to the proactive identification, detection and repair of external SCC in more than 30 pipelines due to the following present susceptibility conditions:

I. External tape wrap coating.

II. High operating stress exceeding 40% of SMYS.

III. High operating temperature exceeding 40°C.

Such pipelines were inspected through EMAT and UTSW Inline Inspection techniques which led to detection and repair of 384 external SCC indications.

> "How to manage your pipeline risk with a practical, repeatable and precise assessment. pipeline integrity monitoring."

4. Discussion and Conclusions:

Pipelines are typically designed using different practices and codes than in-plant piping. While RBI quantitative methodologies have evolved and been applied for in-plant piping, limited or no ready methodology framework has been specified and widely used for pipelines in standardization societies. Alternatively, for pipelines, the concept of risk assessment combined

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with an integrity management system has been widely adopted by the industry.

A semi-quantitative risk assessment methodology has been showcased in this work. The methodology uses a 5x5 risk matrix with five (5) probability of failure levels and five (5) consequence of failure levels. To increase repeatability of application and relativity-based analysis of risk for each pipeline, criteria have been devised for five (5) pipeline threats of failure and three (3) factors for consequence of failure. The threats of failure in the methodology includes projection of metal loss, projection of failure pressure, CP system effectiveness, and internal and external SCC. The factors for the consequence analysis considered inventory volumes, location classification, population density and potential of secondary failures.

Such assessment has been developed and utilized by the co-authors to maintain relative risk analysis of pipelines in order to allow for repeatability, risk trend-analysis, and effective implementation of risk management and mitigation actions.

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Stress Concentration Tomography with Machine Learning for Defect Severity Classification

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Abstract

Defect severity classification holds significant importance within industries that prioritize quality control. This study proposes a novel approach that applies machine learning with Stress Concentration Tomography (SCT) to effectively categorize defects' severity. Through the utilization of machine learning algorithms, the objective is to enhance the precision and efficiency of defect severity classification.

The findings highlight the effectiveness of the technique, notably, the best model achieves a commendable accuracy rate of 90%. The study also underscores the importance of considering both defect variety and dataset size in refining machine learning models for pipeline defect severity prediction, thereby ensuring their applicability in real-world scenarios.

1. Introduction

Inspecting underground pipelines is essential for ensuring their safety and reliability. These pipelines are susceptible to temperature changes, ground shifts, and corrosion, which can lead to structural problems and safety risks. Traditionally, techniques like In-line Inspection (ILI) or NDE methods such as Ultrasonic Testing (UT) or Phased Array Ultrasonic Testing (PAUT) are employed to identify and address pipeline defects (Piazza, 2018). In recent years, Stress Concentration Tomography (SCT) has been used as a non-destructive testing technique that utilizes stress-induced anomalies to identify potential flaws or weaknesses in pipeline structures.

In pipeline integrity investigation, the classification of defect severity holds significant importance. Accurate assessment enables proper mitigation and ensures the dependability of products and systems. In this context, our study introduces an innovative approach by applying machine learning with SCT outputs for defect severity classification. By leveraging historical defect data, machine learning models can identify patterns and relationships that correlate with defect severity. Our overarching goal is to enhance efficiency of SCT through the utilization of machine learning algorithms.

The primary objectives of this study are to create a comprehensive dataset comprising SCT and direct assessment data, including information about defects. Utilizing this dataset, we will explore the correlation between SCT outputs and the calculated defect severity as per the ASME B31G standard. Ultimately, our goal is to create and evaluate machine learning models with the ability to predict the severity of defects using SCT data.

The article is structured as follows: the introduction section presents the research topic, highlighting the application of machine learning and SCT for predicting defect severity. The methodology section outlines the research approach, describing the data collection procedure, explaining how the ASME B31G standard serves as a classification labelling system for the collected data, explanation of feature selection criteria, details of the model training and evaluation process, and the specific metrics employed to gauge model performance. The results section showcases the outcomes of our approach and provides insights into its efficacy. Finally, in the conclusions and future work section, we conclude the article by reflecting on the achievement of prediction objectives, discussing underlying assumptions, and suggesting potential avenues for future research in this field.

2. Methodology

2.1 Data Collection

2.1.1. Stress Concentration Tomography (SCT) data

The SCT data was collected using UNISCAN tool, a specialized set of equipment designed specifically for Stress Concentration Tomography. This dataset includes details about Stress Concentration Zones (SCZs) present within the pipeline and the corresponding stress magnitudes associated with them. These SCZs are significant, as they pinpoint potential locations of structural vulnerability or areas where the pipeline's strength might be compromised.

2.1.2. Direct assessment data

Direct assessment involves excavating around the pipeline to expose its surface for a thorough examination. This procedure enables the identification of various external damages, corrosion, and structural problems. To obtain a comprehensive understanding of the pipeline's condition, we compared the information obtained from the excavation assessment (used as a reference) with the SCT data. This comparison enabled an evaluation of the effectiveness of both the SCT technology and the excavation method in detecting pipeline defects.

2.2 ASME B31G-based severity classification

The ASME B31G standard, formulated by the American Society of Mechanical Engineers (ASME), offers guidelines to assess the enduring strength of pipelines dealing with metal loss caused by corrosion or other defects (ASME, 2012). It introduces a simplified method to measure the significance of these metal loss issues and to decide whether repairs or more evaluation are necessary. The standard considers factors such as size of the defect, its location, the pipeline's material properties and the operating conditions. The classification system within the B31G standard acts as a descriptive labelling tool for indicating defect severity.

B31G Severity Classification steps:

1. Extraction of Defect Characteristics: Defect characteristics were extracted from the recorded data, including defect geometry.

2. Application of B31G Criteria: The safe and burst stress values were calculated from the defect geometry and then compared to the threshold values for different defect categories. Defects were classified based on whether they exceeded specific threshold values.

3. Assigning Defect Categories: Defects were categorized on a scale system derived from the B31G standards, including labels such as "Low," "Moderate," "High," or "Severe," based on the calculated stress level threshold, see Figure

2. An ERF value can also be calculated from the ASME B31G standard to provide a more detailed assessment of the defects' potential impact on the pipeline's structural integrity.

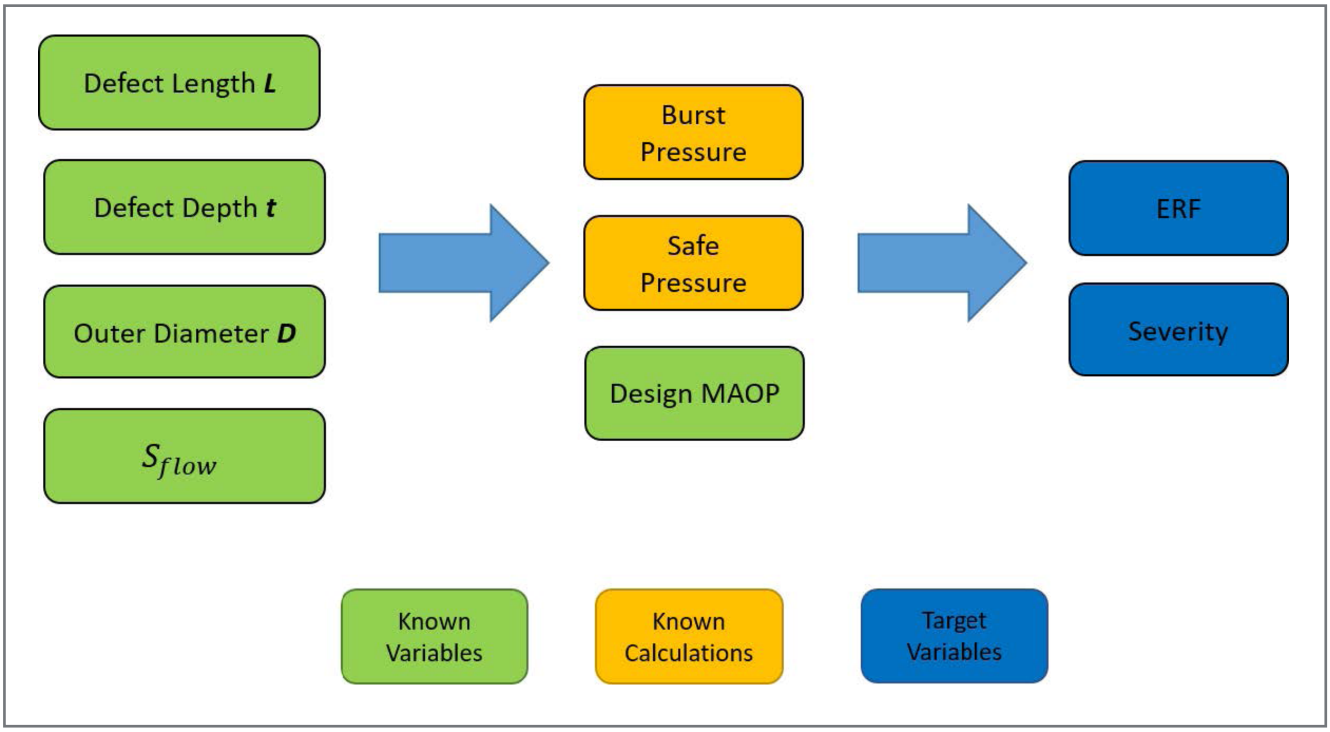

Figure 1: Flowchart of ASME B31G Classification

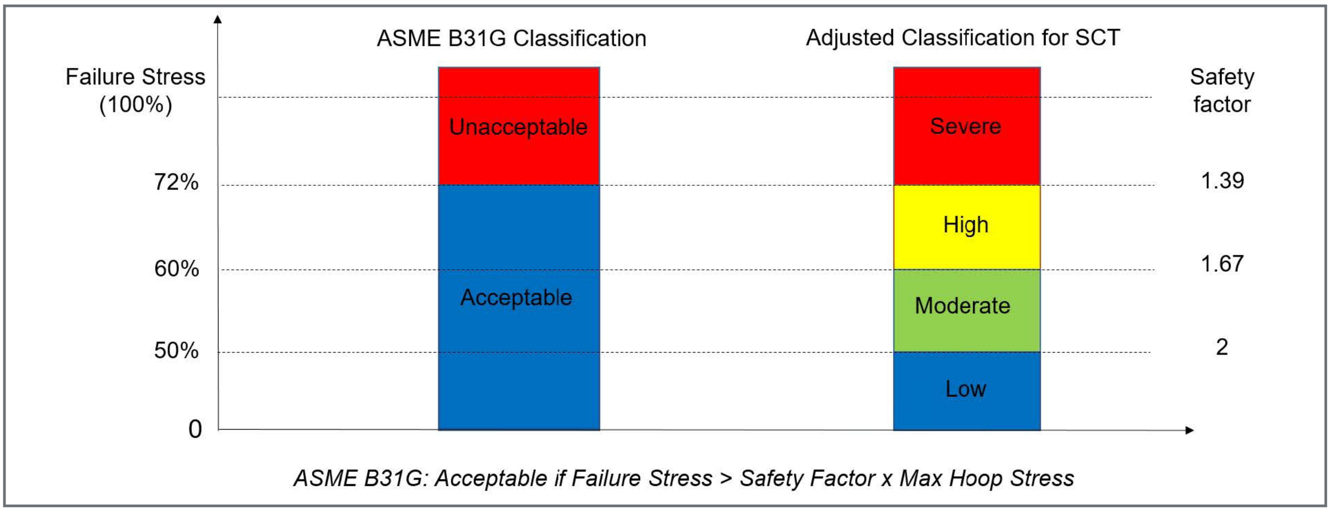

Figure 2: Derived severity scaling system based on ASME B31G standard

2.3 Feature Selection

Feature selection is a crucial step in machine learning that involves choosing a subset of relevant features from the available set of features to enhance model performance and reduce computational complexity.

The features in SCT data used in this study contains:

- Operating Pressure: The pressure at which the pipeline operates.
- Outer Diameter: The specified outside diameter of the pipe.
- Wall Thickness: The thickness of the pipe's wall.
- Design MAOP: The highest pressure that a pipeline is designed to safely handle under normal operating conditions.
- Specified Minimum Yield Strength (SMYS): The minimum yield strength specified for steel pipe manufactured in accordance with a listed specification.
- Anomaly Magnitude: The magnitude of the anomaly at the SCZ location.

In this study, the chi-square test was used for feature selection, especially when dealing with categorical data and classification problems. The chi-square test is a statistical method that measures the independence between a categorical feature and the target variable. It evaluates whether there is a significant association between the two variables. Higher chi-square values indicate stronger dependence, suggesting that the feature might be relevant for predicting the target (Thaseen & Kumar, 2017).

2.4 Model Training and Validation

In this study, various classification algorithms were explored for their ability to accurately categorize defects based on the extracted features. These algorithms included Support Vector Machine, Logistic Regression and XGBoost, each chosen for their potential to handle the complexity of the defect classification task.

The algorithms used in this study went through training and validation, which are two important steps. These steps were carefully planned to make sure the algorithms can accurately classify defects, while being fair and unbiased.

The algorithms were trained using a specific group of defect examples from the collected data. It is important to note that these defects exclusively pertain to corrosion, in accordance with the ASME B31G standard which solely offers a procedure for calculating corrosion-related defects' severity. These examples were already sorted into categories based on the ASME B31G standard. The dataset consists of 25 data points available to train the machine learning models and are distributed as follows:

- Low: 6 instances
- Moderate: 2 instances
- High: 14 instances
- Severe: 3 instances

During training, different methods for the algorithm were chosen and its settings adjusted to achieve optimal results. The algorithms' performance was assessed using a distinct set of defects, kept separate from the training data. These new defects were not categorized in advance. The algorithms had to predict the categories of these unseen defects based on their training. This reflects real-world scenarios where algorithms encounter novel defects. Their predictions were compared to the actual defect categories, measuring their ability to predict new cases effectively.

To generalize the performance of algorithms, the data was divided into 10 subsets. The algorithms were trained on nine of these subsets and tested on the remaining one. This process was repeated 10 times, each time with a different subset left out for testing. This provided a robust assessment of the algorithms' generalization ability, simulating their performance on new defects. The comparison of predictions with actual categories allowed for a comprehensive evaluation of how well the algorithms could predict unseen defects, thereby measuring their real-world utility.

2.5 Performance Evaluation

The evaluation of machine learning algorithms' performance typically centres around predictive accuracy. In our study, we employed a range of distinct indicators to comprehensively evaluate the algorithm's ability to accurately classify defects according to the B31G standard. Accuracy, precision, recall, and F-measure stand as four metrics frequently employed in such assessments.

- Accuracy: measures the overall correctness of the model's prediction
- Precision: measures the accuracy of the model's predictions when it labels an instance as belonging to that class.

$$Precision = \frac{TP}{TP + FP}$$

- Recall: measures the ability to correctly identify all instances belonging to that class out of all the instances that truly belong to it.

$$Recall = \frac{TP}{TP + FN}$$

- F1 Score: a single metrics that balances both precision and recall

$$F1 = \frac{2 \times Precision \times Recall}{Precision + Recall}$$

3. Results and Analysis

Feature	Chi-squared	P-value
Operating Pressure	121.304	**<0.001**
MAOP	95.704	**<0.001**
Diameter	99.624	**<0.001**
SMYS	96.100	**<0.001**
Wall Thickness	89.299	**<0.001**
Anomaly Magnitude	180	**<0.05**

Table 1: Chi-square test results

The chi-square test is used to determine which features are linked to defect severity. Among the features, Operating Pressure, MAOP, Diameter, SMYS, Wall Thickness, and Anomaly Magnitude stand out with relatively high chi-squared scores and p- values less than 0.05, see Table 1. This indicates that these features are probably important factors in predicting defect severity within the model.

Figure 3 shows the performance of the machine learning models with the testing subset. XGBoost demonstrates a relatively consistent performance across all metrics. The precision score, at an average of approximately 0.75, indicates that the model is accurate in its predictions of severity classes approximately 75% of the time. The recall score of approximately 0.78 suggests that XGBoost is effective in identifying a substantial proportion of actual severity instances. The balanced F1- score of around 0.76 further confirms that XGBoost maintains a good trade-off between precision and recall. The model achieves an average accuracy of roughly 0.82, correctly classifying a notable portion of severity instances. However, it is worth noting that there is variability in the results, with a standard deviation of about 0.23 in accuracy, indicating potential fluctuations in its performance.

The Support Vector Classifier (SVC) model displays a consistent and balanced performance, as evidenced by the precision, recall, and F1-score metrics being close to each other. The average precision of approximately 0.87 indicates that the model's predictions of severity classes are correct around 87% of the time. The recall score of about 0.88 suggests that the SVC model effectively captures a substantial portion of actual severity instances. The F1-score of around 0.87 reflects the model's ability to maintain a favourable balance between precision and recall. With an average accuracy of 0.9, the SVC model achieves a high level of correct classifications.

The Logistic Regression (LR) model also exhibits consistent precision, recall, and F1-score metrics, which are comparable to those of the SVC model. The average precision of approximately 0.80 indicates that LR accurately predicts severity classes around 80% of the time. The recall score of about 0.82 suggests that the LR model is effective in identifying a good proportion of actual severity instances. The F1-score of around 0.81 reinforces the model's capability to strike a balance between precision and recall. With an average

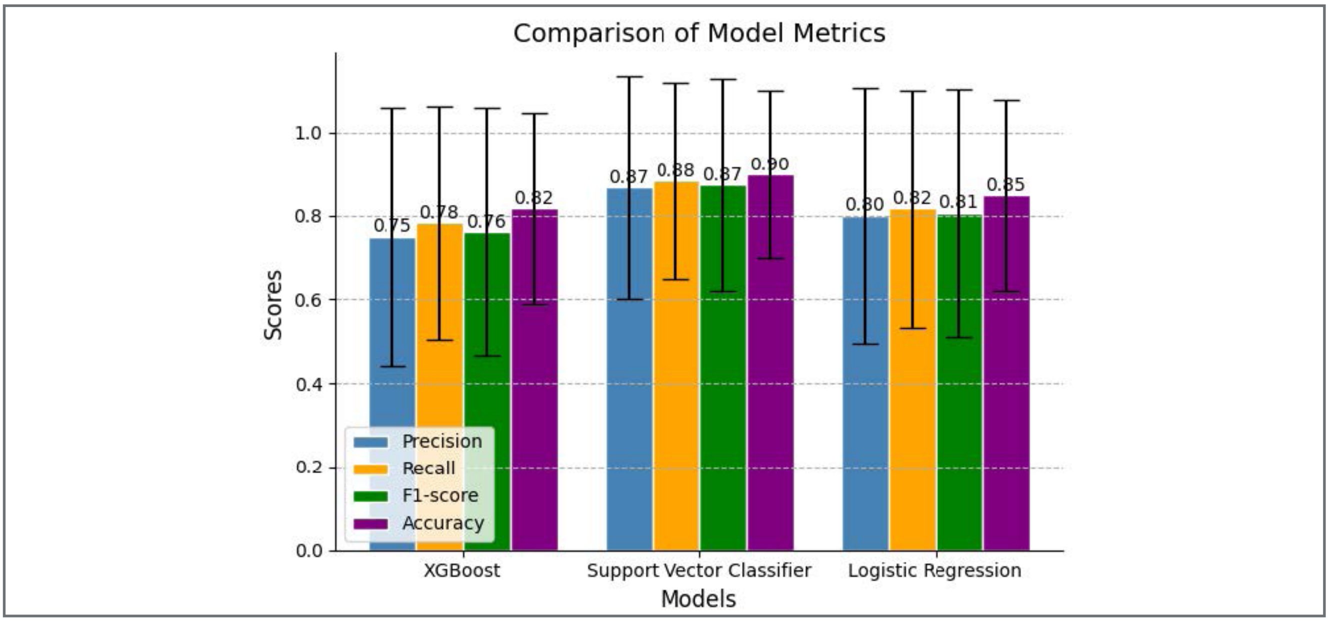

Figure 3: Comparison of the models' performance

accuracy of 0.85, the LR model correctly classifies a notable portion of severity instances.

4. Discussion

The performance of the three algorithms was closely matched, with only slight variations in precision, recall, and F1-score. This suggests that, while each algorithm has its unique approach, all are effective in leveraging SCT data for severity prediction. The slight differences in performance might be attributed to the intrinsic characteristics of each algorithm, such as their sensitivities to different patterns in the data. Notably, the high standard deviations in the results suggest some variability in the models' performance. It might be worth investigating the sources of this variability, such as the data distribution, size, and potential noise in the dataset. Overall, the performance of the machine learning models demonstrates their capability to predict defect severity through the utilization of SCT data. The models developed exhibit a high accuracy rate of prediction. This outcome highlights the effectiveness of employing advanced computational techniques to interpret stress concentration tomography information and transform it into actionable insights for defect categorization.

The machine learning models have limitation in predicting defect severity. Currently, the models are only trained on corrosion-related input data, which means they can accurately assess severity levels only when the underlying cause of the defect is corrosion. It means the models might struggle or provide inaccurate results when faced with defects that are not corrosion-related. However, if the training data were to include other types of defects, such as mechanical or structural issues, the models' predictive capabilities could be improved. With more samples or data points of different types of defects, it is possible to enhance the accuracy and effectiveness of the method.

Another constraint that affects the machine learning models is the relatively small size of the dataset. This limited amount of data can hinder the models' ability to learn complex patterns and relationships effectively. With a small dataset, the models might struggle to generalize well to new and unseen examples, which could lead to overfitting or underperforming when applied to real-world situations. Therefore, it will be benefited to have enough diverse instances to capture the full spectrum of possible scenarios and variations in defect severity accurately. And as a result, it will improve the model's predictive power and robustness further.

5. Conclusion & Future Work

The analysis of machine learning models predicting pipeline defect severity using Stress Concentration Tomography data reveals insights into their performance and limitations. Significant features identified by the chi-square test include Operating Pressure, MAOP, Diameter, SMYS, Wall Thickness, and Anomaly

Magnitude. Among evaluated models, Support Vector Classifier (SVC) and Logistic Regression (LR) show consistent balanced performance with competitive metrics. XGBoost also performs well with stable metrics, though some accuracy variation. In summary, the study has demonstrated the ability to accurately predict the severity of defects by using a machine learning approach with SCT data. Acknowledging the limitations arising from the exclusion of non-corrosion defects influences the models' ability to predict more varied cases, while the limited dataset size affects the comprehension of complex patterns, potentially resulting in overfitting or underfitting performance. Addressing these constraints, like acquiring diverse data and advanced techniques, could enhance model reliability. In conclusion, while the models exhibit promises in predicting corrosion-related defects, the consideration of defect diversity and dataset size stands as a critical factor. The findings emphasize ongoing necessity for model refinement to ensure their efficacy in real-world scenarios.

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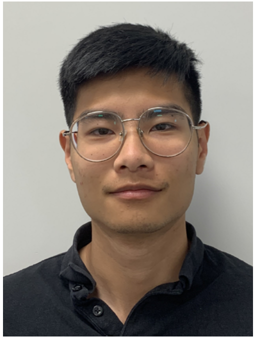

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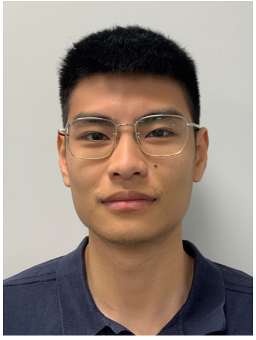

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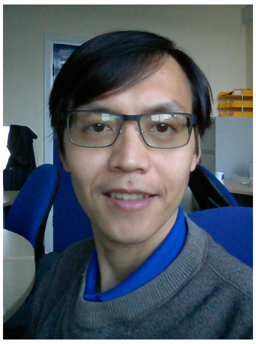

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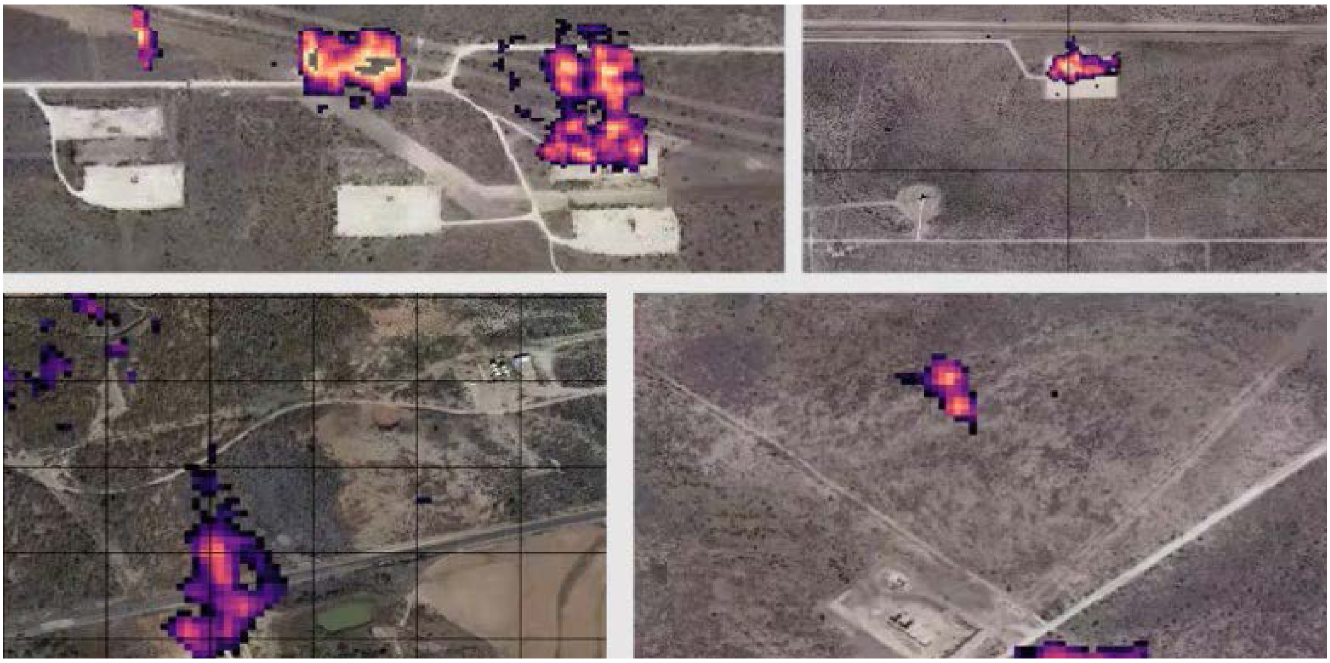

The Arrival Oil and Gas Pipeline Monitoring with Satellite-Based Hyperspectral Imaging

R. P. WEAVER > ORBITAL SIDEKICK

Abstract

Hyperspectral imagery (HSI) began in the 1980s and has been used by the U.S. government for years, but it just recently became available for commercial use. This technology has a vast range of potential applications, with oil and gas pipeline monitoring being one of the most prominent examples. HSI enables unparalleled daily global pipeline leak and change detection capabilities. Now deployed by satellite, it is beginning to replace conventional aerial monitoring compliance while also enabling enhanced emissions detection. This paper discusses the state-of-the-art for HSI, with examples of pipeline leaks and encroachment observed using hyperspectral data and analysis.

Successful HSI deployment will drive a decrease in the number and magnitude of pipeline leaks using frequent, global, high-resolution data collection, rapid and reliable analysis, and reporting of actionable information. This paper focuses on Oil & Gas, but the application spans industries. Across the board, HSI commonly enables use cases throughout the resource lifecycle.

For decades, satellite-based HSI technology has offered the promise of remote detection of hydrocarbons and other disturbances. It is finally becoming scalable and cost-effective for the pipeline operators and thus a reality for cost-effective asset stewardship.

1. Introduction

Tailored and customized access to space has become a reality, with commercial monitoring opportunities from low earth orbit improving asset stewardship in ways that we're just beginning to see. Space technology is pushing the bounds of what is now described as the Experience Era, "where the lines between digital and physical are increasingly blurred."

The state of the art is changing rapidly, even month-to-month, especially in earth observation. Here the satellite platforms themselves are being commoditized while the remote sensing equipment is evolving rapidly. This has enabled much more customized capabilities with shorter durations from initial engineering to deployment. To reiterate, we have seen a shift from expensive specialized platforms performing commoditized services, to inexpensive commoditized platforms performing customized services. As might be expected, none of this mass customization of space-borne data is happening in a vacuum, notably as it relates to the future of industrial asset management. A critical element of technical success in the new space-based- marketplace will be integration of data and imagery into existing information networks. Yet, the critical element for widespread market success will be the seamless integration of robust analysis into business leaders' decision-making tools. In this, there will be increasingly seamless integration of, what individually are incredibly powerful technologies and capabilities, into information products or resources accessible to anyone calling for a subscription.

Orbital Sidekick (OSK) is a leading player in this new arena. OSK developed and during 2023 has deployed its own space-based intelligence technology to collect, process, and analyze advanced hyperspectral data – now providing actionable insights that help solve the world's biggest challenges, including oil & gas pipeline monitoring, carbon credit verification and promoting global security. Imagine what can be done with the sort of information that "Experience Era" companies will create, as these nascent platforms begin to operate, at scale, in our world!

Since its founding in 2016, OSK has set about the goal of developing and deploying a hyperspectral imaging constellation to provide clients with rapid analysis and reporting of captured data for any asset on the planet as often as daily. During 2018, OSK deployed its Hyperspectral Earth Imaging Satellite Test ("HEIST") prototype sensor to the International Space Station, enabling the company to begin its development with space-based sensors, as well as its aerial platform.

During the first half of 2023, OSK finally launched the first of its Global Hyperspectral Observation Satellites, known as the GHOStTM Constellation: during April, GHOSt 1 and 2 deployed from the SpaceX Transporter-7 Mission, and in June, GHOSt 3 launched from Transporter-8. The company will launch three additional equivalent microsatellites during the first half of 2024, each featuring a proprietary hyperspectral imager unique to OSK.

Now in orbit, these first GHOSt satellites will offer unmatched global monitoring capacity, capturing nearly 500 bands of light across the electromagnetic spectrum with 20x greater sensitivity than traditional monitoring. The payload will produce the highest resolution commercial hyperspectral imagery ever in orbit, with a ground sampling distance of eight meters. This advanced imaging capability will support OSK's Spectral Intelligence Global Monitoring Application (SIGMA™) platform, which provides access to OSK's data archive, analytics engine, and intelligent satellite tasking system for commercial and inherently governmental applications. While commercial applications for this technology are exceptionally broad, GHOSt will be concentrated on monitoring oil and gas infrastructure, as well as methane emissions, mining life cycle activities, and select agricultural applications. In preparation for commercial operation using the GHOSt constellation, extensive pilot testing and development work had been conducted in the critical areas of (1) data collection, (2) data analysis and (3) on-line reporting of actionable information to clients. Selected results from the company's pilot testing work, including field results and analysis, will be presented, followed by the very earliest results of data collection from the GHOSt constellation and intelligence reporting from SIGMA.

2. Hyperspectral Imagery (HSI)

Satellite-based hyperspectral imaging is not a new technology. It has been in practice since even before the early 1980s, though especially limited to first-world governments and military superpowers. This is simply because, historically, HSI has been very expensive, data intensive, and cumbersome to work with. It is only in the present time that Moore's Law has begun to catch up with its promise.

As a technology, HSI is generated as a line scan rather than as a captured in a frame. With a hyperspectral scanner, the imager is constantly collecting as many as hundreds of reflected light signals, each with proportional reflectance values from their respective wavebands. Therefore, the hundreds of hyperspectral bands offer orders of magnitude greater insights on the surface characteristics of the world it is observing versus the three colors of human sight. Figure 1 illustrates, for example, generic vegetation features objectively discernible by hyperspectral data.

As knowledge of characteristics of the surface of the earth are developed and become correlated to the characteristics of hyperspectral profiles, libraries may be expanded to catalogue surface features and allow digital characterization of the world around us. To date, publicly available spectral libraries are focused on minerals and soils, agricultural and vegetative features, man-made objects and materials (such as roofing and steel), water and certain liquids, and select chemical compounds.

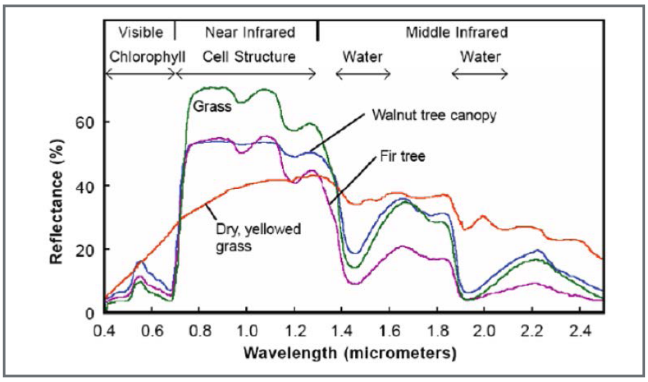

Figure 1: Library Profiles for Standard Vegetative Features

Similarly, publicly available archives exist of HSI collected from certain U.S. government satellite and aerial assets, notably the National Aeronautics and Space Agency (NASA) Hyperion satellite as well as its aircraft-based AVIRIS program. Using its Airborne Visible / Infrared Imaging Spectrometer, NASA collected data over a major known natural gas leak at Aliso Canyon just north of Los Angeles in 2015. Using this data, available in the public domain, it is possible to positively identify the large methane plume widely reported from this location, as depicted in Figure 2. In the frame on the top right, OSK applied a standard methane index which seeks, pixel by pixel, a specific ratio of two prominent reflectance values characteristic to methane. That reveals the plume for this emission source white over orange as a false-colour representation. Other features, however, are also indicated in this frame in white, meaning this index alone isn't sufficient to positively identify the methane.

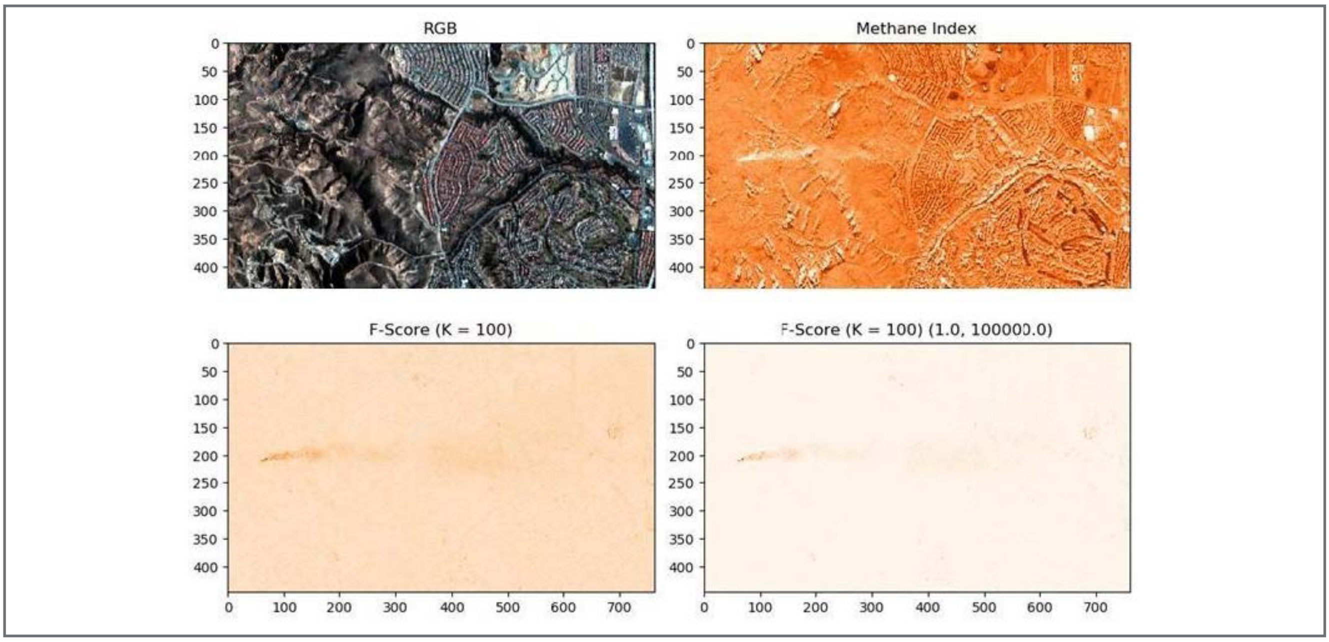

Figure 2: OSK Analysis of NASA Aviris Data over Aliso Canyon, CA

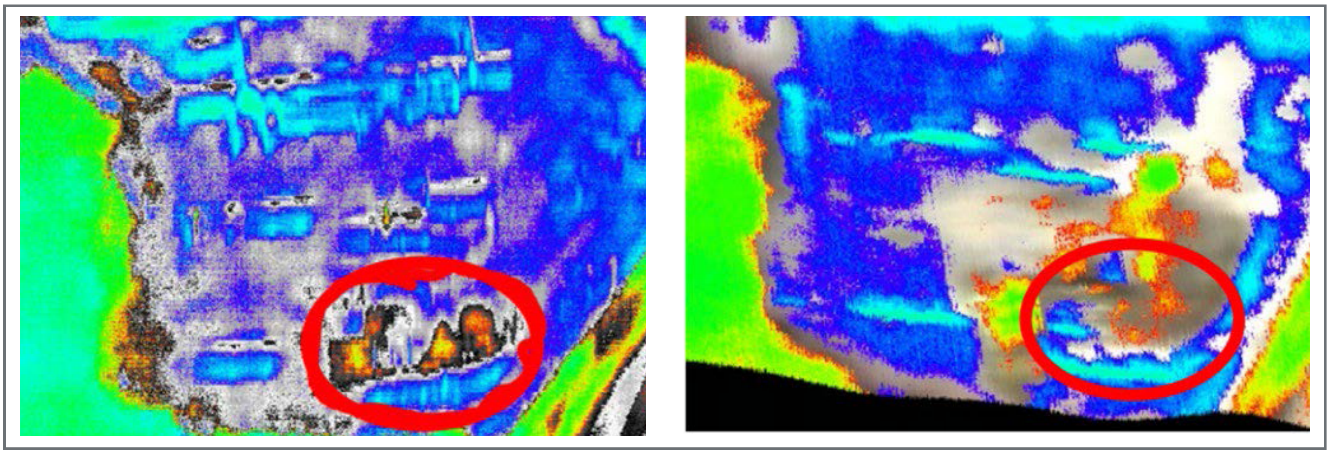

Figure 3: HSI images of Gas Pipeline Manifold Leak

This exercise in finding a natural gas leak illustrates how it is possible to utilize HSI to "tease out" and identify specific features of particular interest, in this case seeking methane signatures. In a similar fashion, OSK is collecting its own HSI in order to objectively analyze pipeline rights of way for detecting any leaked hydrocarbon, soil disturbances and mechanical surface disruptions, new construction, vegetative stresses, and changes over time.

Once a suite of hyperspectral data is collected, calibrated and georectified, the next challenge is analysing the HSI for specific features of interest contained within the data. A profound difficulty has persisted in efficiently generating any sort of a cohesive solution due to the sheer size of the data cubes themselves. Most commercial data systems were not designed to ingest, let alone process, such large-volume, multi-dimensional HSI data cubes. Attempting to process such data without suitable tools will result, at best, in unacceptably long processing times; at worst the data will end up in storage and never analyzed. To address the challenge of such a burden, successful hyperspectral analysis systems will demand that data systems are engineered from the ground up with such heavy demands in mind. At OSK, the company's SIGMA will be the environment through which customers access analytic tools to generate new insights in their data, beyond the initial requirements.

3. Results & Discussion

Between mid-2018 and early 2021, OSK conducted pilot programs using its own proprietary first generation (Gen I) imaging equipment on various platforms, including small aircraft, a small UAV, and with its Hyperspectral Earth Imaging System Trial ("HEIST"), an orbiting satellite unit deployed on the International Space Station. At the same time, two additional ground-based Gen. II sensors were being employed on small aircraft to accelerate the development of analytical tools and automation for rapid hyperspectral data ingestion and tailored analysis once on orbit. And now entering mid-2023, the first data collections from GHOSt are being downlinked from the satellites and analyzed as this paper goes to print.

3.1 Underground Natural Gas Leak – Gen I

In an early, routine aerial patrol over a 100 mile underground natural gas pipeline, a significant soil anomaly was identified at a regularly patrolled manifold, depicted in Figure 3 showing, to the left, a hyperspectral presentation of the soil anomaly. Note the area encircled in red evidencing a clear soil disturbance potentially caused by - and indirectly indicating - a hydrocarbon leak. Further investigation confirmed a small half-inch corrosion leak at this location on a ten-inch pipeline buried one meter below grade.In the image to the right, we see HSI of the same area collected soon after excavation and repair work were completed. Of note is the evidence of construction activity readily apparent within the AOI.

3.2 Matched Filter Target Detection – Gen II

Shoring up OSK's analytics to detect specific targets, rather than express anomalous points in a report, the company designed a series of Matched Filters for specific target identification. In the examples below, a methane plume was detected along a pipeline, shown in Figures 4. And shown in Figure 5 is an area of

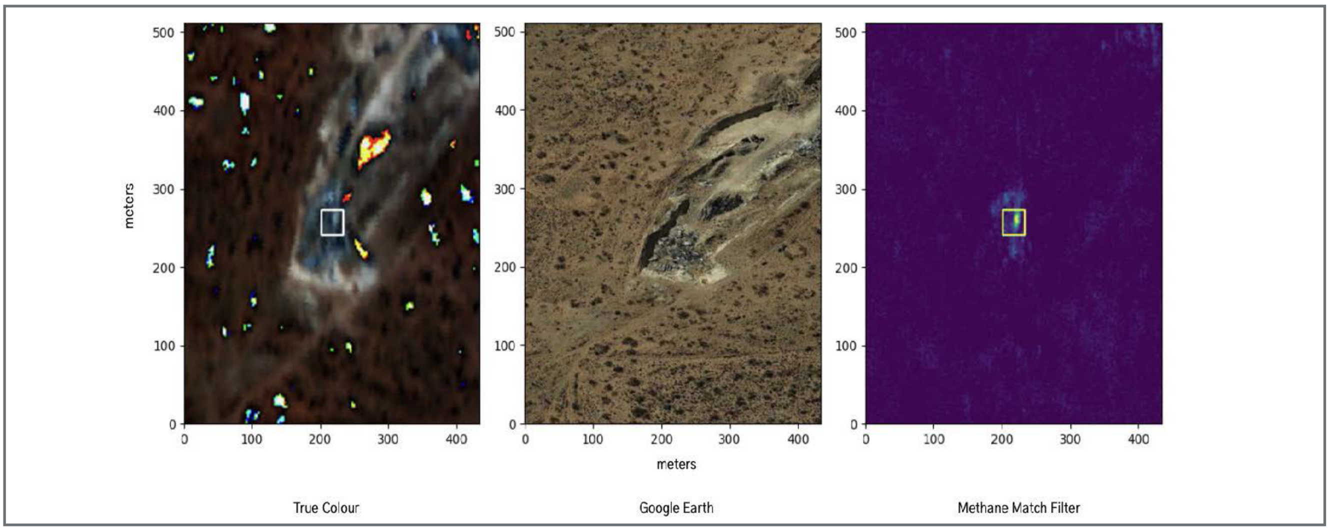

Figure 4: A Detection of Methane Leaking along an Operator Asset. This figure shows our data in the True Colour Image, Google Earth imagery for Scene Context, and the Detection Map of the Methane Matched Filter.

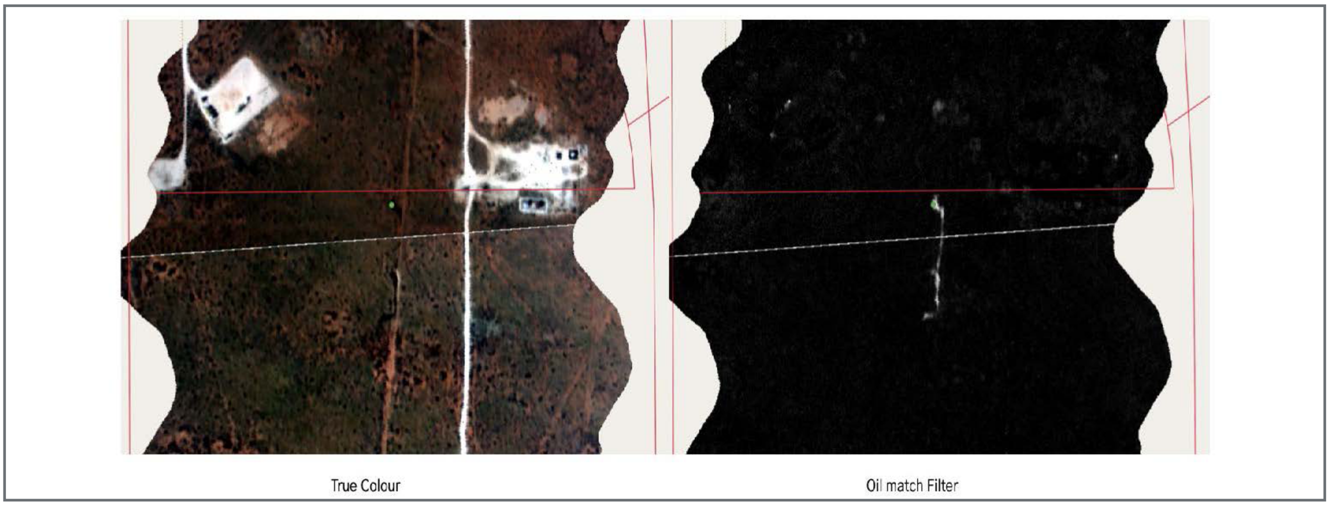

Figure 5: A detection of Hydrocarbon in the soil spilled along an Operator Asset. This figure shows our data in the True Colour Image, Google Earth Imagery for Scene Context, and the Detection Map of0 the Oil Matched Filter.

contaminated soils that was identified near a pipeline right of way (ROW). Each of these examples detect the target of interest with low rates of false alarms.

3.3 Pipeline Patrol Vehicle Detection – Gen II

In this third example of field confirmation of automated analytical techniques to extract information from hyperspectral data cubes, we were seeking the presence of vehicle activity along a pipeline right of way and detached from known public roadways, parking areas or vehicle staging locations. Figure 6 again includes two frames of hyperspectral imagery, on the left an RGB presentation and on the right with a vehicle match filter and an overlaid pipeline shapefile.

In the case of vehicles more than with vapor emissions or oil leaks, we can visually identify individual vehicles in the RGB image. Some of these vehicles are, unsurprisingly and without concern, along a public roadway, while there is a small cluster of vehicles parked away from the roadway and adjacent to a pipeline ROW. Using a vehicle match filter, combined with a digital geofence to exclude locations where such findings need not be reported, the frame on the right isolates only those vehicles that could reasonably be considered a threat to the pipeline operator.

While the priority interest of the authors at present is in harnessing HSI technology to identify oil spills and threats to oil and gas infrastructure, as shown above, extensive development work continues to both continually improve the intelligence used for energy infrastructure detection priorities as well as to build capabilities to employ this technology in the areas of

Figure 6: Aerial Detections of vehicles identified along a Pipeline Right of Way. This Detection has used Geofencing to automatically exclude vehicles traveling a public Roadway.

mining and agriculture.

3.4 Spectral Library Development

The examples presented above demonstrate the utility of HSI technology from multiple platforms for midstream asset surveillance. Commercial success of hyperspectral monitoring will ultimately require the robust ability to gather data on demand and rapidly process the resulting information to identify, with confidence, critical anomalies with a manageable level of false positive findings and minimum of false negatives. With these aerial deployments, and now accelerating with OSK's first three GHOSt satellites in orbit, development of an increasingly robust library of applicable spectral profiles is a priority, including both liquid contaminants, aboveground vapor plumes and a robust yet targeted expansion of analytical capabilities. Results from one of the very first spectral profile development exercises within OSK is depicted in Figure 7.

Here, imagery was collected over garden soil and beach sand samples in a parking lot, captured by drone. These respective soil media were contaminated with known quantities of hydrocarbon (motor oil). The resulting profiles, collected by handheld spectrometer, demonstrate both how increased quantities of contaminants reduce reflectance values consistently across the entire curve, and that introduction of a motor oil introduces a characteristic feature at both 1750 nm and 2350 nm regardless of the underlying soil medium. As to be expected, the prominence of the spectral feature is correlated to the strength or concentration of the contaminant.

As this work continued into 2023 with aerial platforms and now GHOSt, a clearer understanding of detection thresholds and wind effects using latest generation satellite data has been established, enabling rapid integration of GHOSt data into SIGMA analytical. Similar testing is ongoing for a variety of liquid and vapor hydrocarbon and chemical materials, both above and below-ground.

3.5 Preliminary GHOSt Results: Methane Detection in the Permian Basin

The first data to be downlinked from the constellation was over an oil-producing segment of the state of Utah during June 2023. The strip of hyperspectral imagery shown in Figure 8, transposed over high resolution Google Earth imagery, illustrates GHOSt's 8m pixel and effectiveness for identifying feature locations. Within another day or so, the first batch of analytic findings from a GHOSt data set was isolated from a strip of data gathered over central Texas in the eastern range of the Permian oil basin. These findings were most prominently of methane plumes over oil-producing infrastructure.

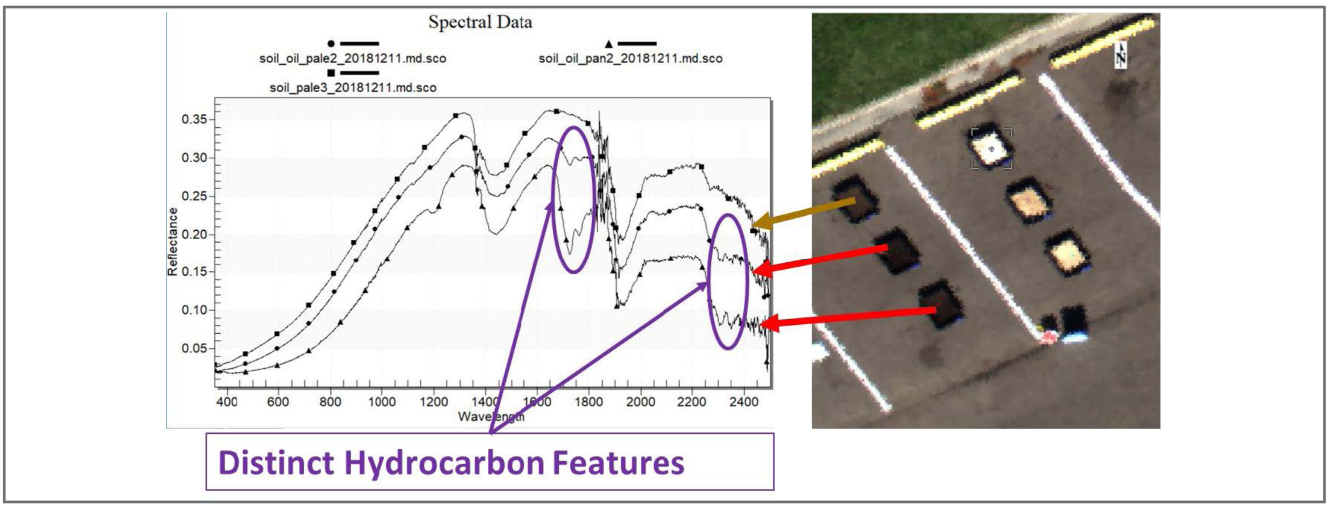

Figure 7: Imagery for developing Spectral Profiles

OSK's first early-stage plume detections have each been estimated in the 200-500 kg/hr range. As additional data and imagery have been collected, and post-processing refinements implemented, observations of targeted anomalies have been further integrated with publicly available high-resolution imagery to improve optical quality of reporting for user convenience. The

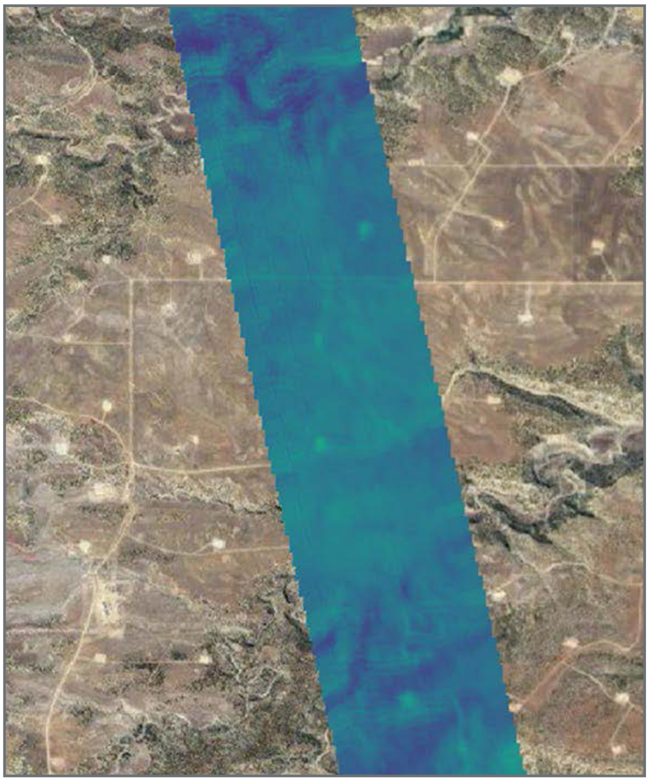

Figure 8: First downlinked Ghost Satellite image, over Utah, United States.

first such examples of this enhanced methane detection reporting are shown in Figure 9.

Ultimately, the path forward is to ensure that operators have the benefit of having such actionable intelligence, in hand in a usable format and in a timely manner. For standardized reporting industry professionals have offered a consensus that 24 hours from collection to reporting would be excellent. For pronounced features, such as large new releases or spills, reporting within the current shift cycle (4-hours or less) will prove exceedingly valuable. OSK is seeking to achieve these standards in delivering results through its SIGMA platform.

3.6 Client Interface – SIGMA

The discussion thus far has focused first on data collection, followed by the process for rapid imagery analysis. The critical third component for a commercially

Figure 9: Enhanced reporting of detected CH_4 Features

compelling hyperspectral analysis tool is the presentation of findings to the end user in a functional format. Are the results of the data collection ultimately conveyed as raw data or as layers of imagery? Or is it fully digested and actionable intelligence? Does such information reach the user via a push notification system, even including real-time notices directly from the satellite to a client representative? Is it an on-line reporting tool with analyzed imagery? Does it flag every anomaly? Does it include changes between the latest dataset and prior collections?

Deficiencies, or, more accurately, a pure absence, in this final layer - the Application layer - has proven to be a critical obstruction limiting the widespread appeal adoption of HSI data and analysis. cubes. Until recently, HSI was the domain of large governments only; it was not viable for the commercial sector. As such, there has remained a dearth of applications able to support the analyst in data interpretation. HSI data is rich, but only useful if mined effectively. SK has attempted to solve this problem of analytical reporting through its SIGMA-Monitor™ tool. This user

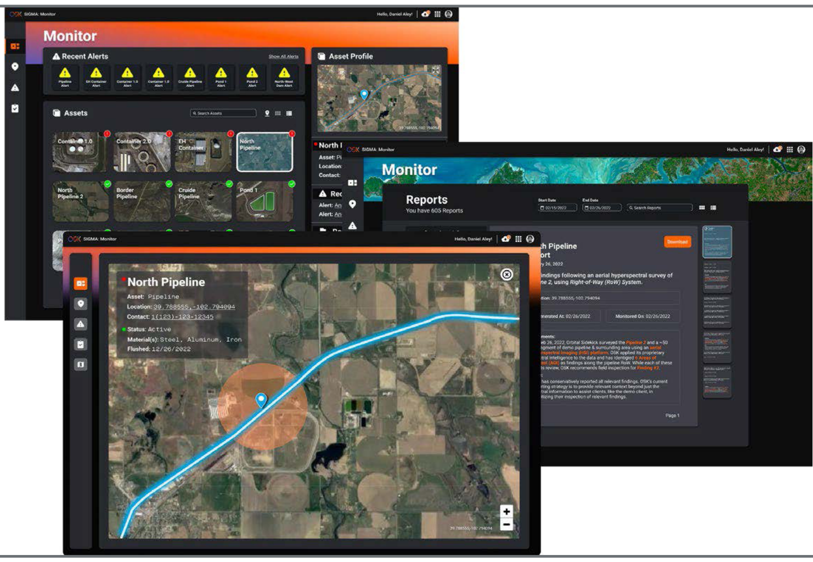

Figure 10: Commercial report of HSI Findings via On-Line SIGMA-Monitor Platform

interface allows users to not only access their imagery, but quickly isolate the individual anomaly reports (or "calls), and feature mapping, as well as to add and review remarks on each call, including validation, explanation, and eventual resolution.

Ensuring that newly accessible satellite-based information streams are made usable to the market will be as important, if not more important, than the underlying technology. Today, findings of anomalies along client rights-of-way are being graphically depicted and reported to operators as they are identified. Figure 10 depicts a screen from SIGMA.

4. Conclusion

In conducting this work to provide actionable insights for oil and gas assets, satellite resources are just a means to an end, which is having access to high resolution HSI over any asset on the globe. Satellites are generally considered the favored platform for obtaining HSI for the simple reason of persistent scalability. But depending upon the application, any method for obtaining suitable imagery is appropriate.

OSK is one company of a growing number that seek to provide improved intelligent solutions for compliance, leak prevention and detection including remote product speciation. The robust imaging technologies we are deploying by satellite and other aerial platforms have been proven in theory and they are finally, after decades of distant promises, being deployed at scale for cost effective, commercial application.

The future holds great promise in this field of imaging for oil and gas. Safer and more environmentally conservative energy production will be the result once the full promise of tailored HSI collection, analysis and reporting is brought to bear on the market.

References

1. Moore's Law refers to Moore's theory, formulated by Intel co-founder Gordon Moore in 1965, that the number of transistors on a microchip doubles every two years, though the cost of computers is halved. Moore's Law states that we can expect the speed and capability of our computers to increase every couple of years, and we will pay less for them. Another tenet of Moore's Law asserts that this growth is exponential. At present, the doubling of installed transistors on silicon chips occurs closer to every 18 months instead of every two years, though some experts assert that computers should reach the physical limits of Moore's Law at some point later in the 2020s.
2. https://www.usgs.gov/labs/spec-lab/capabilities/spectral-library
3. https://earthobservatory.nasa.gov/features/EO1Tenth/page3.php
4. https://aviris.jpl.nasa.gov/

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Pipeline 3D-Positioning at river crossing: Long-Range Magnetic Mapping via Unmanned Aerial System (UAS)

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Abstract

Pipeline networks traverse modern societies' national territories and can be located in areas difficult to access, such as river crossings, making maintenance logistically challenging and potentially dangerous for field personnel. In order to resolve this problem, Skipper NDT has developed an unmanned aerial system (UAS) for magnetic mapping which allows, firstly, quick data acquisition with less than 30 minutes of flight time per 100 m of river inspection. Secondly, an automated survey without putting field personnel at safety risk.

The performance was tested under real field conditions with the collaboration of the incumbent French Gas operator. This paper is based on 3 cases from 160 to 220 m river crossings with a maximum depth of 12 m from water surface. The result shows a strong correlation with existing information while enhancing data quality and reliability. In particular, a 3D model of the river crossing features using QGIS software was made.

1. Introduction

Locations where pipelines cross rivers require special attention to ensure continued safe operation without leakage that can pollute water supplies on which local communities, livestock, and wildlife depend. For this reason, it is especially important for pipeline inspections in these locations. However, Recurrent safety monitoring operations entail the deployment of divers with accompanying operational risks and constraints. In addition, most of the tools available are inefficient due to the presence of water. In particular, traditional Ground Penetrating Radars (GPR) are not applicable.

There are generally two different designs for a pipeline to cross a waterbody. The open-cut crossing method involves excavating a trench across the bottom of the river or depending on the depth of the water, the construction equipment may have to be placed on floating platforms to complete the excavation of the pipe trench. The Horizontal Directional Drilling (HDD) method involves drilling a hole under the waterbody and installing a prefabricated segment of pipe through the hole.

Once installed these pipelines must be inspected and monitored. Many operators are implementing programs to survey their water crossings every 5 to 10 years to determine the depth of cover, to identify water crossings prone to erosion and geometry changes, to detect pipeline leaks, and to assess bending strain using in-line inspection tools [1].

In more extreme circumstances, flooding can wash away a portion of a riverbed leaving a pipeline exposed and susceptible to damage, sometimes called scouring. In the US for example, regulators require pipeline operators to address any conditions, including flooding and a lack of depth of cover, that may adversely impact the safe operation of the pipeline according to the Code of Federal Regulations Title 49 part 195.401(b), 195.452, and 195.412(b), which require operators to inspect pipeline facilities within 72 hours of an extreme weather event such as flooding [2].

Sometimes buried under sediment layers and several feet of water column, these structures may be challenging to survey. Skipper NDT has developed a method for accurately mapping pipelines remotely using UAS – without being in contact with the pipeline or interfering with the flow rate. The method relies on the measurement of the total magnetic intensity above the pipeline right-of-way to encompass its magnetic signature [3]. This procedure turns out to be particularly useful at river crossings to reduce operational risks and help to ensure pipeline reliability, energy deliverability, public safety, and environmental protection.

2. Material, Protocol and Mission

The hardware developed by the Skipper NDT team consists of a payload weighing between 2.2 and 4.2 kg (4.85 and 9.2 lbs) depending on the drone vector capacity. In terms of width, the payload is between 90, and 160 cm (35,4" and 63") which can be mounted under various types of UAS (Figure 1). The main components are the same and comprise: 1) three to four three-component fluxgate magnetometers; 2) a real-time global navigation satellite system GNSS receiver with a centimetric-level precision; 3) a tactical grade Inertial Measurement Unit (IMU); 4) a remote sensor for measuring the distance between the magnetometers and the ground (or canopy) and 5) a proprietary electronic card for data acquisition, digitalization, and synchronization.

The main sensors in this system are the magnetometers and the GNSS, upon which the acquisition of the magnetic map depends. The fluxgate magnetometers are light, 112 g (4 ounces) per unit, and robust sensors that measure the three components of the magnetic field at a 2000 Hz sample frequency. Even if they are considered lower resolution/precision than other magnetometry technologies, they can be calibrated easily before each acquisition, and they are adaptable to neighboring equipment through a compensation process [4].

Light payload UAS imposes stringent constraints on GNSS hardware in terms of weight, precision, and logistics. Real-Time Kinematic (RTK) protocol with a base and a lightweight rover would have been the natural solution but the use of a base complicates the logistics considering theft risks. A 606-g multi-frequency and multi-GNSS receiver was chosen for real-time precise point positioning (PPP) correction services. Corrections ensure positioning accuracies down to ± 4 cm (1.5") at 95% root-mean-square worldwide

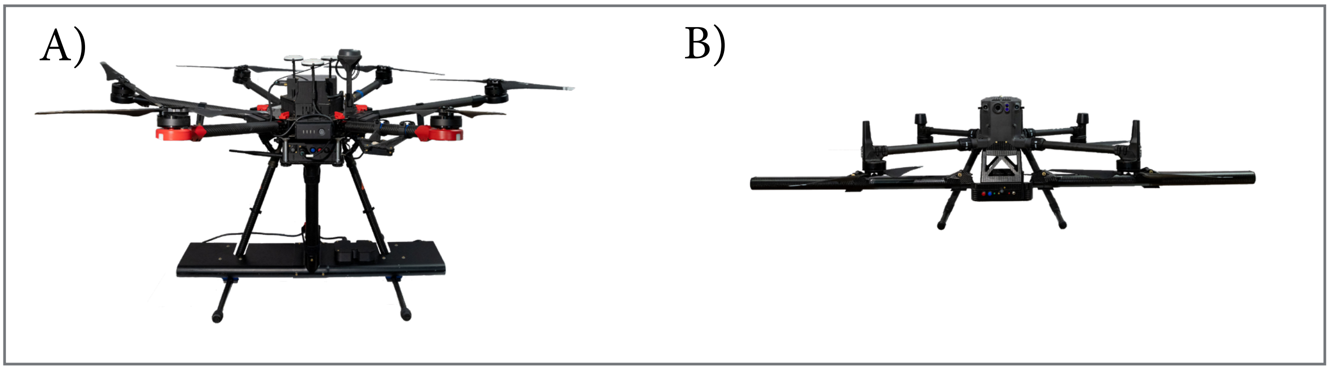

Figure 1: Skipper NDT's embedded system mounted under an off-the-shelf UAS. A) The 4.2kg and 90cm payload. B) The 2.2 kg and 160cm payload.

(between −75° and + 75° latitude) without operational difficulties. This real-time PPP is supported by a post-processed kinematic (PPK) differential correction (by recovering the satellite's ephemeris at day+1) using a permanent base to enhance positioning when signal reception is challenged, for example, near trees or other masks [5].

Other components of the Skipper NDT system serve mainly a corrective purpose. Indeed, flying equipment requires supplementary corrections such as level control and telemetric measurements. A combination of ultrasonic and Lidar measurements is used to evaluate the distance between the magnetometers and the ground or canopy and then infer the depth of cover (depth of the pipeline below ground surface). In this case, the ground corresponds to the surface of the water which makes a distinct water/air interface for the sensors. Thus, we have access only to the depth below the water surface, and a bathymetric survey is necessary to complement the results.

A bathymetric survey is a type of hydrographic survey that maps the details of underwater terrain, illustrating the depth of water and mapping the land that lies beneath the water. Traditionally, bathymetric surveys are conducted using an echo sounder attached to a survey boat or uncrewed vessel, remotely controlled or autonomous – preferably used in surveys of inland waters (rivers, reservoirs, etc.), as in the three case studies discussed in this paper. As the boat moves across the water, the echo sounder generates electrical signals, which are converted into sound waves by an underwater transducer. Soundwaves will bounce off features under the water and this echo is then identified by the echo sounder and the distance to the identified feature is calculated. Bathymetric survey systems rely on highly accurate GNSS systems to link each measured distance to a particular depth on the surveying map. The next stage in a bathymetric survey consists of transforming the data captured from the boat into an elevation model [6].

As part of the “Multi-fluide” decree, GRTgaz is required by the DREAL (the Regional Directorate for Environment, Development and Housing) to inspect its network at waterbody crossings at least every 10 years. The purpose of this study is therefore to identify the areas sensitive to river events that may represent a danger for the gas pipeline in an area of 100 m on either side of the crossing. To this end, detection and a detailed topographic survey are carried out in order to assess:

- The existence or absence of an anomaly (low sediment load).
- The evolution of the sediment load on the pipeline.

A complete inventory of the crossing and its environment is carried out in order to predetermine the geomorphological evolutions of the study area. In accordance with Health, Safety, and Environment requirements, a preliminary visit and a hydrological visit were carried out under La Seine and La Loire rivers with three case studies from 160 to 220 m (525 to 722 ft) river crossings with a maximum of 12 m (39 ft) depth below water surface.

3. Case Study DN900 and quantitative comparison

Two river crossings were done on La Loire river with a 200 m and 220 m (656 to 722 ft) long inspection with a maximum of 3 m and 5 m (10 and 16 ft) water depth, respectively. The river crossing considered for this case

Name of the parameters	Values
Pipeline's Nominal diameter	900 mm / 35 in
UAS model	DJI M600 Pro
Acquisition frequency	2000 Hz
Inspected distance	110 m / 361 ft
Average velocity	7.2 km/h / 4.5 mph
Flight time	37 min
Flight height	1 m / 3.3 ft
Current injection characteristics	0.87 A / 49 V

Table 1: Automatic UAS Inspection parameters on the 900-mm (35") diameter pipeline.

study is the deepest one, performed on La Seine river with a total distance of 160 m (525 ft) from shore to shore with an average 9 m (29 ft) water column. The corresponding pipeline is an X42 grade steel, 900 mm (35") nominal diameter pipeline, installed in 2000 with a double polyethylene coating.

A current injection was necessary with the characteristics described in Table.1. The electrical connection was done 600 m (0.3 miles) away from the inspection area at a test point.

The multibeam bathymetry analysis of the riverbed (Figure 2A) shows topographical irregularities above the pipeline trajectory that are most certainly due to the embankment after the pipe-laying. The main composition of the riverbed is alluvium of clay and sand. The total magnetic intensity map in Figure 2B focuses on the injected current in the pipeline. The maximum field value recorded does not exceed 22 nanoTesla. It can be explained by the distance from the source (13 m / 42 ft) and the potentially higher dispersion of current to the ground considering the high conductivity of the neighboring humid soil.

The total magnetic intensity, resulting from the current injection in the pipeline, allows to clearly distinguish the associated magnetic anomaly described by the Biot-Savart law [7]. A 2D-inversion of the magnetic map along the pipeline with a spacing of 50 cm (19.6") leads to a 3D positioning of the source and allows an elevation profile to be established in Figure 3.

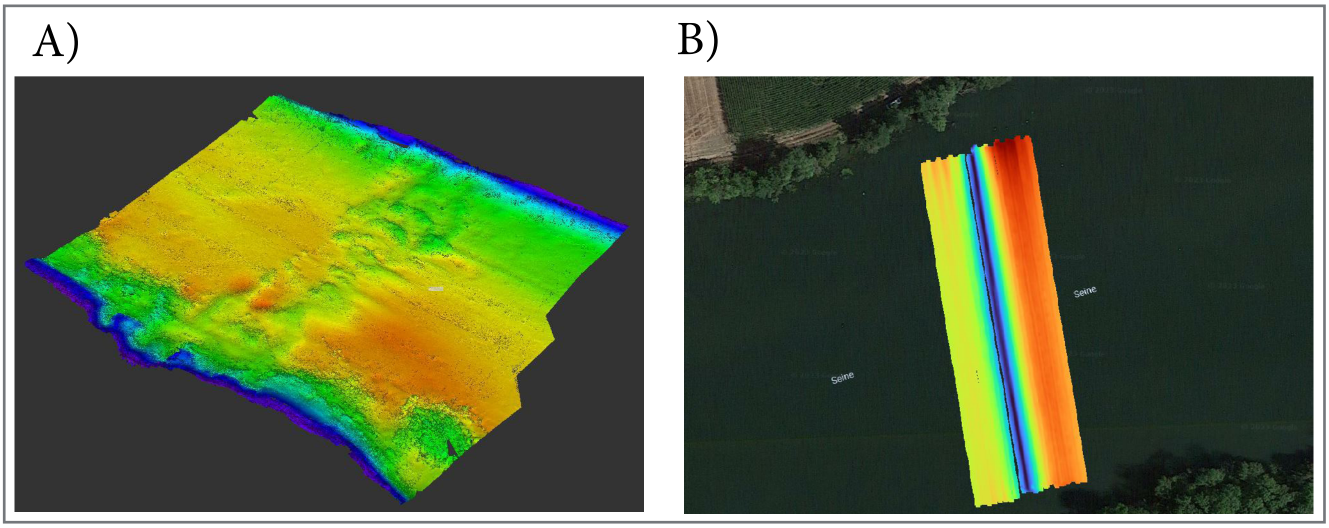

Figure 2: A) Digital Terrain Model based on multibeam bathymetry survey; color scale goes from 7.1 m / 23 ft (blue) to 16.7 m / 52.4 ft (red) above mean sea level. B) Total magnetic intensity of the injected current of the pipeline right-of-way; color scale goes from 0 nT (blue) to 21.8 (red) nT.

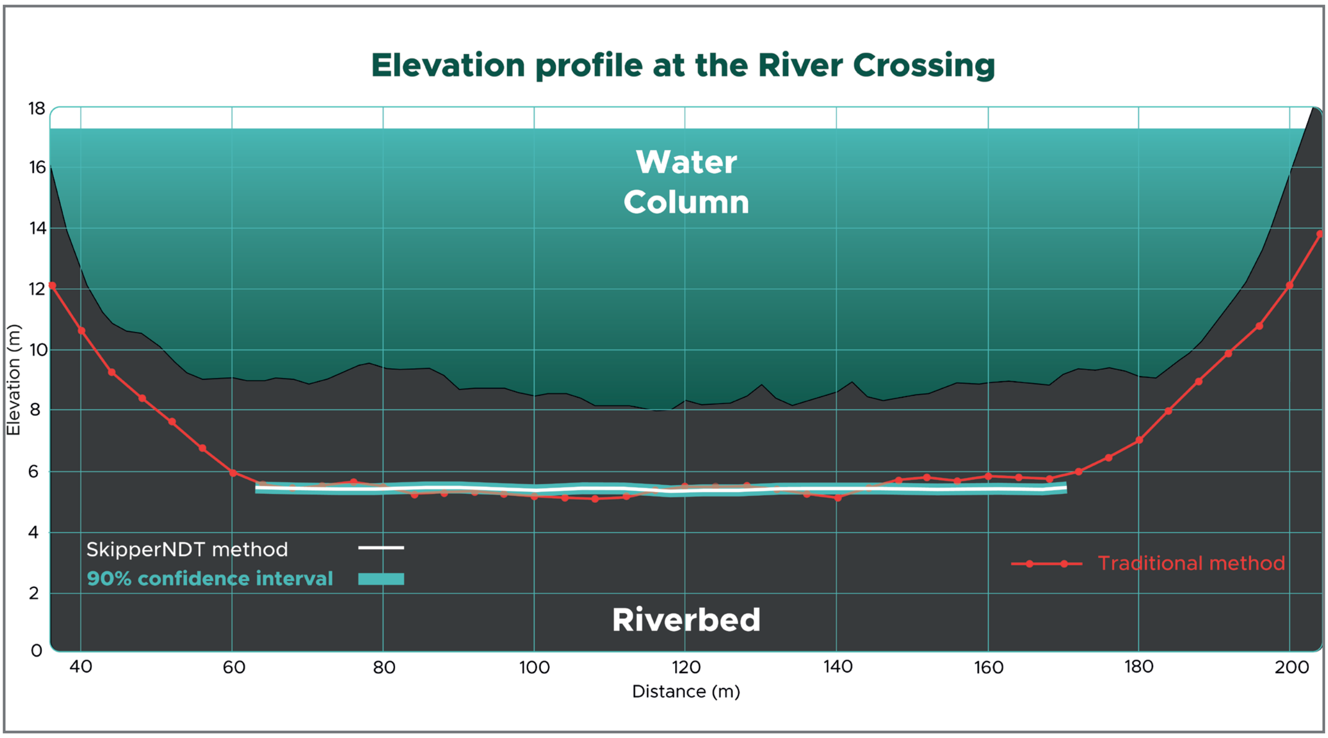

Figure 3: Elevation profile of the 900-mm (35") diameter pipeline at the river crossing, comparing results from the traditional method and from Skipper NDT magnetic mapping.

The so-called traditional method used here requires the intervention of a diver and a team of 3 to 4 people to assess the depth of cover. Using a submersible double depth antenna [8] that communicates the depth results to a ground base team on the river bank, the diver moves at the bottom of the water body detecting the buried line and measuring its depth at a spatial frequency of 2 to 4 m (6.5 to 13.1 ft). Since no positioning system records the trajectory of the equipment during the acquisition, the pipeline is assumed to be straight from one side to the other. The origin of the x-axis corresponds to a pipeline marker on the west bank. At 110 m (361 ft) away from the origin we can evaluate a 9 m (29.5 ft) water column and a 2.9 m (6.5 ft) depth below the riverbed. The total range from the UAS to the centerline of the pipe is 13.4 m (42.6 ft).

The magnetic mapping accuracy and precision were established in our previous papers [9]. An average accuracy of 15 cm and 27 cm for the 90% (5.9" and 10.6") confidence interval, represented by white and light blue lines in Figure 3. According to the specifications, the accuracy of the submersible double depth antenna, used for the traditional method, depends on the depth and corresponds to 15 cm (5.9") on average in this case. Since acquisitions are done by hand by divers on the riverbed, the measurement chain must include an important part of measurement biases that will impact the final accuracy contrary to the automatic UAS acquisition.

Indeed, results of both types of measurement converge around the same average pipe elevation, 5.40 m (17.71 ft) for the traditional method and 5.39 m (17.68 ft) for the magnetic mapping. However, the precision of the results is significantly higher for the Skipper NDT method, with a 3 cm (1.2") standard deviation compared to the 22 cm (8.7") standard deviation for the traditional method. The use of an automated and repeatable method had a significant impact on the precision, being seven times more precise, without depreciating the accuracy levels. An actual 3D-geolocalization of the pipeline, rather than a depth of cover assessment, adds valuable information about planimetric variations. The assumption of a straight pipeline between a riverbank to another is no longer relevant considering the Out-Of-Straightness assessment (OOS). OOS assessment characterizes the linear variation of the pipeline with respect to a theoretical straight line connecting the two ends of the section considered.

Figure 4 shows a deflection of the pipeline that invalidates the straight-line assumption made for traditional methods. At maximum, around 60 m (196 ft)

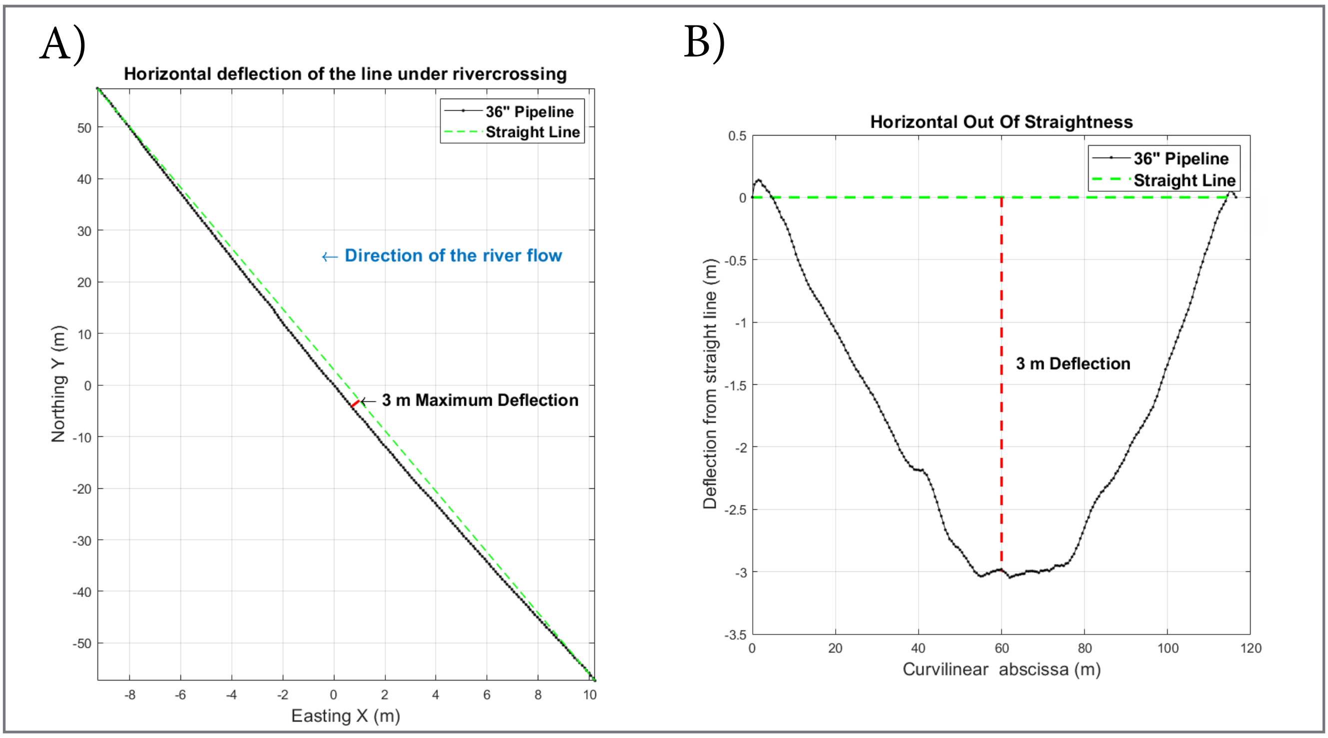

Figure 3: Elevation profile of the 900-mm (35") diameter pipeline at the river crossing, comparing results from the traditional method and from Skipper NDT magnetic mapping.

along the curvilinear abscissa, the pipeline trajectory is offset by 3 m (9.8 ft) over the 116-m (380.5 ft) length of the inspection. This curvature seems colinear to the river flow and in the same direction. However, no conclusions can be made regarding the cause of this geometry since the pipeline could have been installed with this OOS. A comparison with the as-built drawing is necessary to establish whether the OOS existed at the time of installation.

4. 3D Model using Qgis2threejs Plugin

The 3D geolocation generated by Skipper NDT coupled with the bathymetry survey is the basis of an accurate and to-scale 3D representation of the pipeline river crossing. The 3D representation makes it possible to obtain a more intuitive visualization of the data for the operator in order to understand better the characteristics of interest in the structure. In order to facilitate

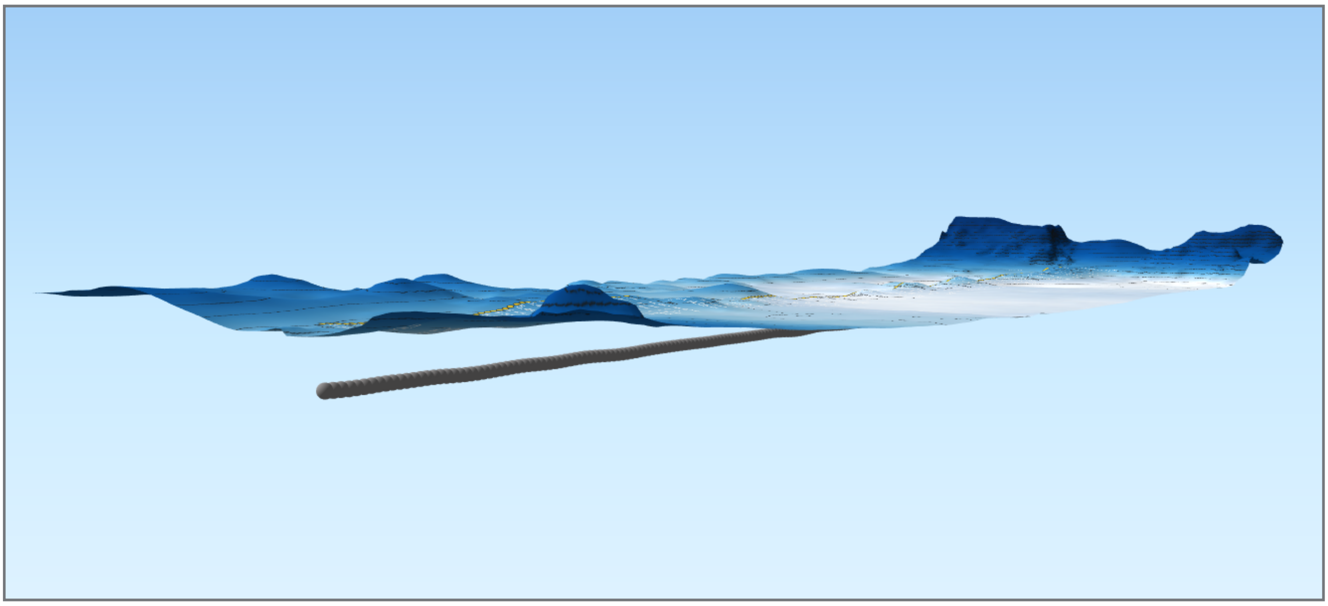

Figure 5: Three-dimensional model showing the pipeline and riverbed using Qgis2threejs plugin.

its visualization, the interactive 3D model can be displayed on a web browser with an HTML file. It can also be managed, in a more complete way, on dedicated GIS software (QGIS, ArcGIS, etc.) equipped with the qgis2threejs extension [10].

5. Discussion

Results obtained on the 900mm diameter pipeline are representative of the other two inspections on La Loire river which have a lower depth below the water surface, between 3 and 5 m (9.8 and 16.4 ft). The case study inspection illustrates the longest range the Skipper NDT technology has encountered to date, with a total distance of 13.4 m (42.6 ft) from the sensors to the pipe's centerline. However, it does not represent a maximum range for the technology. In the appropriate conditions, a measured magnetic signal greater than 15 nT, and enough width on the right-of-way, 2.2 times the average pipe to sensors distance, the technology has an unlimited range.

The tendency for inspected pipelines to present a bow, from 50 cm (19.6") over 200 m (656 ft) up to 3 m (9.8 ft) over 110 m (361 ft) in the case study, in the same direction as the river flow is a phenomenon that needs to be investigated. There are mainly two possible answers to explain this geometry. Either it is a progressive change of geometry due to the river flow, which could require a bending strain assessment and a potential stress relief if above a certain threshold, or a misalignment during the installation of the pipeline.

In both cases, the utility of monitoring precisely the orientation changes in planimetry at the river crossings seems fundamental in this changing environment since it does not imply any operational complications.

6. Conclusion

In summary, magnetic mapping technologies carried out by UAS add significant value to pipeline surveys and monitoring, especially in the case of river crossings. Indeed, this type of inspection entails significant logistical constraints and carries potential physical risks for field operators. In terms of material functioning, Skipper NDT can accommodate harsher operational conditions in terms of GPS coverage and magnetic environment, correction systems have been implemented to overcome GNSS coverage, with PPK solutions, or interference problems with advanced filtering for example.

Compared to the traditional methods considered here, this innovative method seems more efficient and reliable during the acquisition process. Large areas can be mapped rapidly, less than 30 minutes per 100 m (328 ft) of water crossing, with a highly repeatable and reproducible process allowing reliable monitoring of the line over time. Most importantly, this fully automated method enhances the operator's safety, since it can be carried out by one person operating the UAS from the riverbank, without the involvement of divers. The inspection is carried out remotely without contacting the pipeline or interfering with the flow inside the pipeline. It can also be deployed rapidly to respond to potential integrity threats on the structure resulting from extreme weather conditions or external factors.

The precision and high density of the output positioning already showed interesting results in terms of OOS. The natural next step would be to evaluate the capabilities of this technology for bending strain assessments in landslide conditions and profit from the advantage that a remote survey can provide.

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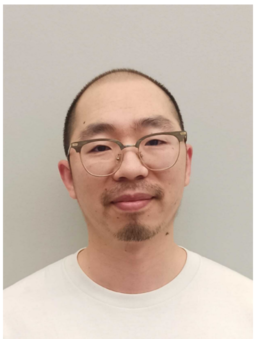

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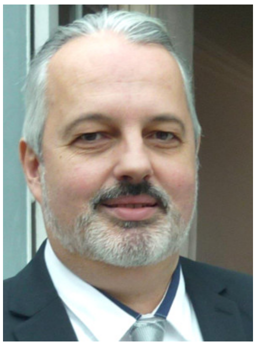

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Ask the Experts

Remote Sensing

Q1) What kind of data can be collected during remote monitoring and what information can be derived from this data?

Multiple types of data are collected. The most important data types to not list them all are:

Hyperspectral data: Information used to detect liquid or gaseous hydrocarbons on the ground and vegetation status.

Positioning data: High accuracy positioning and navigation information used to create visible or hyperspectral mosaics at high resolution and high precision down to a few centimeters to locate leaks, threats or geological data.

Visible images: High resolution imagery froorm a conventional RGB camera made for aerial surveys to detect threats and anomalies like missing markers or exposed pipes.

Q2) What are the key remote sensing technologies commonly used for detecting leaks in oil and gas pipelines, and how do they differ in terms of principle and application?

Typically, remote sensing divides in two categories: active and passive. Active systems use a light source (normally a laser, of which there are many types) to perform detection of specific molecules, whereas passive systems use an external power source (e.g. the Sun) and collect hyperspectral or multispectral data on which detection algorithms are applied.

Detecting leaks in oil and gas pipeline automatically is not a commonly adopted technology. Flyscan is a pioneer in this type of capabilityies for liquid pipelines and is pushing to have it adopted by operators considering its accuracy, robustness and sensitivity for crude oil and refined products. The technologies used by Flyscan are Short Wave Infra-Red Hyperspectral Push-Broom cameras for raw data acquisition, and Ultraviolet Raman Resonance for benzene detection, using a patented and proprietary UV laser active system with very high sensitivity (in ppb-m for benzene). For natural gas pipelines, active systems use infrared lasers.

Other technologies that are widely used are CPM (Computed Pipeline Monitoring, for larger leaks), fiber optic cables, acoustic sensors, floating sensors, or handheld gas detectors. Satellites can also be used for macroscopic leaks, for example using hyperspectral data. All those systems have their pros and cons and are complementary. Using them as a “system of systems” makes pipelines safe.

Q3) In terms of data analytics, how can machine learning algorithms be applied to remote sensing data to enhance the detection accuracy of pipeline leaks and reduce false positives?

Machine learning has been used for many years in remote sensing. It usually consists of training a model like a CNN (convolutive Neural Network) or other types on imagery of the targets of interest in various conditions. The model then uses a series of linear operation to highlight the targets of interest. It is also widely used for image segmentation like detecting cars on images.

Flyscan leverages the power of machine learning on multiple products including threat detection and oil and gas detection. The threat detection machine learning algorithm can identify targets in images in a wide variety of object classess like heavy machinery trucks and help find un-authorized activity on the right of way. Hyperspectral machine learning algorithms help to discriminate between different types of hydrocarbons and also including plastics which are a common interferent for oil and gas detection.

These models take account of the contextual information meaning the images of the target but also what is around them.

Q4) Considering the need for timely response to pipeline leaks, how can remote sensing data be effectively integrated into emergency response protocols to ensure swift actions to mitigate environmental and safety risks?

Remote sensing data can be integrated in emergency response protocols by delivering high quality low latency actionable insights like position of a detected spill for example to allow for precise allocation of resources.

Flyscan also offers context like spill size, location and the level of contamination to help operators react quickly to these alerts. A robust notification system is also in place to signal spills. Our systems are either real-time or quasi-real-time, allowing for a fast response after natural disasters or spills. In addition, remote sensing data can be used to ensure clean up after an event has been successful by documenting the condition of the area and multiple follow ups give the ability to track restoration progress.

Q5) In what ways can cloud cover and extreme weather conditions interfere with remote sensing data acquisition, and what strategies are employed to mitigate these challenges?

Complete cloud cover and extreme weather conditions do not allow for passive remote sensing in the SWIR. In the case of satellites because they can not see through the clouds for certain bands, and in the case of airplane-based hyperspectral because there is not enough power from the sun light.

Partial cloud however can be dealt with using sophisticated algorithms like special filters or scattering compensation to improve signal strength.

Of course, in the case of airplane/helicopter data acquisition, if there is an extreme weather even such as a hurricane, the pilots will not fly, for safety reasons.

The best way to ensure reliable detection of spills is a regular patrol of the right-of-way. Like for medical examinations, routine frequent inspections find anomalies.

This issue's experts

Eric Bergeron, CEO, Flyscan Systems
Eric is the Founder and CEO of Flyscan Systems since 2015. Previously He was Founder and CEO of Optosecurity, which developed, sold, and deployed airport security automation products around the world. The company was acquired by a division of Toyota Industries. Prior to that he worked for start-ups, investment funds and large companies in Quebec, Virginia and The Netherlands. Eric is a senior member of the IEEE, and a member of the Quebec Order of Professional Engineers (P.Eng.). He has a BSc in Engineering Physics from Laval University, a MSc from the University of Quebec, and completed the Entrepreneurship Development Program at the MIT Sloan School of Management.

Alexandre Thibeault, Product Line Manager & Tech Lead, Flyscan Systems
Alexandre leads the design and implementation of hyperspectral systems for hydrocarbon leak detection. This work empowers operators to proactively manage gas, oil, and diesel gas leaks, improving environmental safety. Previous roles involved satellite-based methane detection and the autonomous driving industry. He also worked at CERN, where he participated in antimatter laser cooling research that led to a co-authorship in Nature. He has a B.eng.in electrical engineering from university of Sherbrooke.

With each issue of the journal, the "Ask the Experts" section focuses on a new topic of particular relevance to the pipeline industry. People from the international pipeline community are invited to send in their questions which will afterwards be answered publicly by selected experts from the respective field.

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