Maintenance Robots for Unmanned Sewage Pumping Stations

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1. Introduction

Water and sewage systems play an important role in our lives as part of our living environment. Demand for stable operations and safety assurance in these systems are increasing. To fulfill these needs, a facility's maintenance operations must be upgraded. However, difficult working conditions, the need for 24-hour supervision and other factors have made it difficult to attract sufficient personnel. An increase in the number of unmanned facilities has further amplified the need for automated operation, thus leading to a greater demand for maintenance robots.

This paper describes the system and operations of maintenance robots developed for deployment at unmanned sewage pumping stations.

2. Purpose of Introducing Maintenance Robots to Unmanned Pumping Stations

2.1 Inspection operations at sewage pumping stations

To prevent flooding in areas with low elevations that experience heavy rainfall, sewage pumping stations pump out rain water. They are vital in preventing natural disasters. A facility where operators are not usually stationed is called an unmanned sewage pumping station. There are approximately 40 such stations in Tokyo.

The purpose of inspections at these pumping stations is to maintain a condition that ensures proper pumping when required. This is assured by an inspection of the equipment by human personnel utilizing his senses to monitor conditions and detect malfunction as early as possible. These inspections are normally conducted on a daily basis by an inspector dispatched from a manned pumping station. Approximately 400 items, including equipment status, are inspected.

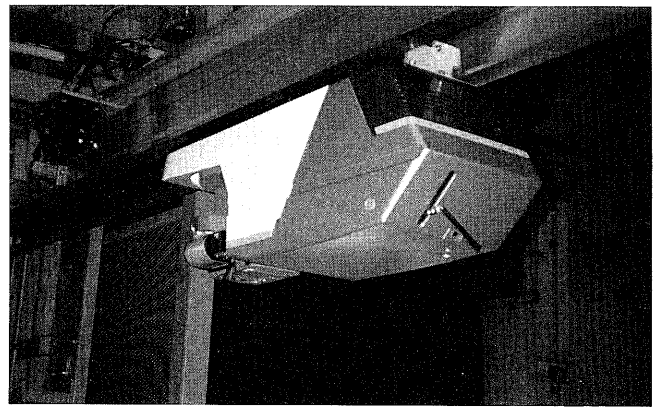
2.2 Objectives of introducing robots

The introduction of robots has the following four objectives:

(1) To reduce the burden of inspection
(2) To detect malfunction as quickly as possible with more frequent inspections
(3) To perform inspections during operating hours, which is difficult at present
(4) To take prompt action when equipment malfunction is reported

Figure 1 shows the exterior of an inspection vehicle (for visible camera).

Fig. 1 Exterior of an inspection vehicle (for visible camera)



3. System Configuration

The maintenance robot is comprised of a mobile inspection vehicle, mounted with a sensor, a rail on which the inspection vehicle runs, an inspection vehicle land control device and a maintenance operation console.

The inspection vehicle and land control device communicate with each other by radio. The vehicle transfers image or voice signals received by the sensors to the control device, which then sends controlling signals to the vehicle. Figure 2 shows the system configuration.

4. Special Features of Maintenance Robots

4.1 Manipulator to enable eye-level inspection

Although introduction of the inspection robot reduces human involvement during inspection, it is difficult for a robot to completely replace a human inspector. In order to maintain a facility that does not impede human inspection, a rail was run across the ceiling along which the inspection vehicle, mounted with a

Fig. 2 System configuration

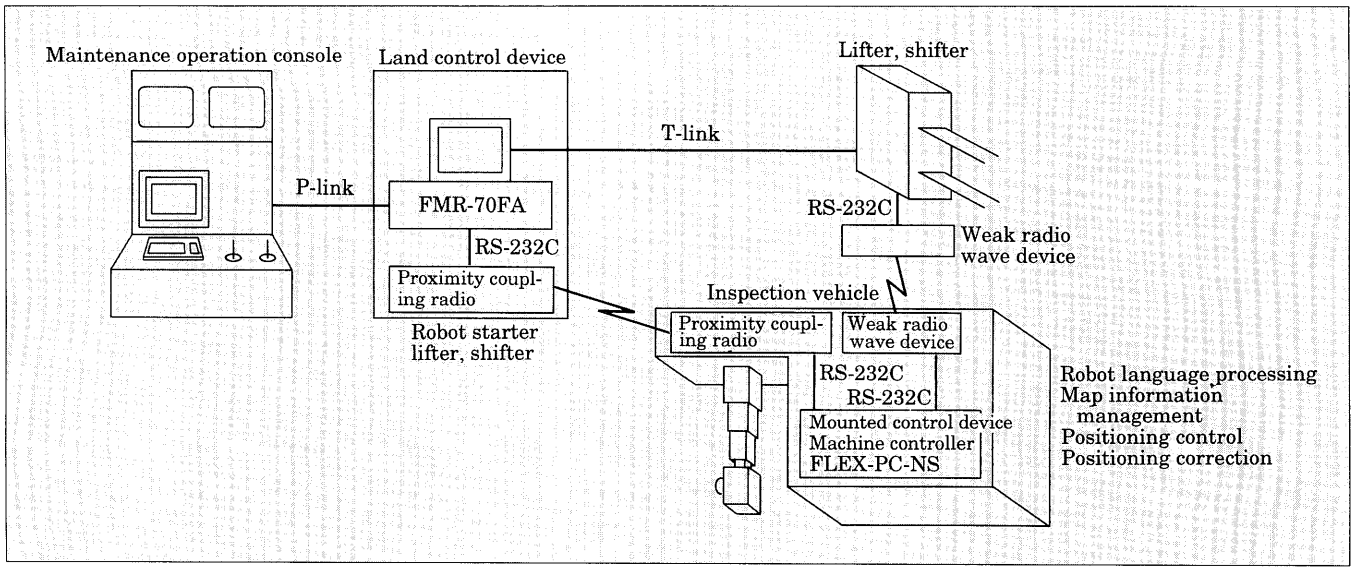
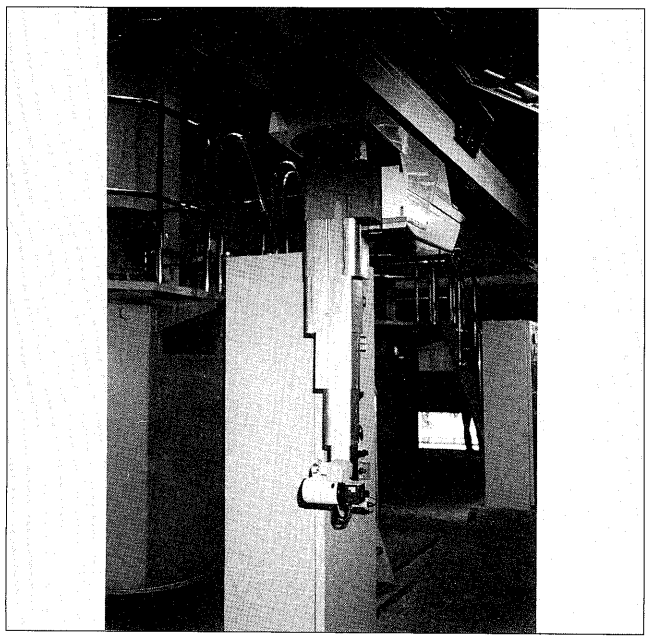


Fig. 3 Exterior of the multistage telescopic manipulator (extended)



camera and other sensors, moves to conduct the inspection.

However, the imagery produced by the inspection vehicle from the ceiling is different from that of an inspector at eye level. This discrepancy makes it difficult to apply typical assessment criteria. To overcome this problem, we developed a multistage, one-meter telescopic manipulator to modify the camera's position. Figure 3 shows the exterior of the multistage telescopic manipulator (when extended).

4.2 Automatic diagnosis of the targeted equipment

Many conventional inspection robots were controlled by an operator. This operator was also required to observe the images taken by the camera mounted on the robot and then to assess the equipment's status. Although, this method does not entirely liberate operators from the inspection process, it results in only a slightly reduced burden. We therefore developed and adopted an automatic diagnosing function to assess the targeted equipment. The robot is equipped with a function to process the data transmitted from the sensors, including image data (binary image data and differential image detection).

5. Details of Robot Inspection

5.1 Inspection items and operation method

The automatic robot inspection includes both daily and emergency inspections. Table 1 shows the inspection items. As Table 2 shows, we developed six operation methods. Selection and operation of the six methods are possible by remote control.

5.2 Inspection route

The robot is installed in the Tokyo Metropolitan Sewerage Bureau's Senju Nishi Pumping Station, a building with one underground and two aboveground floors. It houses a number of rooms targeted for inspection, including the pumping, sedimentation basin and generator rooms. As a result, the inspection route must be branched. To meet this requirement, we developed a mechanism called a shifter which divides the route horizontally and a device called a lifter that enables vertical route distribution. We also installed special fire shutters to maintain the fire prevention zones. Each inspection route is approximately 300 meters long.

Figure 4 shows the inspection route at the Senju Nishi Pumping Station.

Table 1 Items of automatic inspection by robot

Inspection	Item	System	Sensor	Inspection vehicle
Daily inspection	Reading of measuring instrument (round indicator)	Image processing	Visible camera	Vehicle A
	Reading of measuring instrument (longitudinal indicator)			
	Reading of liquid level			
	Comparison between dual sensors and measuring instrument			
	Detection of malfunction in the entire facility			
	Detection of oil and water leaks			
	Inspection using the facility's temperature distribution image		Infrared camera	Vehicle B
	Detection of intruder and fire			
	Sound analysis of facility operation	Acoustic analysis	Microphone	Vehicle A
	Malodor inspection	Malodor intensity assessment	Malodor sensor	
	Automatic inspection of pump and generator operations	Automatic start of inspection vehicle	Visible and infra-red cameras	Vehicles A and B
Emergency inspection	Actions against malfunctions detected during daily inspection		Visible camera	Vehicle A
	Actions against failures			

Table 2 Robot operating methods

Operating method	Details
Regular inspection	Daily inspection at a preset time
Inspection during operation	Equipment inspection during operating hours
Emergency inspection	Shift to equipment inspection positions when equipment is deemed defective Human assessment is normally required
Ad hoc inspection	Automatic inspection upon inspector's instructions
Shift to specified points	Inspection vehicle shifts to the position specified by the inspector
Manual operation	Inspection vehicle operated in accordance with the inspector's instructions

Table 3 Inspection vehicle and mounted sensors

Inspection vehicle A (for visible camera)	Visible camera (with zoom lens) Microphone (high frequency band) Microphone (directional) Malodor sensor
Inspection vehicle B (for infrared camera)	Infra-red camera for thermal measurement (with visible camera) Microphone

Table 4 Specifications of inspection vehicle A (for visible camera)

Running method		Ceiling rail
Maximum running speed		20m/min
Turnig radius		1m
Camera operation range	Vertical travel	−1,000 to 0 mm
	Horizontal radius	−200 to +200°
	Vertical radius	−90 to +45°
Power supply		Trolley
Dimensions		W322 × D968 × H346 (mm)
Mass		68kg

6. Inspection Vehicle

6.1 Inspection vehicle and mounted sensors

To minimize size, two types of inspection vehicles are provided for the maintenance robot: inspection vehicle A for a visible camera and inspection vehicle B for an infrared camera. The sensors mounted on these vehicles are described in the tables below. Table 3 shows the relationship between the inspection vehicles and the sensors mounted on them. Table 4 shows the technical specifications of inspection vehicle A, and Figure 5 shows inspection vehicle A in operation.

(1) Visible camera (with zoom lens)

The visible camera shoots images of the inside of the pumping station and the targeted equipment for monitoring by humans. It also acquires data for automatic diagnosis using the image processing function. The camera has a zoom lens to capture images of objects located in the distance.

(2) Infrared camera for thermal measurement (with visible camera)

The mounted infrared camera enables a non-contact thermal measurement of the equipment. As the infrared camera is unable to identify objects, a visible camera is also provided to capture visible images. Simultaneous viewing of the infrared and visible images enable identification and measurement of the targeted equipment.

(3) Microphones

Two microphones are mounted on the vehicles: a directional microphone that captures sounds coming from the direction of the image, and a microphone with an extensive frequency band that enables frequency analysis of sounds coming from the operating equip-

Fig. 4 Inspection route at the Senju Nishi Pumping Station

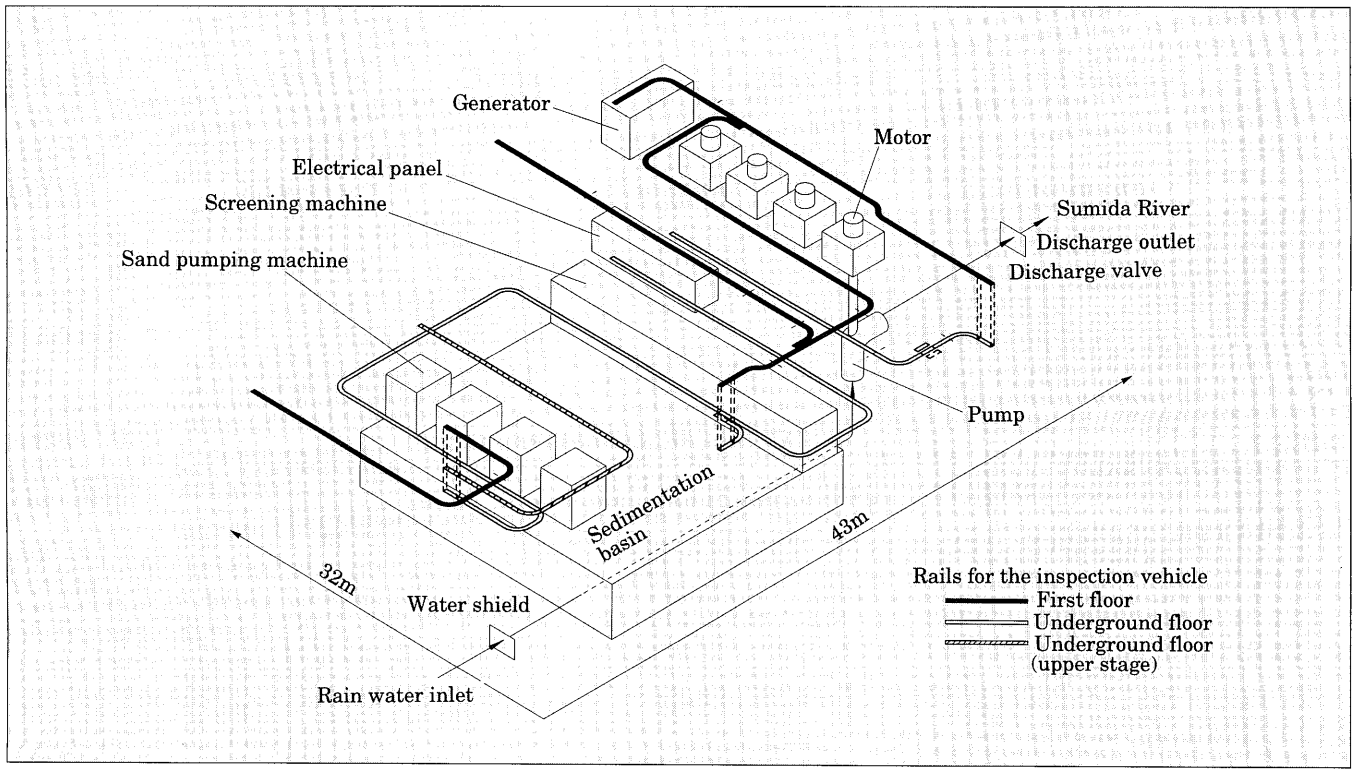


Fig. 5 Inspection vehicle (for visible camera) in operation (reading of the measuring instrument)

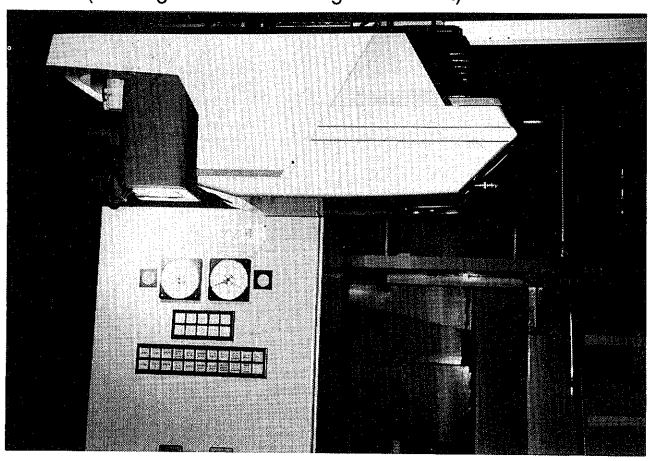
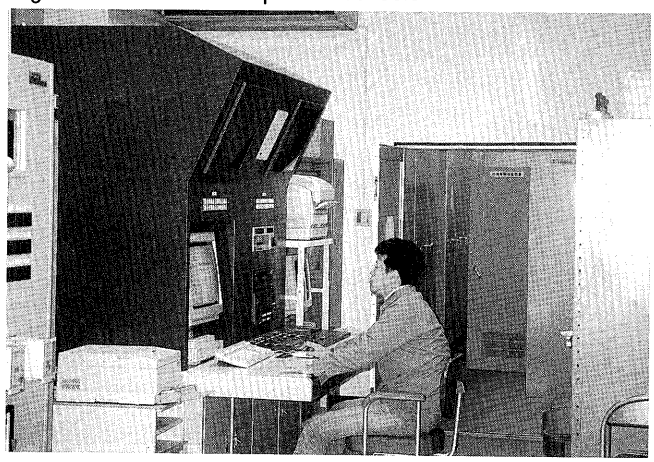


Fig. 6 Exterior of the inspection console



ment.

(4) Malodor sensor

A malodor sensor is mounted to assess the intensity of specific malodors in the pumping station.

6.2 Manipulator

To examine the inspection target from various angles, inspection vehicle A has a manipulator which moves the visible camera horizontally and vertically as well as rotating it up and down.

The mechanism that enables vertical movement is comprised of a multistage (five stage) extensible structure, resembling a car's radio antenna. The manipulator measures 1,300 mm when extended and 300 mm when contracted.

Operational efficiency was also boosted by adding a horizontal rotation angle of ±200° (typically less than ±180°) to facilitate rotation.

7. Maintenance Console

7.1 Maintenance console function

The CRT and operation panel of the maintenance console receive the inspector's instructions, operate the maintenance robot and automatically inspect the targeted equipment. The maintenance console also records inspection results and classifies data also used for other records and report formats. Figure 6 shows the exterior of the maintenance console.

7.2 Automatic diagnosis

(1) Reading the measuring instrument (meter) index

The indicator segment is extracted from the inspection image. The index position of the longitudinal indicator is converted into the values indicated. On the round indicator, the index angle is converted into the values indicated. A comparison between the rated and indicated values serves as the basis for assessment of the equipment status.

(2) Oil and water leak assessment

Oil and water leaks are assessed based on the differential images produced by comparing the inspection images of the targeted and base images (a previous image or an image taken earlier at a fixed interval).

(3) Acoustic diagnosis

A neural network is used to examine the acoustic spectrum of sounds collected by the microphone. A comparison of the spectrum peak bands constitutes the basis of equipment status assessment.

(4) Malodor diagnosis

The values measured by the malodor sensor is converted to verbal malodor intensity assessment levels. Data taken from actual measurements are used as criteria for the sensational scale (expression) of malodor intensity.

8. Conclusion

This paper introduced the inspection robot utilized at an unmanned sewage pumping station.

Improving efficiency and ensuring the stable operation of any facility requires considerable effort. We therefore hope to focus on development, with the ultimate goal of improving the efficiency of maintenance operations.