Access Technology using Robots for Decommissioning Tasks

Gen Endo[1]
[1] School of Engineering, Tokyo Institute of Technology, 2-12-1 Ookayama, Tokyo 152-8552, Japan

On March 11th in 2011, Great East Japan Earthquake occurred and huge Tsunami hit Fukushima Daiichi Nuclear Power Plants. Due to this nuclear disaster, more than 89,000 people still evacuate from their home town. It is generally said that it will take over 30 to 40 years to complete full decommission, and robots must be developed and exploited to achieve such difficult tasks due to high radiation environment. In this talk, I will introduce our research activities and development of various robot systems such as an arm-equipped tracked vehicle “Helios IX”, 3 dimensional coupled tendon driven redundant manipulator “3D-CT arm”, a mobile manipulator with ultrasonic sensors “RhinoUS-I” and ultrasonic measurement system using mobile robot with visual odometry and simultaneous localization and mapping.

.**Keywords:** Decommissioning Task, Mobile Robot, Robot Arm, Ultrasonic Sensors, Access Technology,

1. Introduction

On March 11th in 2011, Great East Japan Earthquake occurred and huge Tsunami hit Fukushima Daiichi Nuclear Power Plants. Although emergency shutdown successfully completed, all power sources were lost and reactor primary vessel melt down. Huge amount of nuclear fuel seemed to be melt down and fall down to primary container vessel (PCV). Fortunately Fukushima Daiichi Nuclear Power Plants are currently under control and continuous cooling by water is carried out to keep steady states. However more than 300 tons of ground water comes into PCV, and radioactive polluted water increases day by day. More than 89,000 people still evacuate from their home town.

It is generally said that it will take over 30 to 40 years to complete full decommission, and robots must be developed and exploited to achieve such difficult tasks due to high radiation environment. Roughly speaking, decommissioning tasks can be classified into two phases. The first phase is initial investigation phase and the second phase is work and operation phase. In the initial investigation phase, robots are used to visually observe internal environment of the nuclear power plants by a camera and measure radiation dose. In this phase, robots are basically used to deploy sensors for interested place and main purpose of the mission is to gather information. Of course, ultrasonic measurement system is one of the promising devise because of high radiation endurance. The second work and operation phase actually needs external work, such as removing obstacles to access interested area, cutting fuel debris into small pieces and so on.

In this talk, I will introduce our research activities and development of various robot systems. First one is Helios IX, which is an arm-equipped tracked vehicle for an initial survey mission. The second one is 3D Coupled Tendon Arm to access confined space to deliver sensors and/or end-effectors. The third one is RhinoUS-I, which is a mobile manipulator with ultrasonic sensors. Currently this system is used for education of graduate students. The forth one is a proposal of ultrasonic measurement system using mobile robot with visual odometry and simultaneous localization and mapping (SLAM).

2. Helios IX

Helios IX has a pair of crawlers, which can independently rotate around the middle of the crawlers, and has a six degree of freedom arm [1](Fig.1). The arm has high power output and can partially support weight of the robot body. Thus, Helios IX can climb a high step by pushing the ground using the arm. The maximum output force is about 80N and it can remove obstacles (Fig.2). It can travel on level ground over 6km/h while the robot can climb stairs of 40 degrees.

Figure 1: Helios IX opening a door

Figure 2: Helios IX lifting a 7kg chair

This robot was sponsored by New Energy and Industrial Technology Development Organization (NEDO) in order to respond urban search and rescue operation. Unfortunately, the project could not pass the intermediate stage gate, however, developed lightweight crawler module is commercialized by TOPY Industries, Limited. The crawler module was used to construct Survey Runner (Fig.3), which actually measured radiation dose in Fukushima Daiichi Nuclear Reactor.

Figure 3: Survey Runner developed by TOPY Industries, Limited. (http://www.topy.co.jp/release/201203/entry396.html)

3. 3D CT-Arm

A very long-reach snake-like robotic arm in the range of 10 meters is expected to be used in decommissioning work inside nuclear reactor containers. We developed a tendon driven system which has the advantage of placing electronic devices protected in the arm's base part which stays out of the reactor container, and only few expensive highly radiation hardened sensors and tools are mounted in the arm tip. Figure 4 shows initial prototype model "Mini 3D CT-Arm"[2], which has 6 degree of freedom. The diameter of the arm is 0.15 m and the length is 2.4 m.

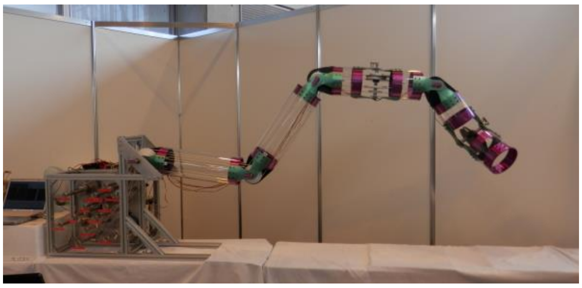

Figure 4: First prototype model Mini 3D CT-Arm

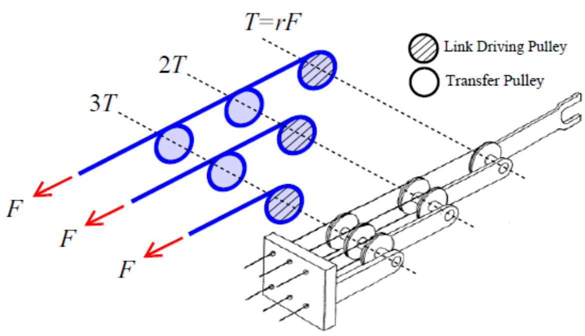

Figure 5: Coupled tendon driven system can multiply proximal joint torque.

Generation of large joint torque is necessary to achieve such a very long arm. We applied the concept of coupled tendon driven mechanism by using special wire-pulley system (Fig.5). By using these wire-pulley arrangements, we can add the distal joint torques to the proximal joint torques, which can make the actuator system compact. This property is very important to deploy the total robot system to the inspection site.

4. RhinoUS-I

Since the decommissioning will take over 30 years from now on, education for the next decommissioning engineers is extremely important. Thus, Advanced Research and Education Program for Nuclear Decommissioning (ARED) entrusted to Tokyo Institute of Technology decided to launch a new lecture class specially designed for a severe nuclear disaster.

RhinoUS-I is developed for the education purpose. The robot is a mobile manipulator with ultrasonic sensors. This robot consists of four active wheels, 3 degree of freedom manipulator and ultrasonic sensors installed at the tip of manipulator (Fig. 6). The mobile base roughly localize robot position by controlling right-and-left wheel rotational velocity, and the arm precisely positions sensor location within a few millimeter accuracy.

Figure 7 shows the experiment in the lecture. Students measured water flow in a tank by controlling robot position and arm posture. This experiment simulated to detect a leakage point in PCV.

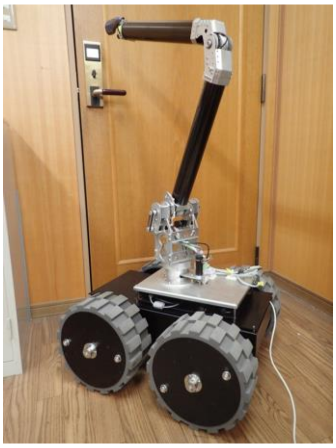

Figure 6: RhinoUS-I, a mobile manipulator with ultrasonic sensors

Figure 7: Students measured water flow in a tank by using ultrasonic sensors. Robot location and arm posture were remotely controlled by the students.

5. Proposal of ultrasonic measurement system using mobile robot

Currently, highest priority task is to detect leakage point of radioactive polluted water. Because the ground water coming in and/or polluted water going out cause serious problem. Moreover, in order to remove fuel debris from PCV, filling with water is extremely important to achieve low radiation dose.

Thus, we are proposing a robotic system that can make flow velocity map of the water in PCV. Figure 8 shows basic concept our proposal. Ultrasonic sensors are suspended through grating, and its height and direction is controlled by reel mechanism which is mounted on a mobile robot. Since measurement range of the ultrasonic sensors is limited, multiple measurements in the different location are required. Thus, after completing measurement, the sensors are lifted up and the mobile robot moves to the next measurement point.

Figure 9 shows ultrasonic sensors. 2 dimensional phased array sensors are used to measure the velocity of the water flow as well as the shape of the surrounding environment. Ultrasonic sensors are potentially capable of measuring not only the shape of debris, but also internal property of debris.

In order to accurately localize ultrasonic sensor position, localization of the robot is crucial. However, fortunately, the robot moves on the grating, which is like a grid with a constant distance. Thus, we can localize the robot by counting the grating mesh. This method can be called as visual odometry.

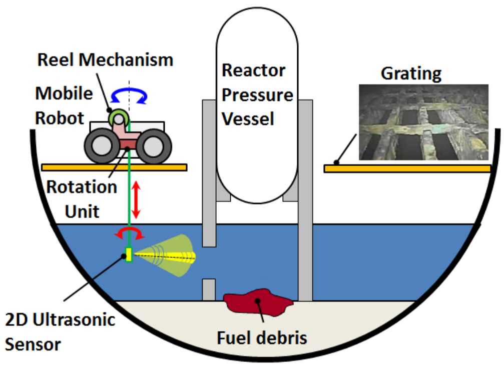

Figure 8: Basic concept of flow map measurement using robotic system with ultrasonic sensors.

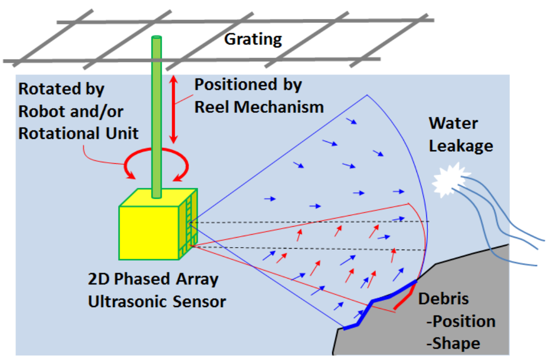

Figure 9: Flow mapping and measurement of the shape of debris

Another way of localization, simultaneous localization and mapping (SLAM) technique can be powerful tool. Although conventional SLAM usually uses a laser range finder, which is fragile to radioactive environment, this method should be considered as a second choice. If SLAM based only on the ultrasonic measurement, I believe the method will be a very powerful and practical method.

6. Summary

This paper introduces my motivation and recent research activities. I believe continuous efforts are extremely important for decommissioning of Fukushima Daiichi Nuclear Power Plants. I hope to contribute to accelerate decommissioning task and I do believe that this work must be a mission for all robotics researchers.

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