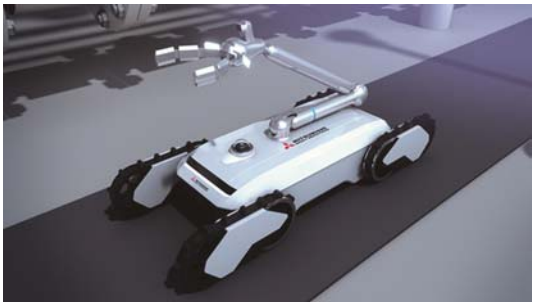
Development of Explosion-proof Autonomous Plant Operation Robot for Petrochemical Plants



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For increasing the patrol frequency of petrochemical plants to ensure reliability while conserving manpower, the robotization of plant patrol checks is being demanded by domestic and foreign petroleum gas operators. However, due to the problems of making a robot explosion-proof, almost no robots satisfy these needs. Mitsubishi Heavy Industries, Ltd. (MHI) has already developed a land-mobile, explosion-proof robot that can be controlled wirelessly within flammable gas atmospheres. Currently, by utilizing this explosion-proof mobility establishment technology, we are promoting the development of an explosion-proof robot for autonomous plant operation to satisfy the above needs earlier than other countries. The robot under development moves autonomously with map information and sensor information, and can automatically acquire plant information such as images of instruments, thermal images, gas concentrations, etc., using the on-board cameras, gas detectors, etc.

1. Introduction

Petrochemical plants under operation require periodical patrols by checkers to detect abnormalities before a disaster occurs. However, there is always a danger of fire and explosion in the plant. In addition, the patrol areas include many high or narrow places, and may be in severe environments such as storms, extreme cold, etc., in some cases. Therefore, ensuring the safety of workers is an important issue for petroleum gas operators. Furthermore, there is the challenge of ensuring plant reliability by increasing the patrol frequency and that of improving the operational efficiency through labor saving and automation to secure earnings regardless of changing crude oil prices.

MHI has completed the development of a remote-control type land-mobile, explosion-proof robot that was started in fiscal 2014 assuming situation checks in a flammable gas atmospheres where people cannot easily approach, such as in the case of a disaster in tunnels, plants, etc. This robot acquired a type examination certificate based on the "Explosion protection guidelines consistent with international standards (Ex2015)"(1) for the first time in Japan as a mobile robot equipped with a large capacity battery.(2)(3)(4) This report describes, as an application example of the establishment technology of explosion-proof mobility that can be controlled wirelessly within flammable gas atmospheres, the development status of an autonomous mobile explosion-proof robot (hereinafter referred to as "explosion-proof autonomous plant operation robot") that carries out patrol checks of a petrochemical plant based on the development of a remote control type mobile explosion-proof robot.

2. Outline of explosion-proof autonomous plant operation robot (first-generation machine)

Currently, in cooperation with domestic and overseas petrochemical plant operators, we are developing a first-generation explosion-proof autonomous plant operation robot that autonomously patrols inside a plant and gathers information. This robot is planned to be deployed to an actual

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plant as early as fiscal 2019, after trial operation and improvement in a simulation plant. **Figure 1** presents an overview of the system and the specifications of the robot under development.

The explosion-proof autonomous plant operation robot (first-generation machine) can autonomously move around a certain floor of a plant according to previously acquired map information and sensor information, and is designed to acquire plant information such as images of instruments, temperatures, gas concentrations, etc., using the on-board visible light camera, thermal camera, gas detectors, etc., while moving according to the preset schedule and patrol route. **Figure 2** shows the appearance and equipment configuration of the prototype explosion-proof autonomous plant operation robot.

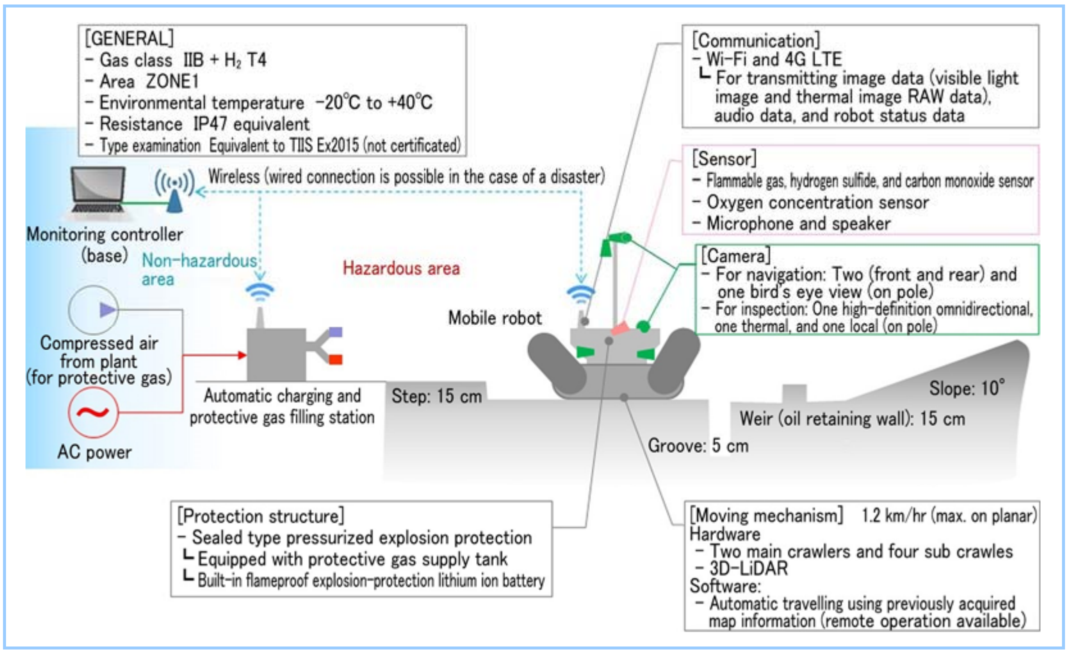

Figure 1 Outline of system and specifications of explosion-proof autonomous robot

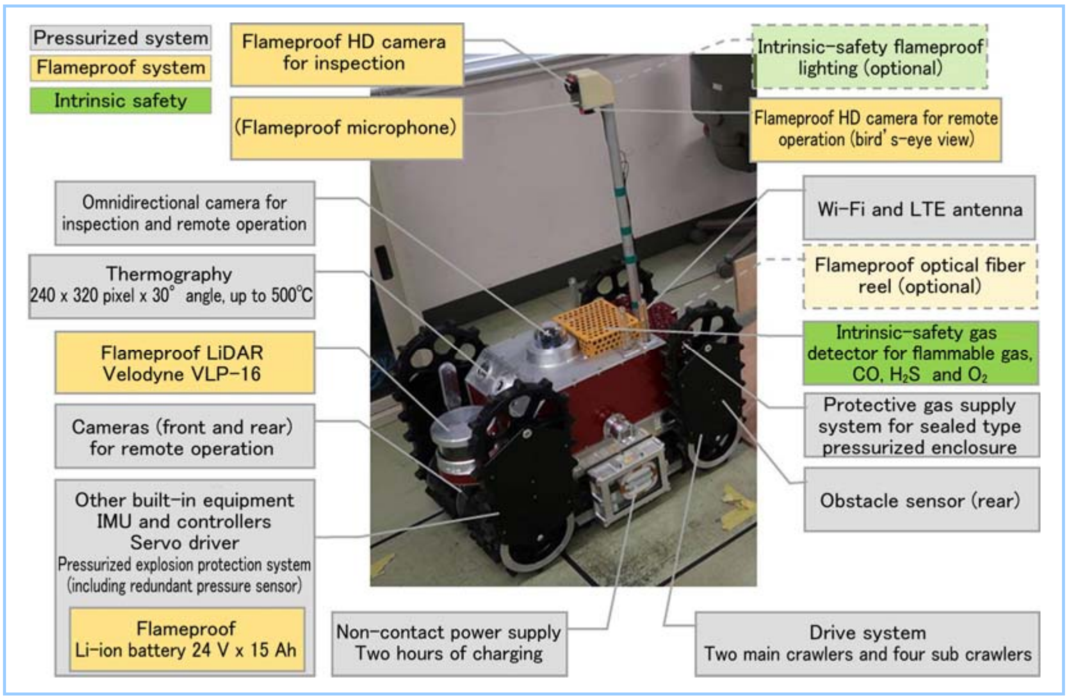

Figure 2 Appearance and equipment configuration of robot

The initial remote-control type robot adopted a pressurized explosion protection structure, which is more complicated but can be lighter than a flameproof explosion protection structure, to realize the development concept of being light enough to be handled manually without requiring lifting equipment for its installation and maintenance. The explosion-proof autonomous plant operation robot maintains this explosion protection performance, which corresponds to Zone 1 (for example, an area where there is a possibility of frequently generating an explosive atmosphere, such as in the vicinity of an opening which discharges flammable gas in the opening and closing of a lid during normal operation and control). With regard to the traveling performance, while keeping the light weight concept of the initial remote-control type robot due to the crawler drive system and pressurized explosion protection structure (total mass 60 kg), the following additions and improvements in the specifications were made to facilitate autonomous patrol and information gathering so that the robot can handle multi-floor operation including stair climbing simply by updating the robot software.

(1) Adoption of filled type pressurized explosion protection structure

The remote-control type land-mobile, explosion-proof robot, which was the base of this development, adopted a sealed type pressurized explosion protection structure with an air tight enclosure, among pressurized explosion protection structures that prevent inflammable gas from entering the enclosure by pressurizing and sealing a protective gas in the enclosure to make the internal pressure higher than the external pressure. However, to maintain the explosion protection function, inert gas (N_2) had to be sealed as the protective gas, which required large pieces of equipment and resulted in complicated operation. For this reason, by modifying the robot so that it has a structure with a pressure accumulation tank to maintain the robot internal pressure and replenish leaked protective gas, a filled type pressurized explosion protection structure was adopted. As a result, air can be used for the protective gas according to the explosion protection regulations and the operation is simplified. **Figure 3** depicts an overview of the explosion protection structure.

The explosion protection regulations stipulate that in the case of a pressurized explosion protection structure, it is necessary to constantly monitor the internal pressure and to provide a protection circuit that shuts off the power supply when the boundary is damaged. If a battery is installed inside the robot in cases where only a pressurized explosion protection structure is used, damage to the robot body forming the boundary may cause the energized battery to contact the flammable gas to initiate firing even when the power supply is shut off by the protection circuit. Therefore, a nesting structure where a battery with a flameproof explosion protection structure is incorporated in the robot body with a pressurized explosion protection structure is adopted.

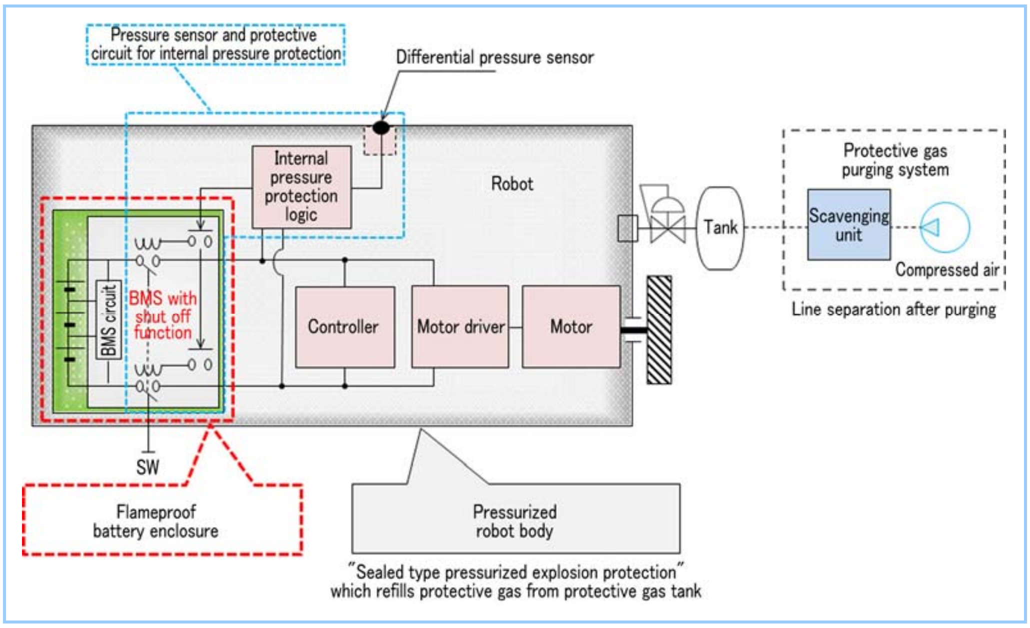

Figure 3 Explosion protection structure of robot

(2) Power supply system for automatically charging internal battery

A non-contact power supply is adopted assuming charging in an outdoor adverse environment (rain, dust, etc.). Glass is the only material that satisfies the antistatic property requirement for explosion protection and has an electromagnetic wave heat generation prevention property during non-contact power supply at the same time. Tempered glass with a thickness of 6 to 10 mm is necessary to satisfy the strength for the explosion protection structure. For this reason, the distance between the power supply side and the power receiving side is inevitably larger than the usual non-contact power supply device. Therefore, to realize adequate power supply (where one hour of robot operation can be made by two hours of charging) even under this condition, a magnetic resonance method is adopted. **Figure 4** provides an overview of the power supply system during trial verification. For the explosion-proof autonomous plant operation robot (first-generation machine), power supply is carried out in a non-hazardous area, but for the second-generation machine, power supply is planned to be carried out in a dangerous area. The explosion protection regulations regulate the radiation of electromagnetic waves in flammable gas atmospheres in a conservative manner. However, we have started consultation with the explosion protection certification agency based on actual electromagnetic field intensity data.

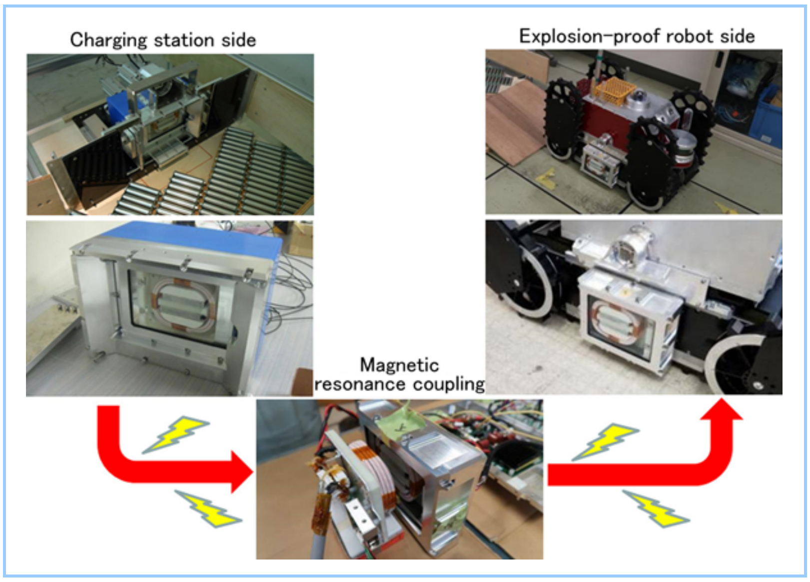

Figure 4 Outline of power supply system

(3) Establishment of charging and filling stations for long-term operation

For the long-term operation of the robot, we established a station where power supply to the battery mounted on the robot is carried out together with air filling to the accumulator tank for maintaining the robot internal pressure, realizing simultaneous charging and filling when the robot returns to the station. The station employs a roller-based guiding mechanism so that the robot can be accurately positioned in the charging system and the filling system with as few sensors as possible. By arranging the rollers of the station diagonally with respect to the robot moving direction, the robot is guided to a position in contact with the innermost wall and one side wall simply by advancing straight ahead. **Figure 5** illustrates the prototype station.

The station was reduced in size to 1 m × 1 m assuming installation in a narrow offshore plant, and as with the robot, its weight was reduced to 60 kg in mass so that it can be handled manually without requiring lifting equipment.

(4) Equipped with autonomous moving system for autonomous plant patrol

The installed robot hardware includes a new explosion-proof 3D laser range finder (LiDAR). This hardware adopts an independent flameproof explosion protection structure, enabling flexible installation and relocation at any position of the robot with a pressurized explosion protection structure. In addition, a self-position estimation and environmental map generation software package called SLAM (Simultaneous Localization And Mapping) is employed and a high-spec computer that can handle advanced software processing is installed. **Figure 6** presents the situation where the robot estimates its own position by comparing information on the environmental map with information acquired by the LiDAR.

(5) Equipped with sensors for collection of plant information

A small camera with a pressurized explosion protection structure is installed on a pole provided at the robot upper body to secure a field of vision similar to that of a patrol checker. It is planned that a manipulator equipped with a thermal camera with a pressurized explosion protection structure on its tip will be installed on the robot in the future to obtain a wide observation field. In addition, a microphone with a pressurized explosion protection structure for collecting sound information emitted from plant equipment has already been developed as a single unit. Furthermore, it is planned that a function to present the heat and gas distribution in the plant and its temporal change to the plant operator will be offered.

(6) Establishment of IoT platform

In addition to Wi-Fi, LTE is also constantly provided as a wireless communication method to connect the robot and the plant operator. Furthermore, as a means to respond to the disruption of communication infrastructure in the event of a disaster, an optical fiber reel for wired communication can be retrofitted as optional equipment.

We are developing an image processing technology for detecting abnormalities regardless of environmental conditions (weather, time, etc.) and a data storage and processing system for presenting a comparison over time for each specified place to the plant operator for detecting abnormalities of equipment based on transmitted plant information. This data can be monitored even at remote locations via a secure cloud, and it is also possible to edit the automatic operation schedule of the robot as necessary. In addition, it is planned to remotely control the robot via the same platform for implementing work that is difficult to perform autonomously, such as the reading of dirty instruments, manipulating switch boards (expected as a function of the future second-generation machine), operating valves to collect samples, etc.).

Figure 5 Appearance of station

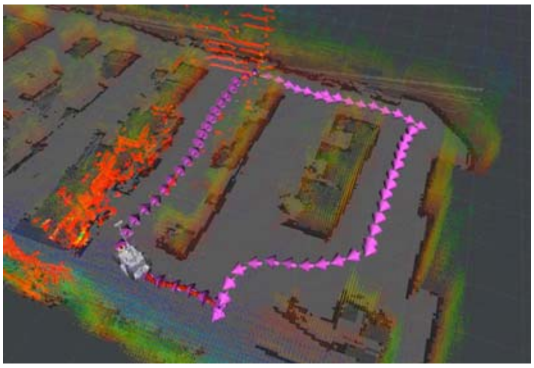

Figure 6 Self-position estimation

3. Future prospects

Most domestic petrochemical plants are onshore downstream facilities for refining operations, and it is relatively easy for human workers to respond to various events in patrol checks or in the case of an accident. Therefore, the requirements for the performance and the cost-effectiveness of a robot that replaces human workers are inevitably stringent. On the other hand, in the case of upstream facilities for petroleum and gas mining mainly located overseas, and for offshore facilities in particular, the work environment is severe even under normal operation, manpower costs at the site are high, and human workers cannot approach at all in the event of an accident, making the remedy and recovery of the situation difficult. Therefore, it is considered that the demand for manpower saving in the plant is extremely high. However, it is not easy to automate all equipment in such environments where flammable gases are present. Therefore, it is thought that there is great expectation for an explosion-proof autonomous plant operation robot that collects information and implements various tasks such as valve operation and sample collection as one device constituting an IoT platform for automation and manpower saving. **Figure 7** is the conceptual model of the explosion-proof autonomous plant operation robot.

To expand the market for plant patrol check robots including overseas in the future, it is necessary to advance development and verification in a step by step manner in cooperation with users through pilot operation in an actual plant. These efforts include the reliability improvement of autonomous operation, the analysis of collected plant information, and the implementation of abnormality diagnosis technology in addition to certificate acquisition of overseas standards (overseas explosion protection standards such as IECEx and ATEX) and the development of the manipulator and autonomous mobile technology for climbing stairs between floors. Although there are many challenges and difficulties that still have to be overcome, we would like to steadily accelerate the commercialization of explosion-proof autonomous plant operation robots.

Figure 7 Autonomous plant operation robot

4. Conclusion

MHI is working on technological development for the establishment of explosion-proof mobility that can be controlled wirelessly within flammable gas atmospheres. In this report, an explosion-proof autonomous robot that performs autonomous patrol check of a petrochemical plant was introduced as an application example of this technology. In the future, we will conduct verification tests and evaluations at domestic and overseas plants, develop a small manipulator and an autonomous stair climbing function, and enable light-duty tasks such as valve operation and patrols on multiple floors. By 2019, we will introduce a prototype autonomous patrol robot equipped with a manipulator to an actual plant, and gradually expand the mobility, abnormality detection functions, and information processing functions.

Technologies for wireless traveling over a long period of time in flammable gas atmospheres can be applied not only to plant operation support, but also to plant inspection. Since announcing the acquisition of a type examination certificate for our remote-controlled explosion-proof mobile robot in 2016, we have received many inquiries about applicability to inspections of pipes and tanks during service or just after stopping service. For actual inspections, explosion protection not only for mobility, but also for the inspection equipment itself (such as ultrasonic probe, laser sensor, etc.) is not easy. However, we will continue to cooperate with users to contribute to the maintenance of plant health and the extension of operating life.

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