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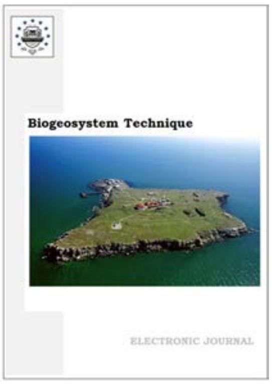

Monitoring Features of the Pipeline Systems Condition

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Abstract

The article is devoted to the consideration of topical issues of organizing continuous monitoring of the pipeline system for pumping extracted natural gas and oil in hard-to-reach places based on the use of a drone port and a swarm of drones. A large amount of natural resources is extracted in the coastal shelf of the northern seas, where the water surface is covered with ice most of the time, and monitoring of the pipeline system by means of the auxiliary fleet is possible only during a short period of navigation, therefore automation of the monitoring process will allow for year-round monitoring and timely identification of emerging problems for their prompt elimination.

Using a drone swarm with a droneport base station makes it possible to increase the efficiency of obtaining information by obtaining it more quickly from several alternative sources and then merging them. When information is received from the drone, the information is cleared of noise and checked for consistency to ensure a higher level of data reliability, which improves the efficiency of system maintenance. Data is cleared from noise by the drone port, while merging data from coherent sources and building a visual model of the pipeline system status is performed by a stationary computer after data is transmitted from the drone port via fiber-optic communication channels. The visual model, combined with parametric data obtained from sensors installed inside the pipeline, allows artificial intelligence systems to predict potential emergency conditions and plan routine repairs of the pipeline infrastructure until a real accident occurs with serious consequences. The introduction of an automated continuous monitoring system will allow the pipeline to be operated according to its actual technical condition, thereby reducing operating costs and ensuring the safety of its operation.

Keywords: monitoring, pipeline system, drone port, drone swarm.

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1. Introduction

Energy constitutes one of the foundational sectors of the economy and plays a critical role in sustaining modern society (Atdaeva et al., 2024). It encompasses not only resource generation challenges but also issues related to distribution and consumption.

Currently, oil and coal extracted from the Earth's subsurface represent the predominant share of global energy resources. As is well known, these reserves within the Earth's crust are finite; consequently, humanity actively seeks equivalent substitutes.

Replacing coal and oil with natural gas substantially reduces harmful atmospheric emissions, thereby contributing to the preservation of the Earth's ozone layer and improving the operational efficiency of thermal power plants.

Significant volumes of natural resources are extracted from the continental shelves of northern seas, raising the acute challenge of transporting these commodities to the mainland. While maritime shipping is widely employed for this purpose, vessel-based delivery of oil and natural gas represents a highly costly undertaking – particularly in northern seas, where such operations become infeasible during winter months due to ice cover. Pipeline transportation presents a viable alternative, offering greater economic efficiency and reduced operational complexity.

Pipeline operation for oil and gas transportation necessitates continuous condition monitoring through readings from embedded sensors, supplemented by periodic external inspections. For submerged pipeline sections, such activities can only be conducted using auxiliary vessels and exclusively during ice-free periods – a condition that, in northern seas, occurs for only a brief annual window. Relying on auxiliary fleets for pipeline monitoring constitutes a costly seasonal operation feasible solely in the absence of ice cover. Given that pipeline failures may occur at any time of year, the implementation of alternative monitoring methodologies becomes imperative.

2. Materials and methods

Pipeline inspection monitoring represents a comprehensive suite of non-destructive testing (NDT) and diagnostic procedures designed to identify defects (corrosion, cracks, deformations), assess residual wall thickness, verify weld integrity, and evaluate insulation quality. These procedures employ techniques including ultrasonic testing, radiography, liquid penetrant and magnetic particle inspection, as well as visual examination – often integrated within automated systems for continuous monitoring and residual service life assessment.

The principal objectives of pipeline monitoring include:

1. Defect detection: Identification of corrosion, erosion, cracks, dents, and pitting.
2. Geometric control: Measurement of wall thickness and deviations from design geometry.
3. Weld assessment: Verification of joint quality.
4. Component diagnostics: Examination of valves, flanges, supports, and hangers.
5. Insulation evaluation: Assessment of anticorrosive coating and thermal insulation integrity.

3. Discussion and results

The overarching purpose of monitoring is to ensure the safety and reliability of pipeline infrastructure, prevent accidents and gas leaks, facilitate maintenance planning, and extend the operational lifespan of pipeline assets. Pipeline failure in aggressive marine environments poses severe ecological consequences.

For monitoring pipelines in inaccessible locations, automated inspection using unmanned aerial vehicles (UAVs), commonly termed drones, offers a practical solution. However, a single drone proves inefficient for rapid assessment of extensive pipeline segments; consequently, drone swarms coordinated by a specialized hub – the drone port – are typically deployed.

A drone port constitutes an advanced unmanned technology complex designed for automated drone deployment, recovery, and maintenance to support pipeline section monitoring. The primary limitation of autonomous drones remains restricted operational duration due to battery capacity constraints. Even with contemporary lithium-ion batteries, modern quadcopters rarely sustain flight beyond 30 minutes. Drone ports address this limitation by providing infrastructure for drone recovery, recharging, and preparation for subsequent inspection missions. This infrastructure enables the establishment of continuous automated monitoring networks capable of rapid response to unforeseen operational incidents.

Such drone ports have already been implemented for monitoring terrestrial pipeline segments in remote terrain. For instance, the HIVE drone port (Figure 1) can replace a drone's battery in under three minutes. Additionally, it transmits acquired data to a central server and simultaneously charges up to four battery pairs. Through the HIVE system, drones maintain near-continuous operational readiness. In 2022, HIVE underwent field testing at facilities operated by SIBUR Holding. Previously, Moscow's municipal search and rescue service tested the drone port over water bodies. Deployment of HIVE commenced in Innopolis, Tatarstan, in 2020 (Zhang et al., 2021).

Fig. 1. HIVE drone port, Russia

Integrated with the drone port, a swarm of observation drones equipped with sensor arrays performs dual functions: acquiring data from pipeline-embedded sensors and conducting autonomous surveillance of pipeline infrastructure integrity and ambient environmental parameters – including air temperature and chemical composition – to detect leaks and support ecological monitoring. Such drones may be outfitted with high-resolution cameras, thermal imagers, gas analyzers, and supplementary sensors (Figures 2, 3; Faniadis, Amanatiadis, 2020).

For marine pipeline segment inspection, deployment of a seabed platform connected to onshore energy and data resources via subsea cable is proposed. This platform would facilitate recharging of marine monitoring drone swarms and aggregate transmitted data for preprocessing, fusion, and relay to coastal monitoring stations. Development of such seabed platforms is currently underway.

Fig. 2. DJI Matrice 300 RTK drone with Zenmuse H20T payload and U10 gas analyzer

Underwater drones have gained utility in pipeline monitoring owing to their capacity to operate within inaccessible and hazardous submerged environments. These vehicles can descend to considerable depths, withstand saline water exposure, and capture high-fidelity imagery using integrated cameras – including 4K resolution systems. Control methodologies encompass tethered teleoperation, radio-frequency guidance, and fully autonomous navigation systems.

Fig. 3. Aboveground pipeline section

Underwater pipeline inspection vehicles (UPIVs) represent specialized craft equipped with 4K cameras, LED illumination systems, and sensor arrays capable of inspecting submerged infrastructure at depths ranging from 200 to 5,000 meters, thereby eliminating the need for hazardous diver operations. Prominent models such as the Chasing M2 Pro Max (Figure 4) incorporate sonar systems and manipulator arms for leak detection. This drone platform is engineered for complex subsea operations, inspections, and scientific research – enabling access to previously unreachable depths and facilitating investigations once deemed impracticable.

Fig. 4. Chasing M2 Pro Max underwater drone

Key advantages of the CHASING M2 PRO MAX include:

1. A 4K UHD camera with high light sensitivity produces detailed, vivid imagery even at significant depths and under low-light conditions, enabling precise image recognition for problem classification.

2. Modular architecture permits integration of supplementary equipment – including robotic manipulators, sonar systems, and specialized sensors – to address mission-specific requirements, affording exceptional operational flexibility.

3. Operational depth capability extending to 200 meters unlocks new possibilities for subsea research, permitting inspections and documentation in previously inaccessible locations.

4. Eight high-torque thrusters deliver superior maneuverability and stability in underwater currents, ensuring precise and reliable vehicle control under challenging hydrodynamic conditions.

5. Extended mission duration facilitated by swappable battery systems enables prolonged operations without frequent surfacing for recharging, thereby enhancing operational efficiency.

6. Intuitive mobile application interface with integrated intelligent functions simplifies operation even during complex mission profiles.

This industrial-grade underwater drone is designed for hydraulic structure inspection, vessel hull examination, drilling rig maintenance, pipeline and channel surveys, search and rescue operations, sediment and water sampling, and high-resolution video documentation. A coordinated system comprising multiple underwater drones and a drone port can rapidly and comprehensively inspect extended subsea pipeline segments, generating actionable intelligence for maintenance decision-making.

All data transmitted by the drone swarm accumulates within the drone port's information repository. Given the multiplicity of drones, redundant measurements of identical parameters for the same object may be transmitted concurrently. Furthermore, noise interference may corrupt transmitted signals. Consequently, prior to database storage, data must undergo denoising and consistency verification through a data fusion procedure integrating information from coherent sources (Hafeez et al., 2021, Smagin, 2012).

Following this filtering protocol, noise-reduced data – particularly slow trends – are archived within the monitoring information base. Data fusion redistributes the information flow, generating maxima and minima that more accurately reflect the monitored phenomenon. Integration of multi-source information enhances measurement precision and reliability beyond the capabilities of any single data source.

Sensor-acquired data undergo preliminary processing by the drone port's onboard processor to prevent heavily corrupted measurements from entering the operational database. Processed data are then accumulated in real time within the Blender 3D software suite's database to construct three-dimensional computer graphic models (Smagin, 2012).

Effective noise filtering reduces measurement uncertainty and enhances sensor accuracy. This process must address two noise categories: persistent noise (additive white Gaussian noise) with relatively stable amplitude, and random impulse interference induced by external factors.

Upon monitoring completion, all acquired information must be synthesized to generate a unified visual model representing both external and internal pipeline conditions (Marshal'ko et al., 2023). For maintenance and repair planning, visualization through graphical and video modeling provides an effective decision-support tool. Blender 3D software offers a convenient platform for constructing such models, enabling generation of visual representations of pipeline external and internal structure based on filtered data.

To prevent accidents and enhance pipeline operational safety and efficiency, autonomous monitoring systems incorporating artificial intelligence (AI) have been developed and deployed over recent (Islamov, et al., 2017; Askarov et al., 2018; Askarov et al., 2019; Tagirov et al., 2017; Iqbal et al., 2021; 2022; Erdelj et al., 2017).

Contemporary integrated monitoring systems typically incorporate machine intelligence software-neural networks – whose predictive accuracy for identifying failure-prone locations averages 95 %, substantially exceeding conventional defect detection methodologies.

AI-enabled software undergoes training using predefined parameters against databases containing extensive examples of adverse events and their consequences. This process enables the system to recognize correlations between input variables and expected outcomes, subsequently generating predictive models to identify or anticipate potential failures before they escalate into critical incidents (McDonald, 2019). For instance, the system may accurately detect equipment wear signatures or damage indicators and recommend appropriate remedial actions.

The AI system receives real-time pipeline condition data from the central data aggregation hub – the drone port – which collects signals from pipeline monitoring points and observer drone swarms. Artificial intelligence processes and interprets these inputs to generate assessments of current network status (Akay, 2022).

4. Conclusion

The monitoring methodology proposed in this article – employing drone ports and drone swarms for data acquisition, noise reduction, and fusion of coherent data sources – enhances the efficiency of pipeline maintenance planning and execution.

Implementation of automated year-round monitoring systems will enable condition-based pipeline operation, thereby reducing operational expenditures while ensuring operational safety.

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