Robotics Technologies for Decommissioning of Fukushima Daiichi – 17077

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ABSTRACT

The Fukushima Daiichi Nuclear Power Station (NPS) of Tokyo Electric Power Company (TEPCO) was the site of a severe nuclear accident after the 2011 Off the Pacific coast of Tohoku Earthquake and subsequent tsunami. Extensive structural damage occurred in the NPS facilities, including such environments as the reactor buildings and the primary containment vessels (PCVs). These are high radiation areas, having underwater areas, narrow spaces and so on. It is necessary to determine the extent of contamination and the location of debris to plan decommissioning operations. Survey targets in the past few years have been focused on inspections of the basement of the reactor buildings and the inside of the PCVs. Human operators cannot access these environments and work in them directly. Therefore, remotely operated robots and measurement technologies are needed to carry out various operations. For underwater surveys, we have developed a submersible crawling swimming robot that can avoid obstacles and inspect wide areas as it moves around. A shape-changing robot has been developed for passing through narrow spaces and crawling on rough floors. An ultrasonic imaging method combined with convex scanning and a divergent beam has been proposed to visualize environments in turbid water. In this paper, we describe details of the two survey robots and the underwater imaging method.

INTRODUCTION

For the safe and speedy decommissioning of the Fukushima Daiichi NPS, internal survey techniques have been expected to provide an understanding of the current rector plant status. After the accident, the Government of Japan and TEPCO prepared the “Roadmap towards Restoration from the Accident” [1]. According to the roadmap, inspecting the PCVs and stopping water leakage from the lower part of the PCVs are to be carried out from FY 2013 to FY 2017, and water filling into the lower part of the PCVs is to be started in FY 2018. After that, surveying PCV internals and stopping water leakage from the upper part of the PCVs are planned. Then, an in-core survey will be implemented to observe structures and melted fuel debris in the reactor pressure vessels (RPVs). Fuel debris removal is planned from FY 2021. In the Fukushima Daiichi NPS, such environments as the reactor buildings and the PCVs are high radiation areas, having underwater areas, narrow spaces and so on. Fig. 1 shows a schematic drawing of a reactor building and some components. Survey targets in the past few years have been focused on inspecting the basements of the reactor buildings and the inside of the PCVs in order to investigate water leakage points and melted fuel debris distribution. Human operators cannot access these environments and work in them directly. It must be assumed that water quality of the operation environments is turbid as identified in a previous survey [2]. Therefore, remotely operated robots and underwater measurement technologies are needed to carry out various operations.

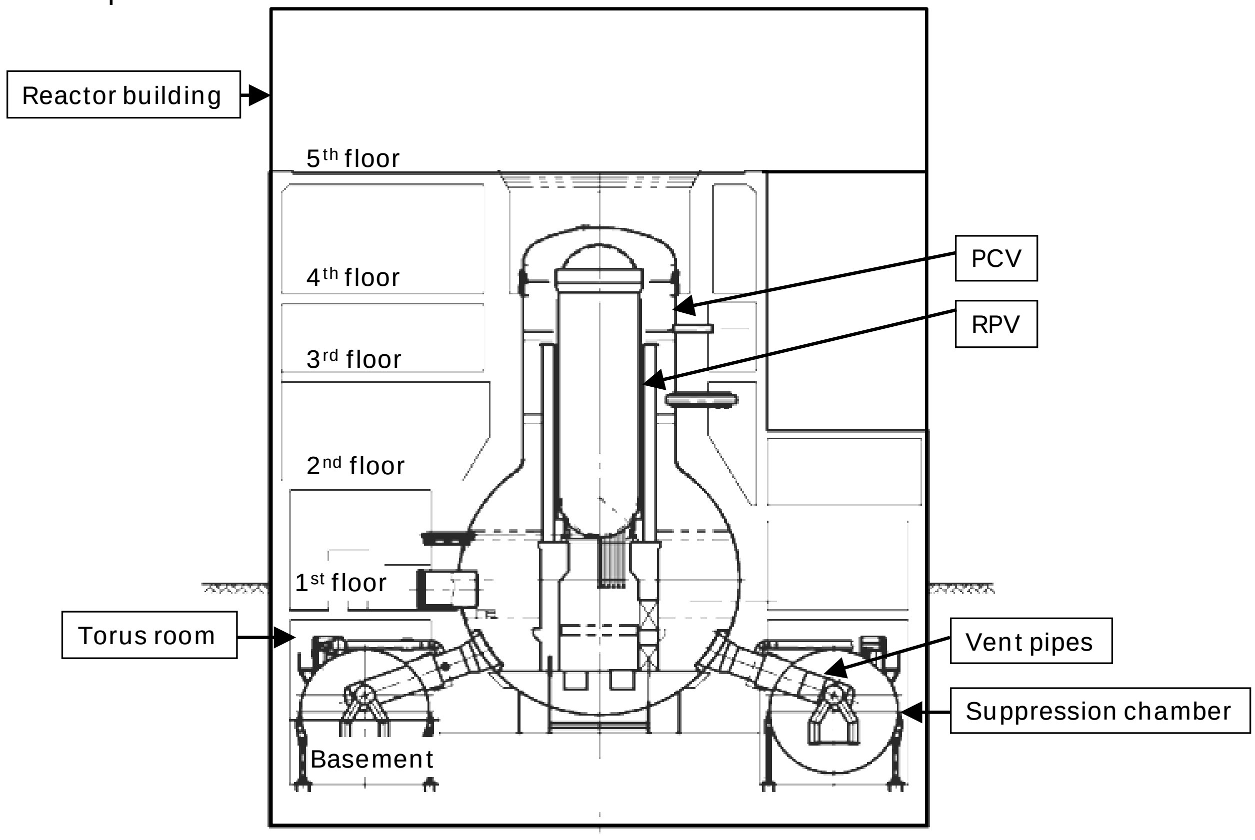


Fig. 1. Schematic drawing of a reactor building.

SUBMERSIBLE CRAWLING SWIMMING ROBOT

The submersible crawling swimming robot was developed to survey narrow spaces in water environments [3][4]. The robot was used for investigating water leakage points in the basement of the reactor building, especially the torus room. Fig. 2 shows a photo of the robot. The robot has six thrusters and two crawlers. Four vertical thrusters are used for vertical movement, and two horizontal thrusters are used for horizontal movement. The robot can also move on a floor and climb on a vertical wall using its crawlers. The robot has the dimensions: length, 605 mm; width, 450 mm; and height, 330 mm. The weight is 31.5 kg in air, and 1.5 kg in water. 80 m umbilical cables are connected to a power supply and they also provide a communication route with operators.

Fig. 3 shows movement modes of the submersible crawling swimming robot. To avoid obstacles and increase accessibility in narrow spaces, swimming and posture changing functions are useful. Fig. 4 shows the procedures for posture change. The robot hovers close to a wall, and changes its posture 90 deg by controlling the thrust forces automatically. After adhering to the wall, crawlers are used to move. We confirmed that the robot can avoid obstacles in a water tank by swimming and changing the posture through controlling its thrusters.

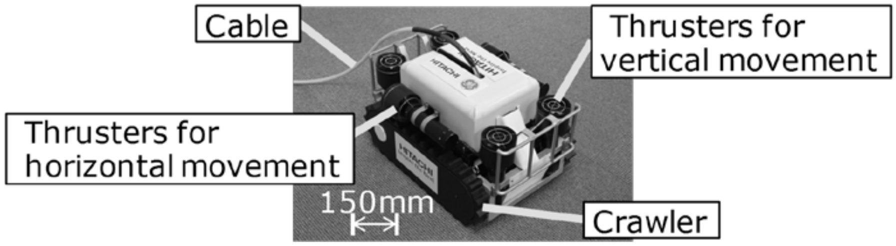


Fig. 2. Photo of the submersible crawling swimming robot.

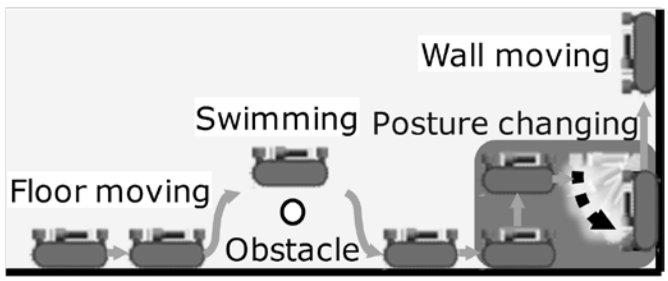


Fig. 3. Movement modes of the submersible crawling swimming robot.

Fig. 4. Procedures for posture change.

SHAPE-CHANGING ROBOT

The shape-changing robot was developed to pass through narrow spaces and to carry out surveys while crawling on rough floors [3][5]. The robot was used for investigating the inside of the PCV. Fig. 5 shows a photo of the shape-changing robot. The robot consists of three components: the main body and two compact crawlers. The crawlers are mounted on the body with shape-changing gears. By controlling the gears, the crawler is rotated 90 deg in relation to the body. When the robot is changed to the I-shape (which can be roughly considered to be cylindrical) it has a diameter that is less than 100 mm, and the weight is 7.5 kg. Maximum thrust force is 100 N and it is sufficient to pull an umbilical cable.

Fig. 6 shows movement of the robot. To pass through narrow spaces such as pipes, the robot changes to the I-shape in which its two crawlers are arranged in a line. After entering the survey area, the robot changes to the U-shape and it is able to crawl on rough floors such as grating floors.

We assume that the robot will be applied to making PCV internal surveys, and this environment was previously found to be a high radiation area, with a dose rate of 70 Sv/h [6]. Generally, it is known that electronic devices are damaged by radiation. For that reason, most of the electronic devices are separated from the robot and arranged in a low radiation area. The robot has only motors without motor drivers and encoders, and a CCD image chip is mounted on the robot. Therefore high radiation tolerance (about 1000 Gy) is realized.

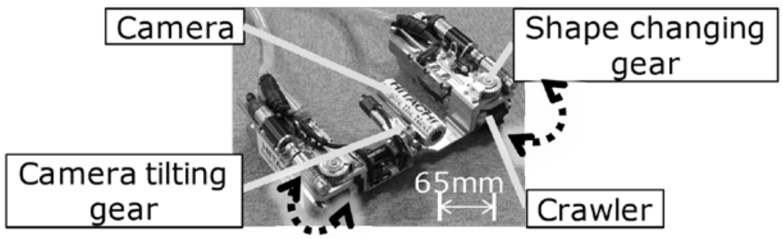


Fig. 5. Photo of the shape-changing robot.

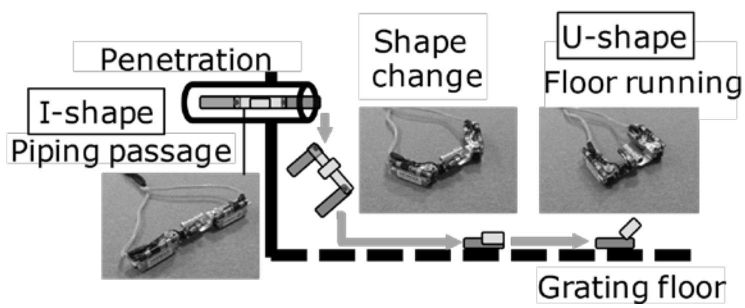
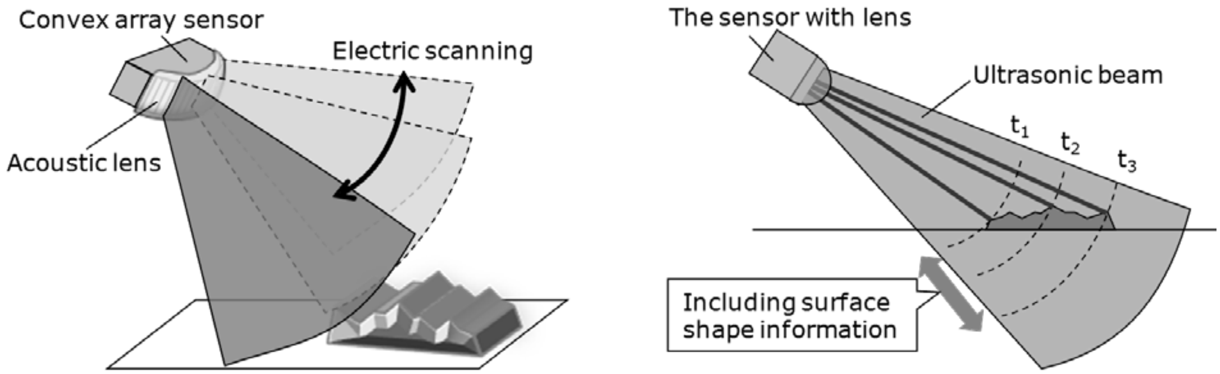


Fig. 6. Movement of the shape-changing robot.

ULTRASONIC UNDERWATER IMAGING

In this section, measurement technologies are described to visualize environments in turbid water. Fig. 7 shows an ultrasonic imaging method that we proposed. The beam scanning method is shown in Fig. 7 (a). Ultrasonic beams are focused in a direction parallel to the element array direction and defocused in a direction perpendicular to it. Each beam has a thin fan shape and is scanned electrically in a manner similar to that of sector scanning. Information on the surface shape of an underwater object is obtained as the difference of time-of-flight in each spread fan beam, as shown in Fig. 7 (b); this is a similar method to that used for acoustic lens sonar devices [7][8].



(a) Spread fan beam scanning (b) Imaging method using time-of-flight

Fig. 7. Ultrasonic imaging method using convex array sensor and lens.

A grating panel and a cylindrical weight were measured as a confirmation experiment of imaging performance. The configuration of the experimental setup is shown in the schematic diagram and photos in Fig. 8. Frequency of the ultrasonic wave was selected as 2 MHz, in consideration of transmission in water. Spread angle of fan beam was approximately ±10 deg. Small transducer elements were arrayed along a convex shape. Locations of measurement objects were about 1 m from the ultrasonic array sensor.

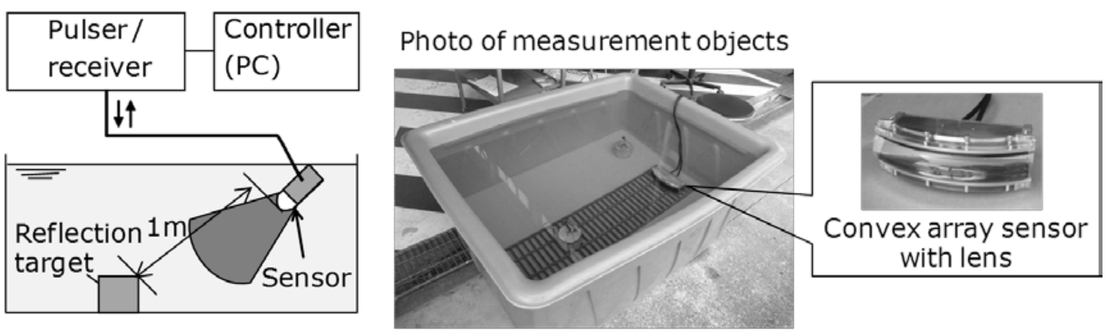
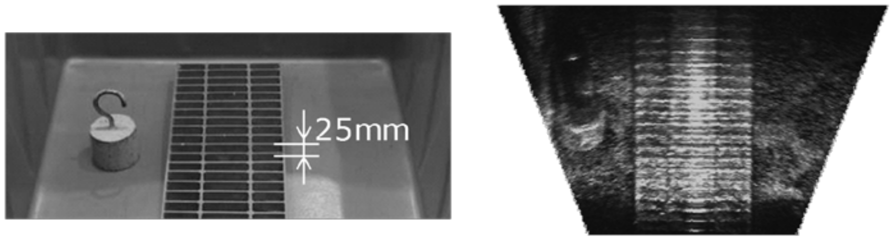


Fig. 8. Configuration of experimental setup and measurement targets.

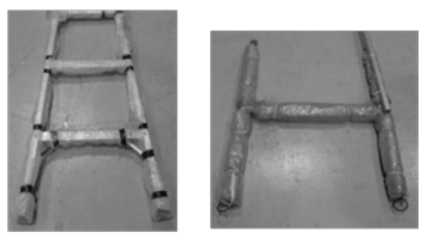
A photo of the measurement targets and the measurement results of the ultrasonic imaging are shown in Fig. 9. The ultrasonic image was displayed as a bird's-eye view with a three-dimensional effect. From the experimental results, the reflected wave from the object surface was measured as the difference in propagation time. A wide region was visualized with the three-dimensional effect although the electronic scanning was only one-dimensional convex scanning of spread fan beams. Furthermore, spatial resolution was about 20 mm because the 25-mm spacing of the grating panel was identified.



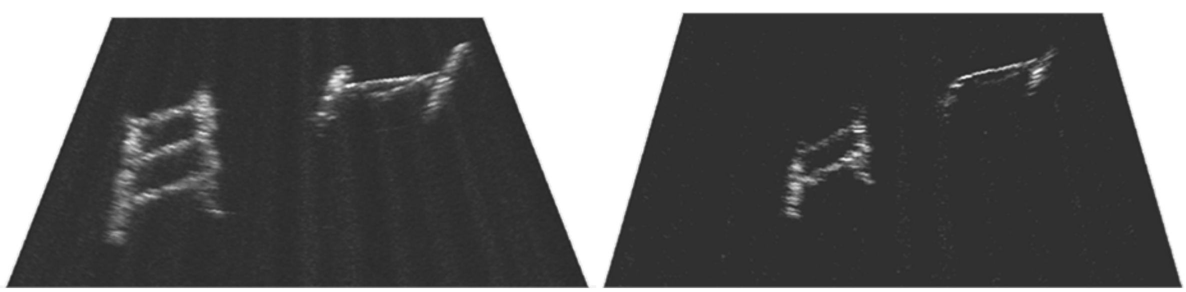
(a) Photo of measurement targets (b) Ultrasonic imaging

Fig. 9. Measurement results of our proposed imaging method.

We also evaluated the performance of long-range measurements. Fig. 10 shows long-range measurement results. A ladder-shaped object and an H-shaped object shown in Fig. 10 (a) were set in a large water tank as reflection targets. For measurement distances of 2.0 m and 4.0 m, reflection target images were obtained in real-time, and the 20 mm frames of the reflection targets were recognized as shown in Figs. 10 (b) and (c).



(a) Reflection targets



(b) Measurement distance 2.0 m (c) Measurement distance 4.0 m

Fig. 10. Measurement results in long-range.

CONCLUSIONS

We have already applied these robots to Fukushima Daiichi NPS for surveying the basement floor of one of the reactor buildings and the PCV internals. We confirmed that these robots successfully carried out surveys in narrow spaces. We have developed underwater environment visualization techniques based on the ultrasonic phased array technology. This paper presented the imaging method that combined the convex array sensor and the acoustic lens for wide area visualization. Based on this development, we are continuing to develop robots and measurement technologies for surveying and carrying out tasks to achieve fuel debris removal.

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