Utilization of Robots for Autonomous Inspection in Offshore Unmanned Facilities

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In recent years, the deployment of robots for plant operations has been accelerating, accompanied by initial evaluations of their practical applicability by end-users. YOKOGAWA has also been pursuing entry into the robotics business; however, the design of realistic use cases currently remains underdeveloped for both vendors and users. This study, supported by the Nippon Foundation and the international offshore technology consortium DeepStar, focuses on the design and demonstration of robotic use cases for offshore unmanned platforms. For this purpose, we employed the EX ROVR, an explosion-proof plant inspection robot developed by Mitsubishi Heavy Industries, to conduct verification trials in a simulated offshore platform environment under an on-premises system configuration. Through these trials, we identified technical challenges associated with practical operating conditions. The results of this study provide concrete guidelines for the implementation of robotic systems in plant facilities.

INTRODUCTION

In recent years, the plant industry has been required to address not only challenges such as ensuring safety and improving operational efficiency, but also dealing with a shortage of skilled workers. Against this backdrop, advances in industrial robotics and AI have driven a growing trend toward automation and remote operation of patrol inspections and monitoring tasks that have traditionally been performed by humans. In particular, the introduction of robots to automate hazardous or repetitive inspection tasks traditionally performed by humans is expected to be an effective means of improving both safety and operational efficiency.

Offshore platforms, typified by the oil and gas industry, are situated in harsh, hazardous environments isolated from land, where routine patrol inspections and emergency responses within the facility are indispensable. This work is carried out under severe environmental conditions, such as high heat and humidity, salt damage, and strong winds, and in the presence of serious hazards, such as exposure to toxic gases such as hydrogen sulfide, so ensuring worker safety is a major challenge. Furthermore, because flammable gases are handled, the entire facility is operated as a hazardous area, making the working environment even more demanding. In addition, the remote locations of these facilities result in high costs for personnel deployment and rotation, creating a need for improvements in long-term operational efficiency. For these reasons, the need to introduce robots for inspection operations at offshore platform facilities is exceptionally high.

However, the deployment of explosion-proof autonomous mobile robots capable of operating in such environments remains limited. Contributing factors include technical constraints associated with explosion-proof certification, the difficulty of demonstrating long-term operation and ensuring reliability in harsh offshore environments, and the lack of use-case designs and evaluation examples grounded in actual operational conditions.

With this as background, Yokogawa, with support from the Nippon Foundation and DeepStar (an international offshore technology development consortium) and in collaboration with major companies in the oil and gas sector, conducted use-case design, system development, and demonstration trials for robotic operations on offshore platforms. Through this initiative, we identified the requirements and challenges associated with practical robot deployment. We further developed an autonomous patrol inspection system combining an explosion-proof autonomous inspection robot (EX ROVR) manufactured by Mitsubishi Heavy Industries, Ltd., with our OpreX Robot Management Core (RMC; Figure 1) robot integration management system.

This article reports on the results and findings of this work and discusses concrete guidelines for implementing robotic systems in plant facilities, as well as the future direction of facility maintenance.

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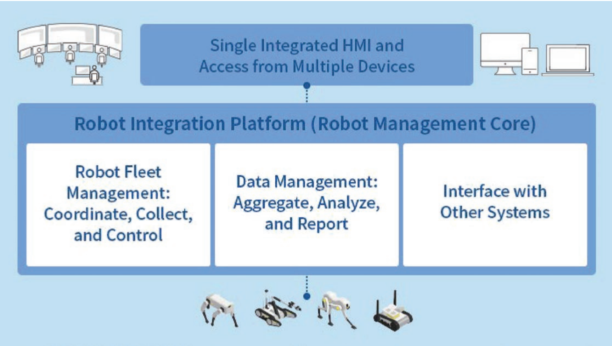

Figure 1 Conceptual diagram of the OpreX robot management core (HMI: Human Machine Interface)
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CURRENT STATE AND CHALLENGES OF ROBOT OPERATING ENVIRONMENTS ON OFFSHORE PLATFORMS

General plant facilities are designed with human workers in mind, and the placement of measuring instruments, valves, and other equipment—including their positioning, height, direction of operation, and access routes—is based on the physical dimensions and range of motion of workers. As a result, steps, narrow passageways, steep staircases, and other structural features ill-suited to robot navigation are found throughout these facilities.

Robot operating conditions are even more demanding on offshore platforms due to dense concentrations of equipment and piping in confined spaces. Closely packed piping and equipment can obstruct measurement sensors, potentially impeding data acquisition. Safety regulations, including restricted-access zones requiring permits to enter, also limit the flexibility of robot operation schedules and tasks.

While mobile robots can be built to explosion-proof specifications for operation in hazardous areas, the sensors and onboard equipment compatible with explosion-proof requirements are limited, and high-powered lasers and certain optical measurement instruments may not be permissible. As a result, the operational scope tends to be confined to flat walkways, making it difficult to fully replace human inspectors with robotic systems across an entire facility.

Communication also poses significant challenges. For security reasons, many offshore platform facilities operate in closed network environments isolated from external networks, restricting cloud-based control and data sharing. Satellite communications are unsuitable due to high latency and low bandwidth, and even where fiber optic connections are available, external connectivity is often not permitted. Robot operations thus require an on-premises communications and management infrastructure.

To date, most demonstrations in this field have involved short-term trials with non-explosion-proof robots or remotely operated equipment; there have been few long-term autonomous patrol inspections in hazardous areas, and few integrated evaluations encompassing multiple inspection tasks. This highlights the pressing need to establish a robot operating model suited to real-world field environments. Table 1 presents the anticipated challenges in robot operations on offshore platforms and the corresponding technical requirements for addressing them.

Table 1 Anticipated challenges and technical requirements for robot operations on offshore platforms

Category	Anticipated challenges	Technical requirements
Robot management	Round-the-clock robot monitoring and support across shift rotations	Implementation of autonomous patrol, anomaly detection, and primary judgment functions
Communications environment	High latency and low bandwidth of satellite communications; restrictions on external connectivity	Implementation of an on-premises operational platform capable of operating within a closed network environment
Utilities	Limitations on permanent installation of power, air supply, and communications equipment; stringent approval procedures	Energy- and space-efficient design; utilization of existing equipment
Facility environment	Salt damage, bird damage, typhoons, military radar interference, wide operating temperature range (−25 to 50°C)	High corrosion resistance, waterproofing, and weatherproofing; wide operating temperature range compatibility; accommodation of extended maintenance intervals
Certification requirements	Weight, size, and onboard equipment restrictions imposed by explosion-proof and marine classification certifications	Explosion-proof compliant hardware; establishment of alternative measurement methods

Resolving these challenges requires an optimal system design that encompasses robot hardware specifications, communication configurations, and operating procedures. To meet these requirements, we developed a system centered on an explosion-proof autonomous patrol robot, a closed-network communications infrastructure, and an integrated application platform.

Overall System Architecture

The overall system architecture (Figure 2) for enabling stable long-term robot operations on offshore platforms comprises the following elements.

Communications Infrastructure for Stable Operation in a Closed Network Environment

A closed network environment is established using a private Long-Term Evolution (LTE) network, and an on-site server is operated within it to ensure communication stability and security.

Robot Capable of Long-Term Autonomous Operation in Hazardous Areas

We adopted the second-generation EX ROVR, designated

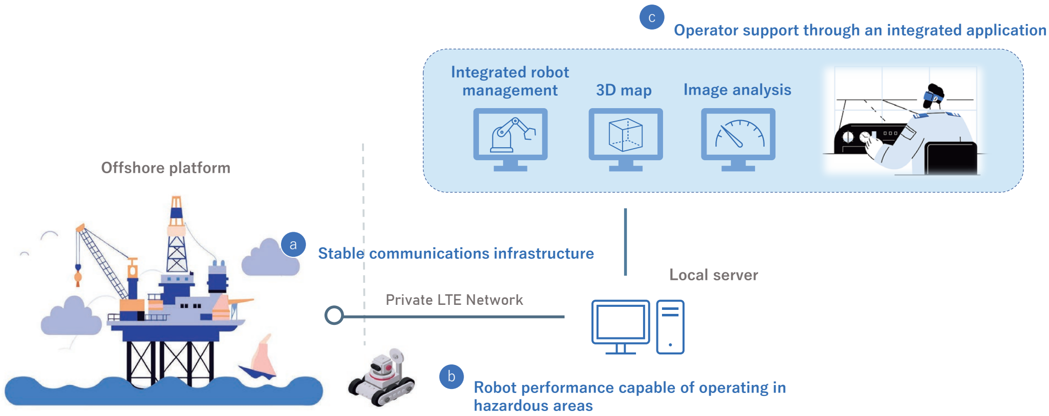

Figure 2 System architecture for achieving autonomous patrol inspection on offshore platforms

"ASCENT," which holds the Japanese certification for explosion-proof electrical equipment (Technology Evaluation for Explosion-proof Products) and certification under the IECEx scheme, an internationally recognized certification system for equipment used in explosive atmospheres. The EX ROVR is designed to eliminate potential ignition sources under normal operating conditions in Zone 1 environments (environments in which explosive gas atmospheres are present or likely to occur), enabling autonomous patrol and data collection in hazardous areas. It is also equipped with stair-climbing capability, giving it high traversability across multiple floors (Figure 3).

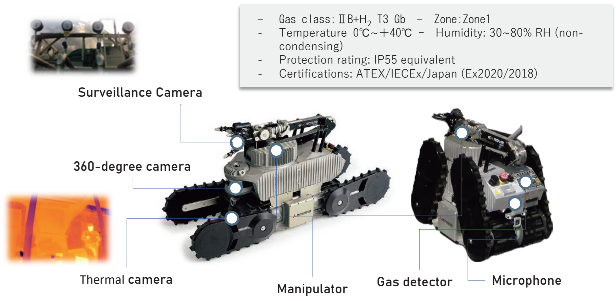

Figure 3 Key specifications of the EX ROVR

Integrated Application for Operator Support

The integrated management system centralizes robot operation, monitoring, and administration, and incorporates AI-based automatic analysis of field instruments as well as remote operation support utilizing 3D mapping. This enables comprehensive decision-making support for remote operators responsible for platform operations.

Demonstration Test Environment

Demonstration tests were conducted at the Yokogawa Manufacturing Komagane Plant, configured to simulate an offshore platform. The facility is equipped with a private LTE network, and the rooftop features measurement targets representative of real-world conditions, including pressure gauges, valves, and rotating equipment. Details of the environment are provided below.

Building Exterior and Rooftop Inspection Area

Pressure gauges, valves, rotating equipment, and other instruments are installed in this area, where tests were conducted to read instrument values, monitor temperature, and collect sound (Figure 4).

Figure 4 Building exterior and rooftop inspection area at the Yokogawa Manufacturing Komagane Plant

Access Route to the Rooftop

Outdoor staircases were included in the patrol route to simulate the multi-level structural environment characteristic of offshore platforms. Stability and safety during staircase ascent and descent were evaluated, and locomotion performance was verified (Figure 5).

Figure 5 Access route to the rooftop simulating a multi-level structural environment

Network Configuration

A closed network environment based on a private LTE network was established to replicate actual offshore operating conditions, and the robot management system along with associated servers were operated on top of this infrastructure (Figure 6).

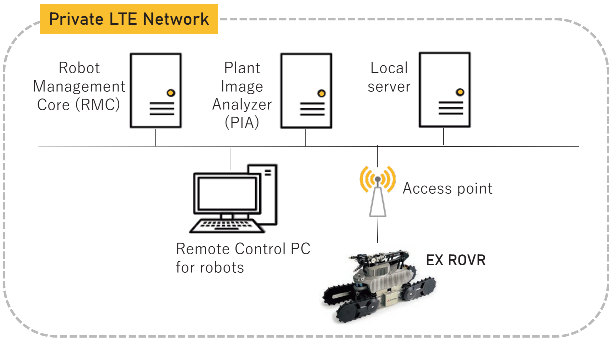

Figure 6 Network configuration for demonstration testing

DEVELOPMENT OF THE INTEGRATED MANAGEMENT SYSTEM AND DEMONSTRATION TESTS

This section describes the development of an integrated management system in an environment simulating an offshore platform and the results of its operational performance evaluation. By conducting a consistent series of activities from environment setup through implementation of individual functions to testing under assumed real-world operating conditions, we demonstrated both the system's effectiveness and key operational considerations.

Figure 7 Wooden base installed at an obstacle location on the test route

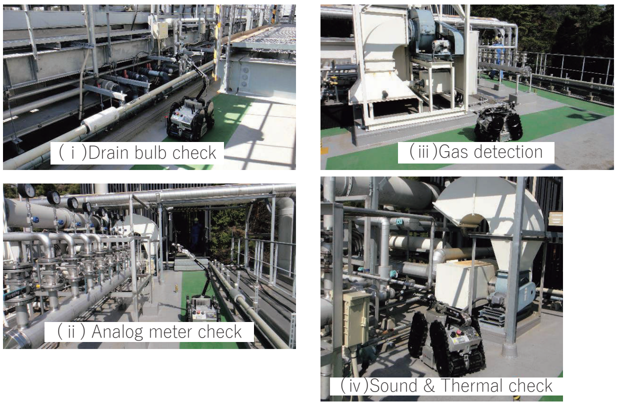

Figure 8 Robot inspection tasks performed during the demonstration trial

On-Premises Environment Setup and Robot Operation Evaluation

We established an on-premises environment that simulates the operating conditions of an offshore platform and migrated the EX ROVR's operational server to this configuration. We operated the EX ROVR over a private LTE network and evaluated the robot's autonomous operation performance in the on-premises environment.

As field conditions, the test route included staircases, steps, and narrow passageways. The route included an obstacle on a landing and a section with an insufficient passageway width; a wooden base was installed to cover the obstacle and secure a navigable path, allowing the robot to travel over it (Figure 7).

Inspection tasks were as follows: (i) image acquisition for confirming valve open/closed status, (ii) photography of analog instruments, (iii) gas concentration measurements near air conditioning units, and (iv) acquisition of acoustic data and thermal imagery from rotating equipment (Figure 8). The acceptance criterion was successful acquisition of the specified data at all inspection points.

Test results confirmed that the robot stably traversed the route, including steps and staircases, and that each sensor system, including the optical camera, thermal imager, gas detector, and acoustic sensor, operated satisfactorily with successful acquisition of all data types. Some degradation in optical camera image quality was observed under certain conditions, such as backlighting and rain. However, the robot was overall confirmed to be capable of stable operation in the on-premises environment and to demonstrate sufficient performance for autonomous inspection under the assumed conditions. At the same time, the results highlighted the importance of designing the physical environment to be robot-friendly in order to facilitate smooth robot operations.

Evaluation of Process Parameter Reading Accuracy

We integrated the EX ROVR's image acquisition capability with our AI image analysis application, the OpreX Plant Image Analyzer (PIA), and verified the accuracy of meter readings for common instruments such as pressure gauges and thermometers.

The verification involved acquiring meter images under three categories of unfavorable imaging conditions: poor lighting (instruments placed in shade or low-light conditions), partial occlusion of the instrument face due to dirt or deposits, and cases where the shooting angle was constrained by reflections or halation from the surrounding environment. Measured values were then automatically extracted using the

PIA.

The results confirmed accurate meter readings under all conditions shown in Figure 9, demonstrating that the application can stably extract instrument values across a wide range of environmental conditions and offers both high measurement accuracy and robustness to environmental variability.

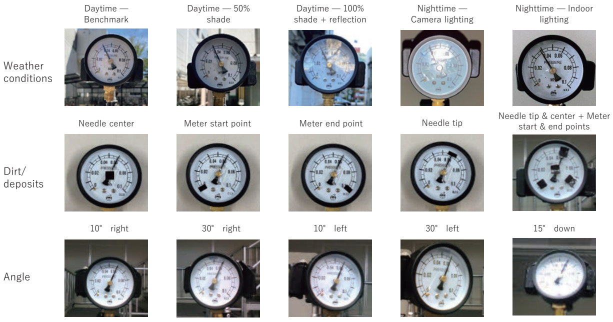

Figure 9 Meter images used for instrument reading by the PIA

Development of an Integrated 3D Map Display Application

One of the challenges in robot operations on offshore platforms is ensuring robots can respond rapidly and flexibly to plant emergencies. In emergency situations, robots must perform non-routine tasks that cannot be handled by autonomous navigation alone, requiring remote operation by an operator. Doing so is extremely difficult, particularly for less experienced operators, because remote operation relies on video feeds from cameras mounted on the robot, making rapid situational awareness difficult. To address this, the present study developed a user interface that integrates and displays the robot's position and inspection point information on a pre-generated 3D map, enabling operators to maintain a comprehensive, bird's-eye view of the entire facility. This not only supports remote operation during emergencies but also enables operators to intuitively correlate acquired data with the robot's position across a variety of tasks, including temperature monitoring, noise monitoring, gas leak detection, on-demand inspection, and remote troubleshooting.

A mobile device's light detection and ranging (LiDAR) sensor and a 3D scanning application were thus used to generate the 3D map of the entire simulated facility, enabling faster and lower-cost modeling than conventional approaches using dedicated 3D scanners (Figure 10). However, 3D models generated by this method combine all objects into a single model and are subject to resolution constraints inherent to wide-area scanning. For this reason, objects serving as robot inspection points were individually scanned to produce high-resolution models, which were then used in conjunction with the overall model (Figure 11).

Overlaying the robot's position onto the 3D model constructed in this manner resulted in a user interface that allows patrol inspection routes to be visualized at low cost and enables operators to intuitively grasp the overall status of the facility. Furthermore, image data acquired by the robot were aggregated in the RMC, and the results of PIA analysis were integrated into the inspection points on the 3D map. This allows operators to access all data related to robot operations and inspections in a unified view within a single 3D map viewer (Figure 12).

Figure 10 3D model of the Yokogawa Manufacturing Komagane Plant generated using a mobile device

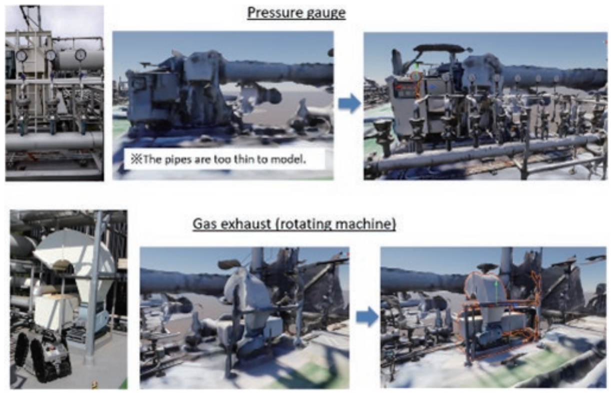

Figure 11 Example of inspection target replacement using a high-resolution model

This integration established an environment that enables efficient visualization of robot patrol inspections on a 3D map, providing a useful foundation for remote monitoring and operational support.

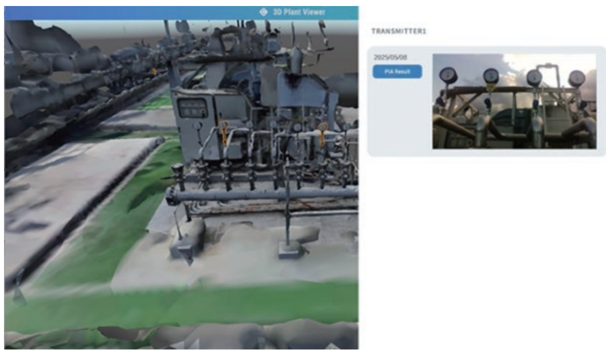

Figure 12 3D map viewer visualizing robot position and inspection data

Integration Testing

In the on-premises environment established at the Komagane Plant, a test route was configured to include staircases, steps, and narrow passageways, and operational verification of the integrated management system as a whole was carried out through the following procedure, covering the end-to-end workflow from 3D map generation of the on-site environment through autonomous execution of inspection tasks to retrieval of results:

1. Create the robot's patrol inspection route and scenario.
2. Execute the prepared scenario from the RMC.
3. Conduct an autonomous inspection by the robot and confirm its position remotely using the 3D map.
4. Retrieve inspection results, perform automatic analysis of process parameters, and then confirm the results on the 3D map.

The integration test results confirmed that the robot executed each inspection task defined in the pre-configured scenario without issue, and that the acquired image data and measured values were integrated and displayed on the 3D map following automatic analysis by the PIA. This verified that the robot's position and inspection results could be monitored in a unified manner from a remote location and demonstrated that the integrated management system can smoothly execute the patrol inspection process at a practical operational level.

Discussion

This demonstration trial confirmed that autonomous patrol inspection using a mobile robot is technically feasible on offshore platforms. Nevertheless, it is desirable that plant facilities be designed so that robot travel paths and inspection target placements allow autonomous mobile robots to perform at their full potential. Access to elevated or confined areas, visibility of instruments and valves, and stability of the communications environment are important considerations in future plant design.

CONCLUSION

This research and development effort demonstrated the technical feasibility of autonomous mobile robot operations on offshore platforms and the utility of system integration, establishing a foundation for safe and efficient inspection work in hazardous areas. This makes it possible to automate simple yet demanding inspection tasks that have traditionally been performed manually, thereby reducing the burden on workers and standardizing inspection quality.

Going forward, by integrating this system with drones and production control systems, we will advance the realization of smart plant operations capable of comprehensive, real-time monitoring and management of entire facilities. Furthermore, with a view toward application not only in the oil and gas sector but also across diverse industries (e.g., chemicals, electric power, and food manufacturing), we aim to establish an integrated next-generation plant management platform that enhances the safety, efficiency, and sustainability of plant operations by standardizing operating conditions and facility design guidelines and pursuing international deployment of the technology.

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