Autonomous Drone Swarms for Pipeline Leak Detection

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Summary

A system of autonomous Artificial Intelligence enabled drones can be utilized as a rapid response system for oil & gas pipeline leaks.

Traditional approaches to pipeline leak detection include combinations of static sensors such as pressure, fiber-optic, temperature etc., with SCADA systems for remote monitoring and alerting.

When a potential leak is detected by observing abnormal pipeline monitoring parameters, a time-critical response is necessary to confirm the existence, location, and magnitude of the leak in the field. Such a task often involves hazardous environmental conditions with a high risk to the field workforce.

An autonomous swarm of intelligent drones equipped with a multitude of sensors, such as optical and thermal cameras, and chemical sensors, can automatically be dispatched to the field in seconds, perform the leak detection task in a minimal amount of time, with high precision and reliability.

Challenge

The Pipeline Leak Problem

Pipeline operators are required to monitor their pipelines and take preventive measures to minimize the risk of leaks. Modern pipelines are designed and constructed with advanced materials and technologies to reduce the risk of leaks and spills, but no pipeline is completely immune from the potential of a leak.

Whether it's on a crude oil, natural gas, or a petroleum product pipeline, a leak or a spill can cause incredible environmental damage, irreparable harm to the population and wildlife, and extremely high cleanup costs.

Causes of Pipeline Leaks

The main causes of pipeline leaks include:

a) Material deterioration, e.g., corrosion caused by weathering, exposure to the environment, humidity, temperature variations, and air, that lead to weakened components and increase the risk of a leak.
b) Equipment failures, mechanical or electrical in nature, that cause the pipeline to operate outside of nominal conditions.
c) Accidental damage from construction projects, human error, as well as natural disasters that can cause difficult to detect structural defects in the pipeline.
d) Attacks from malicious groups, cyber-attacks as well as ground attacks with critical damage causing shutdowns.

Consequences of Pipeline Leaks

Pipeline leaks can release harmful chemicals and pollutants into the environment, contaminating soil, water, and air. This can harm wildlife, plants, and aquatic ecosystems, and have long-term impacts on the environment. Exposure to leaked chemicals and pollutants can pose health risks to humans, including respiratory problems, skin irritation, and even cancer.

The impact to energy companies is immense. Pipeline leaks can result in significant economic losses, including cleanup costs, compensation for damages, and lost revenue from interrupted operations. Legal and regulatory consequences, including fines, penalties, and changes to regulations and standards further add to the financial strain. The damage to the reputation of the pipeline operator and the industry leads to increased scrutiny and public opposition to pipeline projects.

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Current Methods of Leak Detection

The current methods of pipeline leak detection include:

a) Visual / inspection methods
b) External sensory methods
c) Internal sensory methods

Human field inspections and inspections aided by drones and robots are used for direct detection and confirmation of pipeline leaks at the point of leak. This is also the most hazardous method as it can expose humans or physical assets to safety risk.

External sensors such as fiber-optic cables, acoustic sensors, vapor, and liquid sensing tubes are used to either directly detect the presence of materials in the environment or indirectly to detect the adverse effects to environmental conditions such as outside temperature resulting from the presence of the materials.

Internal methods commonly include pressure, flow, and temperature measurement devices, combined with SCADA systems for real-time operational data collection and analysis, and statistical and simulation models that detect deviations in the flow.

Problem With Current Approaches

Major challenges with existing methods of pipeline leak detection include the reliability of the detection, and precise causal and location assessment.

The methods that are best suited for automated, continuous detection, such as remote sensors and models, are also the least suited for precision and reliability as they give general indications. Additional positive confirmation is necessary from close proximity to verify the presence of hazardous materials in the environment resulting from the leak and pinpoint the precise location and cause that can then be remedied.

When a potential leak is detected, an urgent response is needed as any delays in reaction time can exacerbate the problem further. This often requires mobilizing a field workforce quickly and dispatching them to a potentially hazardous environment for a prolonged period.

The uncertainty of the location and cause of the leak demand high mobility and agility of the inspection team, in terms of sensory and maintenance equipment, access to terrain etc. At the same time, inspection results require a very high degree of confidence to avoid the escalating negative effects to pipeline operations. It is therefore not surprising that pipeline operators resort to expensive solutions to tackle this issue.

Solution

We propose a fully autonomous solution based on a swarm of intelligent drones that is automatically dispatched to the suspected location of a pipeline leak, carrying a diverse set of sensors and communication equipment allowing it to positively confirm the nature, magnitude, severity, and precise location of the leak.

Drone Swarm System Architecture

A Drone Swarm is a system of independent but coordinating unmanned aerial vehicles (UAV) that collectively navigate to the desired target area and perform the leak detection mission. Individual drones in the swarm communicate via a local network established by the swarm to coordinate tactical decisioning, exchange information, identify targets etc.

Each drone in the swarm is equipped with one or more sensors needed for pipeline leak detection. The drones need not be equipped with the same types of sensors, although redundancy improves the likelihood of a successful mission. A small drone swarm consisting of 3 to 4 drones can carry up to 10 or more small to medium-sized

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sensors, exceeding the load carry characteristic of a common industrial drone. Sensors commonly used include optical cameras, thermal and infrared cameras, chemical detectors, temperature, pressure, and humidity sensors, magnetometers etc.

In addition to onboard sensors that collect local data in real-time, drones in the swarm are equipped with Artificial Intelligence (AI) capabilities. Applied to the data collected from onboard sensors, AI can be utilized for automatic detection tasks, e.g., with machine vision and predictive models, as well as real-time tactical decisioning around search navigation.

The ground supporting equipment includes launch/landing pads with automatic charging capabilities, communication equipment, and computing equipment for data processing.

Operation

An autonomous drone swarm for pipeline leak detection can be especially powerful when integrated with the existing leak detection methods. When fully integrated with the SCADA system, the drone swarm can be programmed to react to specific triggers, perform automatic mission planning, including drone and sensor selection based on operational parameters, and dispatch the swarm to the target area, all in a matter of seconds and without any human intervention.

After takeoff, the autonomous drone swarm carefully navigates to the target area avoiding physical obstacles. It then dynamically selects survey targets and ensures detailed coverage of the potential leak locations observing in close proximity and from multiple vantage points. Collected sensor data is relayed back to the centre for final decisioning.

Upon mission completion, the swarm returns to the centre, landing autonomously on the launch pad where it recharges for the next mission.

Example Application Scenario

A common application of an autonomous drone swarm for leak detection in a natural gas pipeline would include a small 3 to 5-drone fleet. One of the drones would be equipped with a communication router and its role is to establish a local communication network allowing the swarm uninterrupted local communication and coordination in the field, far away from the centre. Other drones in the fleet would be equipped with thermal cameras and temperature sensors. Their role is to detect visible plumes of hot gas around the pipeline and hot spots in the structure using onboard machine vision capabilities, as well as changes in outside temperature.

Key Benefits

An autonomous drone swarm solution for pipeline leak detection offers numerous business benefits to pipeline operators. Improved safety record, lower cost of operations, fewer unnecessary shutdowns are some of the main benefits.

A drone-based response system can help to reduce the reaction time in case of spills, leading to lower total cost of cleanup and lower likelihood of environmental impact. It also helps to avoid costly field operations in cases when faulty sensor readings indicate false detections.

The solution dramatically improves the safety of the field workforce. As a first response system, a drone swarm can assess the environmental conditions improving the situational awareness and operational intelligence for the ground workers that follow. It thus avoids putting the workers in harm's way.

In addition to being used as a rapid response system, continuous drone-based monitoring of the pipeline helps with prevention. Defects that commonly lead to spills can be spotted earlier, before they cause larger damage, leading to cost

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savings, better safety record, and uninterrupted operations.

Although more novel from the technology perspective, an autonomous drone swarm solution helps to lower total maintenance costs as it reduces the use of expensive transportation equipment (e.g., helicopters) and optimizes the deployment of the ground maintenance workforce focusing their efforts to the most critical areas only.

DeepMAV.ai Products

About Us

DeepMAV.ai is an advanced drone-based Artificial Intelligence lab based in Toronto, Canada. Our primary R&D focus is distributed intelligence and drone swarm technology. We are working on implementing fully autonomous, intelligent, multi-sensor equipped, swarms of Micro-Aerial Vehicles to solve problems in energy & utilities, agriculture, infrastructure, natural disasters, and safety & security.

Our proprietary technology includes Artificial Intelligence (AI) solutions based on deep and reinforcement learning and distributed coordination, that enable a system of drones to act as a cooperative swarm when performing a complex task. Our autonomous drone swarms utilize on-board sensors, inter-drone and drone-to-centre communication, and machine learning on tasks such as obstacle avoidance, mapping, localization, target detection and tracking, flight control and navigation.

Drone Swarm

Drone Swarm is a completely assembled, ready-to-fly, intelligent multi-sensor drone system, equipped with our proprietary onboard software solution running on the companion computer. It is built on a PX4-based quad-copter drone architecture, and equipped with GPS, optical and infrared cameras, distance sensors, and inertial sensors. It supports various add-on sensors such as thermal cameras, HD/4K optical cameras, chemical sensors, audio sensors etc.

It enables users to operate their drone fleets as a coordinated swarm, executing missions with distributed intelligence, and taking advantage of capabilities such as onboard machine learning, communication & coordination, autonomous flight with obstacle avoidance, and simultaneous localization and mapping.

Product capabilities:

- Autonomous navigation with obstacle avoidance
- Drone-to-drone and drone-to-centre communication, position tracking, and coordination
- Flexibility to break formation or fly as a swarm
- Visual object detection using onboard machine learning
- Object motion tracking and following
- Add-on sensor support, e.g., thermal cameras, HD/4K optical cameras, chemical sensors, audio sensors, environmental sensors etc.

To find out more about DeepMAV.ai products, visit our website or contact us via email.

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