Preliminary Study of a Surveillance Robot System in the Radioactive Waste Storage Facility

Wonseo Lee[a*], Sugon Shim[b], Dongseok Ryu[a], Tack-Jin Kim[a]
[a] *Korea Atomic Energy Research Institute, 111, Daedeok-daero 989beon-gil, Yuseong-gu, Daejeon, 34057*
[b] *KoreaTech Univ., 1600, Chungjeol-ro, Dongnam-gu, Cheonan-si, Chungcheongnam-do, 31253*
**Corresponding author: wonseo@kaeri.re.kr*

1. Introduction

Surveillance is one of the most important issues in radioactive waste managements to monitor abnormal situations [1, 2]. Since the amount of radioactive waste is continuously increased according to the operations of the nuclear power plants, the number and storage capability of global radioactive waste storage facilities are increasing nowadays [3]. The increasing radioactive wastes may result in increasing surveillance areas and repetitive surveillance works, and these can cause increased risks of radiation hazards and reduced work efficiency of human workers in the storage facilities. In this paper, a preliminary concept of the surveillance robot system is proposed for surveillance operations in radioactive waste storage facilities. The surveillance robot system is composed of a surveillance robot, its operating software (SW), and coordinating SW which can communicate with the radioactive waste management SW of the facility. A prototype of the surveillance robot system was developed, and experimental verifications were conducted in the real radioactive waste storage facility of KAERI.

2. Concepts of the surveillance robot system

The configuration of the proposed surveillance robot system is represented in Fig. 1. The surveillance robot can patrol and move in the radioactive waste facility by using its mobility function, and it can monitor the current conditions of stored radioactive wastes by using embedded sensors. The coordinating SW serves as a middleware between the radioactive waste management SW of the facility and the surveillance robot operating SW. When the radioactive waste management SW transmits the information of an event and related target area according to the estimated current status (e.g. normal, abnormal, etc.), the coordinating SW converts the information to the predefined operation mode of the robot and a specific location in the area as a destination of the robot. Then, the robot operating SW transmits the raw sensor data (e.g. vision, LiDAR, radiation, etc.) and information of the current position periodically. Finally, the coordinating SW converts them to the current status of the robot (e.g. ready, moving, arrive, etc.), processed results of the sensor data, and convergence map which contains the two-dimensional (2D) map, current robot position, and sensor data. In these architecture, operators of the radioactive waste management SW can remotely monitor the status of the event area and figure out the next steps to respond the expected results of the event based on the processed data and the convergence map.

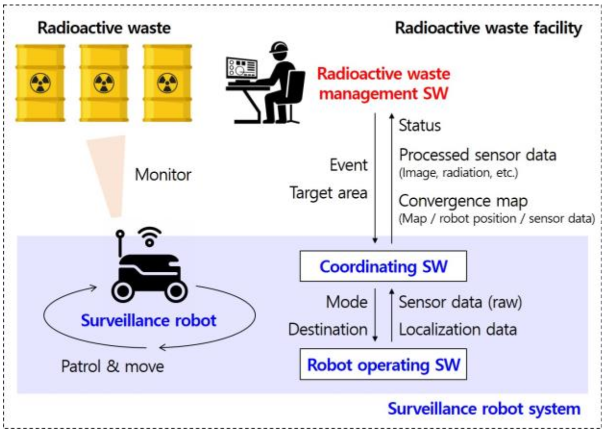

Fig. 1. Configuration of the surveillance robot system

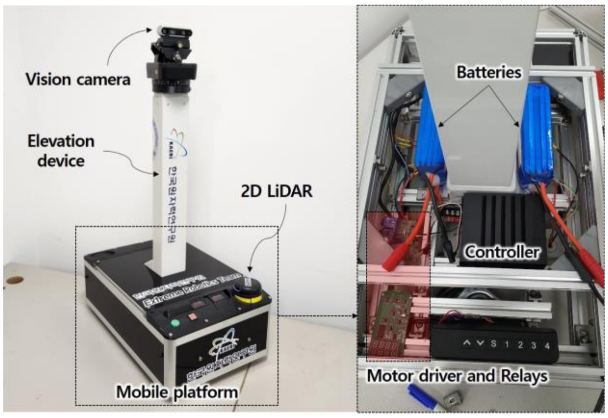

Fig. 2. A prototype of the surveillance robot and its structures

To implement the proposed surveillance robot system, a prototype of the surveillance robot was fabricated and assembled as shown in Fig. 2. The differential drive mechanism was applied for the mobility function, and two geared motor (*DWG-4562-12B*, D&J With, Co., Ltd, China) and a motor driver (*RoboClaw 2×15A*, Pololu, USA) were utilized for the driving mechanism. A vision camera (*RealSense d435*, Intel Corp., USA) was mounted at the top of the elevation device to monitor the radioactive wastes placed at various height of the facility. 2D LiDAR (*RPLIDAR A3*, Slamtec. Co., Ltd., China) was installed to top of the mobile platform of the surveillance robot to gather point-cloud data for 2D mapping and localization. The operating SW of the surveillance robot was developed by using robot operating system (ROS), and the communication

(a)

(b)

Fig. 3. (a) The surveillance robot and the generated map data in the real radioactive waste storage facility. (b) Captured image obtained by the vision sensor with the measured radiation data.

between radioactive waste management SW and coordinating SW was constructed by utilizing a Wi-Fi mesh network system.

3. Experiments

To verify the proposed surveillance robot system, experiments were conducted in the real radioactive waste storage facility of KAERI. A digital twin SW of the radioactive waste storage facility was utilized for the radioactive waste management SW, and the coordinating SW utilized WebRTC and NATS services for streaming media data and messages with the digital twin SW, respectively.

In experiments, the mobility, elevation, and communication with the digital twin SW functions of the surveillance robot system were examined first to secure the safety in the radioactive waste storage facility. Second, mapping procedures of the facility were conducted by using a simultaneous localization and mapping (SLAM) library named of Cartographer to construct and visualize 2D spatial information of the facility as shown in Fig. 3(a). The surveillance robot was teleoperated by operators during the mapping procedures, and the operators manipulate the surveillance robot at the control station placed in the start position by considering the real-time image obtained by the mounted vision camera. Then, local coordinates of the constructed 2D map was matched with global coordinates of the overall facility map data managed by the digital twin SW. To evaluate the mapping and localization performance, the estimated positions and measured positions were compared at two points in the facility. According to the results, the estimated results obtained by Cartographer show position errors less than 10 cm which is an enough level of errors to navigate in the facility with stationary obstacles. Finally, the surveillance robot navigated to target region when the coordinating SW receives messages from the digital twin SW about the pseudo-event information, and successfully transmitted the media and measured radiation data to the digital twin SW as shown in Fig. 3(b).

4. Conclusion

In this paper, a surveillance robot system for semi-automated surveillance operations in the radioactive waste storage facility. The preliminary concept of the overall system, prototype of the surveillance robot, and coordinating SW consisting the proposed surveillance robot system were developed. To verify effectiveness of the surveillance robot system, the coordinating SW of the system was connected to a digital twin SW of the radioactive waste facility which can perform as the radioactive waste management SW, and the basic functions of the prototyped surveillance robot were verified in the real facility. The mapping procedures to construct 2D spatial information of the facility were performed by a Cartographer SLAM library and teleoperations, and the accuracy of the obtained 2D map information was verified. Finally, pseudo-surveillance missions were successfully conducted by navigating to target regions and transmitting media and measured data in real time.

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