HUB TECH IA

Deliverable report 10

AI and IAGEN Application Use Case

Methane Leak Detection in Vaca Muerta, Neuquén, Argentina

I. Introduction

Growing concerns about climate change have highlighted the critical importance of mitigating greenhouse gas emissions, among which methane occupies a prominent place due to its high global warming potential, especially over short time horizons.

The oil and gas industry is an anthropogenic source of methane emissions, released during various stages of hydrocarbon exploration, production, processing, transportation, and distribution. In this context, early and accurate detection of methane leaks has become a pressing need for environmental protection, operational efficiency, and regulatory compliance.

The Vaca Muerta Formation, located in Neuquén Province, Argentina, represents one of the most significant unconventional hydrocarbon reserves in the world. Its vast expanse and growing oil and gas extraction activity, using techniques such as hydraulic fracturing, make the region a focal point for methane emissions monitoring and mitigation. The application of advanced sensing technologies, such as computer vision, offers a promising avenue for addressing this challenge in an automated and efficient manner.

This report aims to provide a comprehensive and professional analysis of the application of computer vision to methane leak detection in Vaca Muerta, complementing and enriching existing information to offer a more complete and authoritative perspective.

II. The Challenge of Methane Emissions in Vaca Muerta

El metano (CH_4) es un gas de efecto invernadero significativamente más potente que el dióxido de carbono (CO_2) en el corto plazo. Durante los primeros 20 años después de su liberación a la atmósfera, el metano tiene un potencial de calentamiento global más de 80 veces superior al del CO_2. Esta característica subraya la urgencia de reducir las emisiones de metano para frenar el ritmo del calentamiento global en las próximas décadas.

The Vaca Muerta Formation, a vast shale formation spanning approximately 30,000 square kilometers in Argentina's Neuquén Basin, hosts significant unconventional oil and gas reserves. Its geology is characterized by organic-rich source rock, making it a prolific source of hydrocarbons.

Hydrocarbon production in Vaca Muerta has experienced exponential growth in recent years, becoming a key driver of Argentina's total oil and gas production. This increase in production has been accompanied by an increase in the number of hydraulic fracturing wells. The scale of the operations and the vast expanse of the formation pose an inherent risk of methane leaks, whether due to equipment failure, operational errors, or infrastructure deficiencies.

Hydrocarbon extraction presents several environmental challenges, including intensive water use, toxic waste management, and concerns about potential seismic activity.

Independent investigations have detected significant levels of methane and volatile organic compound (VOC) emissions using optical gas imaging (OGI) cameras at various fracking, processing, and storage facilities in the region.

These findings suggest that methane emissions in Vaca Muerta are a real problem that requires continued attention and monitoring to ensure responsible and sustainable production.

III. Fundamentals of Computer Vision for Methane Leak Detection

Computer vision is a field of artificial intelligence that seeks to empower machines to "see" and interpret the visual world. It involves the acquisition, processing, and analysis of digital images and videos to extract meaningful information.

In the context of methane leak detection, computer vision is used to analyze images and videos captured by various sensors, with the goal of identifying visual patterns that indicate the presence of a leak.

A key technology in this field is optical gas imaging (OGI). OGI cameras use specialized spectral filters to visualize gases like methane, which are invisible to the naked eye. Methane absorbs energy at specific mid-infrared wavelengths. OGI cameras detect this absorption and visually represent the gas as a cloud or plume, allowing operators to identify the location and extent of the leak. The ability to directly visualize methane leaks provides an intuitive and valuable method for detecting them at oil and gas facilities.

IV. Artificial Intelligence Algorithms in Computer Vision for Methane Detection

Artificial intelligence (AI) plays a fundamental role in automating image and video analysis for methane leak detection. Machine learning algorithms, particularly convolutional neural networks (CNNs), are widely used to process images captured by OGI cameras and detect patterns indicative of methane leaks.

CNNs are deep neural network architectures specifically designed to process grid data, such as images. They are trained using large datasets of labeled images, indicating whether a methane leak is present or not. During the training process, the CNN learns to identify relevant visual features, such as the shape, motion, and intensity of gas plumes, that distinguish a methane leak from other elements in the image.

Specific CNN architectures, such as GasNet, have been developed and optimized for OGI image-based leak detection. The application of AI algorithms, especially CNNs, enables automated and potentially more accurate methane leak detection compared to manual analysis of OGI imagery, reducing reliance on operator judgment. This automation facilitates continuous monitoring and faster detection, which is crucial for timely mitigation.

Additionally, machine learning algorithms can analyze motion in OGI images to improve leak detection. Methane plumes can often appear translucent in OGI images and can be difficult to distinguish from the background. By observing the movement of methane relative to static elements in the image, algorithms can identify leaks with greater confidence.

The Smart LEAK Detection (SLED) system, developed by SwRI, is an example of how machine learning is being applied to merge OGI images with data from other sensors and analyze motion to detect and quantify methane leaks. The use of machine learning improves the reliability of methane detection by differentiating actual leaks from other visual artifacts or movement, leading to a reduction in false alarms.

V. Methane Leak Detection Technologies: A Comparison

Methane leak detection in the oil and gas industry is addressed through a variety of technologies, each with its own advantages and limitations.

- Traditional Methods:
    - Point Sensors: These stationary sensors are installed at specific locations to continuously monitor methane concentrations in the air. They can be highly sensitive at monitoring points, but their spatial coverage is limited, and they may miss leaks that occur between sensors.
    - Portable Leak Analyzers (Sniffers): These are mobile devices used by personnel to manually detect leaks by holding the sensor close to infrastructure components. They are useful for identifying the exact source of a leak at close range, but they are laborious, slow, and can expose operators to safety risks in hazardous areas.
- Advanced Technologies:
    - Optical Gas Imaging (OGI) cameras: These infrared cameras visualize methane leaks in real time, allowing large areas to be scanned from a safe distance. While they are safer for operators and allow for efficient inspection, they are expensive, and their effectiveness can be affected by weather conditions and

temperature differences. Furthermore, manual image analysis requires trained operators.

- Drones (UAVs): Unmanned aerial vehicles equipped with methane sensors (OGI cameras or laser sniffers) perform aerial inspections efficiently. They can cover large, inaccessible areas and provide precise location data using GPS. However, flight duration is limited by battery life, there are regulatory restrictions, and their operation is dependent on weather conditions. Image stabilization can also be a challenge.
- Satellites: Satellite sensors offer global coverage for large-scale methane detection and quantification. They are capable of detecting large emission events, but their spatial resolution is lower than that of drones or ground-based methods, and they may miss smaller leaks. Coverage can also be affected by cloud cover.

Table 1: Comparison of Methane Leak Detection Technologies

Technology	Advantages	Limitations
Point Sensors	Continuous monitoring, high sensitivity at fixed locations	Limited spatial coverage
Portable Analyzers	Mobile devices locate leak sources	Laborious, slow, safety risks for the operator

OGI cameras	Real-time display, large-area scanning, safer operation	Expensive, weather and temperature dependent, require trained operators for manual use
Drones (UAVs)	Coverage of large and inaccessible areas, cost-effective, accurate location data	Flight time limitations, regulatory restrictions, weather-dependent, image stabilization challenges
Satellites	Global coverage, large emissions detection, regional/national inventories	Lower spatial resolution, smaller leaks affected by cloudiness may be missed

The choice of methane leak detection technology depends on the specific needs and context of the application, considering factors such as scale, cost, accessibility, and desired accuracy. Combining multiple technologies can provide a more comprehensive solution.

VI. Application of Computer Vision in Methane Leak Detection in Vaca Muerta

Computer vision has great potential to improve methane leak detection at Vaca Muerta oil and gas operations. Computer vision algorithms can automatically analyze OGI images collected by fixed ground cameras, drones, or even aircraft in the region.

The use of fixed OGI cameras, combined with AI-driven analytics, enables continuous monitoring of facilities. Systems like FLIR ADGILE provide automated, real-time detection and alerts for methane leaks. This continuous monitoring can provide early warnings of leaks, enabling faster response and mitigation, potentially reducing overall emissions and associated risks.

Drones equipped with OGI cameras and AI algorithms offer an efficient solution for inspecting the vast Vaca Muerta region, including wells, pipelines, and other infrastructure. Integrating satellite data with AI can identify potential leak hotspots throughout the region, which can then be investigated in greater detail using drones or ground-based methods. Initiatives such as MethaneSAT and Carbon Mapper are providing valuable data for this purpose. A multi-layered approach, combining satellite surveillance for broad coverage and anomaly detection with drone-based CV-enhanced OGI and ground-based for detailed inspection, offers a robust solution for Vaca Muerta.

Additionally, computer vision can analyze video feeds from surveillance cameras already deployed at oil and gas facilities to detect visual indicators of gas leaks or liquid spills. Companies like Plainsight and Visionify offer AI-powered visual automation suites for the oil and gas industry. Leveraging existing infrastructure by adding AI-powered computer vision capabilities can provide a cost-effective way to improve leak detection without significant investments in new hardware.

VII. Application of IAGEN in Methane Leak Detection

1. Functionality and Scope of IAGEN

Generative Artificial Intelligence (GENI) is a branch of artificial intelligence that focuses on creating new content, such as models, images, code, or text, from existing data. This technology uses advanced algorithms to analyze large amounts of information, identify patterns, and generate new and original content that is often indistinguishable from human-created content.

In the context analyzed, IAGEN models can analyze images and videos captured by specialized cameras, both from drones and fixed devices, installed in strategic areas of the infrastructure. Using computer vision algorithms, the technology identifies visual patterns associated with the presence of leaks, even under adverse lighting conditions or in complex environments.

2. **Specific Technologies and Models**

- Convolutional Neural Networks (CNN): Essential for image processing and analysis, these networks detect anomalies and patterns that suggest the presence of leaks.
- Semantic Segmentation Models: These models allow for the isolation and highlighting of specific areas in images that could correspond to methane emissions, improving detection accuracy.
- Real-Time Detection Algorithms: Integrated into the system to continuously analyze the video stream, generating immediate alerts upon detection of potential leaks.
- Integration with Operational Management Systems: Direct connection to centralized monitoring platforms, enabling immediate corrective actions and a coordinated response to incidents.

3. **Operational and Strategic Benefits**

- Early and Accurate Detection: The ability to identify leaks in seconds allows for rapid intervention, minimizing the impact of the incident.
- Cost Reduction: By reducing reliance on manual inspections and reducing the frequency and severity of repairs, operating costs are optimized.
- Improved Safety: A rapid response to leaks significantly reduces risks to personnel and the environment, raising the level of operational safety.
- Scalability and Adaptability: The solution can be adapted to various operating conditions and configurations in Vaca Muerta, allowing for integration into multiple stages of the production chain.

VIII. Agentic Flow for Implementation

1. **IAGEN Agents Concept**

In recent years, generative artificial intelligence (GAI) has revolutionized the way we interact with technology, enabling the development of systems capable of generating content, answering complex questions, and assisting with highly demanding cognitive tasks. From this capability, a new technological architecture has emerged: GAI-powered agents. These agents are not simple conversational interfaces, but autonomous systems that can interpret instructions, make decisions, execute tasks, and learn from their interactions with the environment.

An IAGen agent combines large language models with additional components such as external tools, memory, planning, and autonomous execution. This allows them to operate in complex environments, with the ability to break down objectives into steps, coordinate multiple actions, interact with digital systems (such as databases, APIs, or documents), and adapt to context changes in real time. These qualities distinguish them from traditional chatbots and open up a range of more sophisticated and customizable applications.

At the organizational level, these agents are being used to automate processes, generate data analysis, assist in decision-making, and improve the user experience, both internally and externally. For example, they can take on human resources, legal, financial, or logistics tasks, and even tasks linked to the technical areas of production processes, acting as intelligent assistants that collaborate with human teams. This ability to integrate knowledge and execute tasks autonomously transforms the way organizations can scale their operations without losing quality or control.

Furthermore, agentic workflows—structures where multiple agents collaborate to solve complex problems—allow responsibilities to be distributed among different agent profiles, each with specific functions. This creates hybrid work environments where humans and agents coexist, optimizing time, costs, and results. The ability to connect agents with tools such as Google Drive, CRMs, or document management platforms further expands their capabilities.

The development of IAGen-powered agents represents a crucial step toward a new era of intelligent automation.

Among the benefits of authentic workflows powered by generative AI models is the ability to automate entire production processes, end-to-end, and even add value by leveraging the capabilities of language models based on these technologies.

However, its implementation also poses technical, ethical, and legal challenges, ranging from responsible design to human oversight. Therefore, understanding its architecture, operational logic, and potential impacts is critical for its effective and safe adoption in diverse professional contexts.

2. Phases of the Workflow with IAGEN designed and proposed

The IAGEN implementation process is structured in phases that ensure effective integration and agile incident response:

a. Data Collection:

   - Image and Video Capture: Using strategically placed drones and fixed cameras.
   - Environmental Sensor Integration: Complement visual information with gas sensor data for a more complete view.

b. Processing and Analysis:

   - Image Preprocessing: Improving visual quality through normalization, contrast adjustment, and noise reduction techniques.
   - Application of Computer Vision Models: Use of CNNs and semantic segmentation models to identify anomalous patterns associated with leaks.

c. Alert Generation:

   - Interpretation of Results: The algorithms assign a risk score to each image

or video analyzed.
  - Immediate Notification: Integration with centralized management systems that send alerts to response teams.

d. Response and Mitigation:

  - Activation of Emergency Protocols: Once the anomaly is confirmed, the security protocol is activated to intervene and mitigate the leak.
  - Logging and Documentation: Incident data is archived for analysis and continuous improvement.

e. Feedback and Continuous Improvement:

  - Post-Event Analysis: Evaluation of system effectiveness and adjustments to detection parameters.
  - Model Update: Incorporating new data to improve the system's accuracy for future detections.

2. Description of the Agents Involved

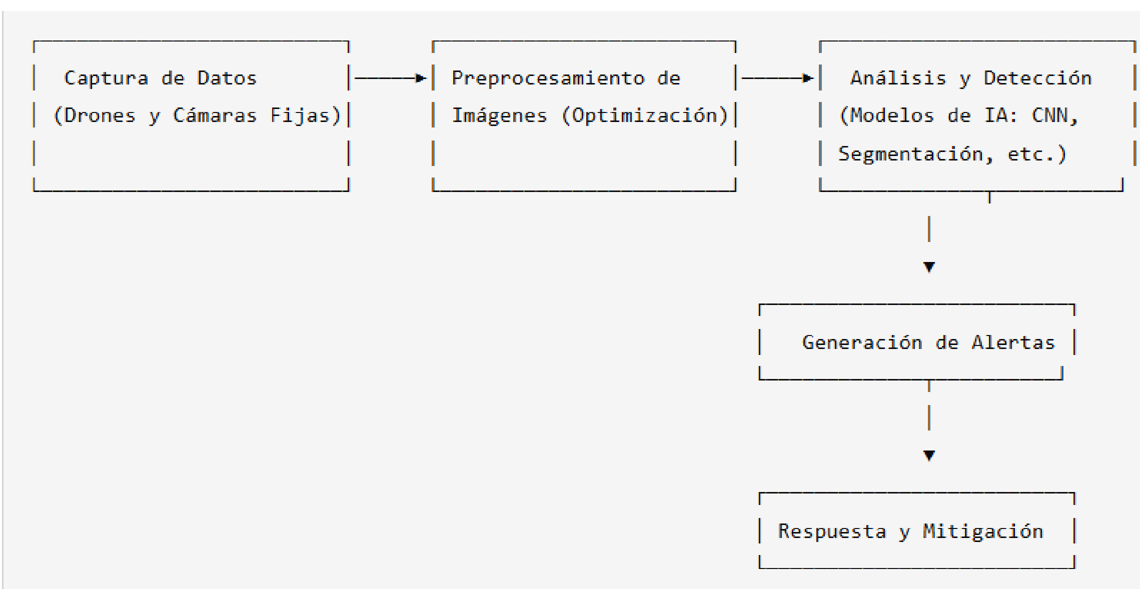
The system is composed of different agents, each with a specific role within the operational flow:

- Capture Agent: Drone and fixed camera teams responsible for collecting images and videos in real time.
- Preprocessing Agent: Module responsible for improving image quality by removing interference and adjusting parameters to optimize data input.
- Analysis Agent: IAGEN core that applies computer vision algorithms to detect anomalies associated with methane leaks.
- Alert Agent: Integrated system that evaluates the risk score and sends immediate notifications to the control center.
- Feedback Agent: Module that analyzes logged incidents and adjusts the model to improve detection in the future.

3. Concrete Example of Agentic Flow

Consider a facility in Vaca Muerta with multiple critical points:

Step 1: A drone equipped with an infrared camera flies over the facility every two hours, capturing images of strategic areas.
Step 2: Images are transmitted to a central server where the preprocessing agent optimizes visual quality and removes interference.
Step 3: The analysis agent identifies a thermal anomaly in the pipeline area, generating a high risk score.
Step 4: If the score exceeds the defined threshold, the alert agent sends an immediate notification to the control center, activating emergency protocols.
Step 5: Intervention teams are deployed to assess and mitigate the leak, while the entire process is documented.
Step 6: Following corrective action, the feedback agent collects and analyzes data to update and fine-tune the model, ensuring continuous improvement.



IX. Regulatory Framework and Environmental Commitments in Argentina

Argentina has made significant commitments to combat climate change, including submitting its Nationally Determined Contribution (NDC) under the Paris Agreement, pledging not to exceed net emissions of 349 million tons of carbon dioxide equivalent by 2030. The country has also announced its intention to reduce methane emissions by at least 30% by the end of the decade, based on 2020 levels. These national commitments underscore the need to adopt effective emissions detection technologies in key sectors such as oil and gas.

Argentina's regulatory framework for oil and gas activities is established at both the federal and provincial levels. This evolving regulatory landscape, with an increasing focus on emissions measurement and reduction, will likely drive greater adoption of advanced methane detection technologies, such as computer vision-enhanced systems.

In addition to government regulations, there are industry initiatives and collaborations that promote methane emissions reduction, such as the Oil and Gas Decarbonization Charter (OGDC). These industry-led efforts, coupled with government regulations, can accelerate the adoption of best practices in methane detection and mitigation.

X. Effectiveness Metrics and Evaluation of Methane Leak Detection Systems

- The effectiveness of methane leak detection systems is evaluated using several key metrics.
- The detection rate, or probability of detection (PoD), indicates the percentage of leaks of a given size that the system can detect under specific conditions. Specifying the PoD along with the minimum detection threshold (MDT) is crucial to understanding system reliability.
- Accuracy refers to the system's ability to correctly identify a leak (low false positives) and accurately locate and quantify the source of the leak. Response time is the time it takes for the system to detect and report a leak once it occurs.
- Sensitivity (MDT) is the smallest leak rate that the system can reliably detect.
- The false alarm rate indicates how often the system incorrectly signals a leak.

- Quantification accuracy is the accuracy with which the system can measure the methane emission rate.
- Finally, spatial resolution is the level of detail in identifying the leak source location, relevant for satellite and drone-based systems.

To compare the performance of different leak detection technologies, standardized testing and evaluation protocols are essential. Initiatives such as the Methane Emissions Technology Evaluation Center (METEC) play an important role in this regard. Clearly defined and consistently measured KPIs are essential for assessing the effectiveness of methane leak detection systems and for making informed decisions about technology adoption.

X. Recommendation to achieve short-term and scalable AI and IAGEN-based solutions

Short-term investment in AI agent implementation teams in technology and training: Investment is required in proofs of concept and pilot testing. The focus here must be on developing the talent needed to implement these solutions, as there is a trend toward cost reduction in systems that enable "no-code" and "low-code" automation. For the first stage, it is also recommended to recruit teams with experience in AI agent design and implementation. Finally, it is key to form an in-house team to support and foster an agentic culture that redefines human-machine interaction.

XI. Conclusion

Methane leak detection is of utmost importance in the oil and gas industry, especially in high-production areas like Vaca Muerta. Methane emissions have a significant impact on climate change, and mitigating them is crucial to achieving global and national climate goals.

Computer vision, powered by artificial intelligence algorithms, is emerging as a powerful tool for improving the accuracy, efficiency, and automation of methane leak detection. The combination of technologies such as OGI cameras with intelligent image analysis offers significant potential for early and accurate leak detection across the entire oil and gas infrastructure in Vaca Muerta. A comprehensive and professional approach to methane leak detection, supported by a robust regulatory framework and the adoption of clear effectiveness metrics, is essential to ensuring responsible and sustainable hydrocarbon production in the region.

Additionally,

- IAGEN's application for methane leak detection enables swift and accurate responses, reducing the risk of critical incidents and optimizing operations in Vaca Muerta.
- Integrating computer vision into complex environments offers substantial improvements in terms of safety, efficiency, and reduced operating costs.
- The implementation of this system is aligned with environmental and safety regulations, strengthening the competitiveness of companies in a demanding market.

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