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Development of a robot system as a tool-carrier machine for the decontamination process of nuclear power plants

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Summary: As part of the ROBDEKON [1] project, the Karlsruhe Institute of Technology, Institute for Technology and Management in Construction (KIT-TMB), is developing a robotic system designed to position two tools for the decontamination and clearance measurement of concrete walls in nuclear power plants. To achieve this objective, a lifting platform (Manitou 100-VJR) has been retrofitted with essential electronic components, including controllers, sensors, actuators, communication modules, and safety systems, thereby transforming it into a robotic system termed "DekontBot". The developed system supports operation in both teleoperation mode and (semi-)autonomous mode. Additionally, a graphical user interface (GUI) has been designed for DekontBot, enabling users to visualize its operations through RViz2 on the ROS2 platform and control the system in an intuitive and user-friendly manner. This paper provides a detailed description of the development process and implementation steps undertaken for the DekontBot.

Keywords: robotic, automation, decontamination, plc, Robot Operating System (ROS), nuclear power plant (NPP)

1. Introduction

On April 15, 2023, the last three nuclear power plants Emsland, Neckarwestheim 2, and Isar 2 were taken offline. Currently, there are 25 nuclear power plants and research reactors in Germany at various stages of decommissioning and dismantling [2]. Globally, approximately 297 nuclear power plants are expected to begin decommissioning by 2030 [3]. Until now, decommissioning and dismantling activities have largely been carried out manually. Organizations such as the OECD have concluded that the current technological capabilities in the dismantling process are not being fully utilized. By increasing the use of robots and automation technologies, it is possible not only to reduce costs but also to lower radiation exposure for the personnel involved in the decommissioning process. Given the number of nuclear power plants undergoing dismantling, there is significant potential for digital solutions in this area. [4]

The ROBDEKON project, commissioned by the Federal Ministry of Education and Research (BMBF), focuses on developing autonomous and semi-autonomous robotic solutions to enhance autonomy during decontamination processes in hazardous environments [5]. As a part of the ROBDEKON, in collaboration with Karlsruhe University of Applied Sciences and Götting KG, the Karlsruhe Institute of Technology, Institute for Technology and Management in Construction (KIT-TMB), is working on a comprehensive automation chain for the decommissioning of nuclear power plants [6].

This automation chain consists of several components, including the GammaBot, which is used for environmental exploration involving geometric and radiological measurements, and the implementation of Building Information Modeling (BIM) for digitization and detailed planning [7]. The chain also includes autonomous decontamination and clearance measurement facilitated by portable robotic tools integrated into the autonomous carrier device, DekontBot. Additionally, the transportation of radioactive waste is managed by an autonomous forklift truck [8]. A visual representation of the system is provided in Figure 1.

Fig. 1. closed automated chain for decommissioning of NPPs

2. Devolopment of DekontBot

The objective of this research is to develop universal, robot-based solutions for a fully automated decontamination process that can be flexibly adapted to varying environmental conditions. The following sections provide a detailed description of the third step in the process: automated decontamination.

2.1 Description of the robot's main task

If the locations of hotspots or contamination are identified using the GammaBot, these areas require decontamination. To address this need, an automated, robot-portable milling tool for decontaminating concrete walls has been developed at KIT-TMB. Following the decontamination process, the surfaces are measured autonomously to verify whether they meet the required decontamination standards. For this purpose, a second tool, the "Contamination Array" [9], has been developed. The primary function of the DekontBot is to position these two tools effectively, either in teleoperated mode or (semi-)autonomous mode, depending on the operational requirements.

2.2.Description of original platform

To achieve the described objectives, the "Manitou 100-VJR" platform was further developed and automated to serve as the base vehicle. The platform measures approximately 1.2 meters in length, 1 meter in width, and 2 meters in height. Equipped with a manipulator featuring three degrees of freedom, it can reach heights of up to 8 meters using a telescopic joint and an arm. Additionally, the system is capable of positioning tools with a maximum weight of 270 kg. A visual representation of the system is provided in Figure 2.

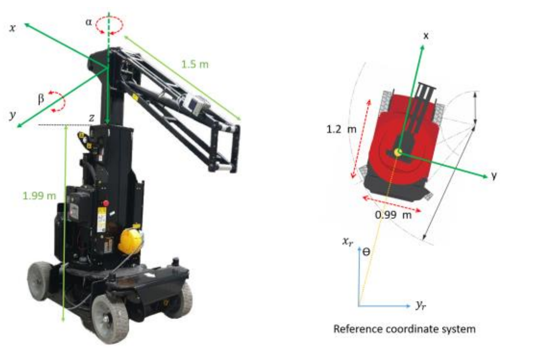

Fig. 2. Dimensions and degrees of freedom of the DekontBot

2.3 Description of the integrated electronics

The foundation for an automated decontamination system is the mobile platform described in Section 2.2. To transform this platform into a fully automated decontamination system, it was equipped with the necessary components (Figure 3). A Rexroth CtrlX3 EtherCAT control unit was integrated, connecting to the motor controller via a CAN-EtherCAT gateway and interfacing with sensors to determine the manipulator's position. Two inclination sensors were installed to measure the arm's position on the manipulator, while two wire-draw encoders were used to monitor the positions of the telescopic joint and the tower. The motor controllers relay critical data, such as motor current, voltage, and temperature, back to the control unit. For localization, the platform was outfitted with two SICK microScan3 lidar sensors, which calculate the vehicle's position and transmit this information to the control unit using UDP signals. System safety is managed by a SICK-CPU0 safety CPU. Safety scanners mounted on the platform can detect people and obstacles in the vicinity, generating warning signals when necessary to prevent collisions or accidents. Additional safety measures include tilt sensors and safety switches, which are installed to prevent the platform from overturning. Safety-critical signals are routed through a gateway to the control unit. In hazardous situations, such as potential collisions or risk of overturning, the decontamination system stops operation, waits until conditions are safe, or recalculates and selects an alternative trajectory to reach its target destination.

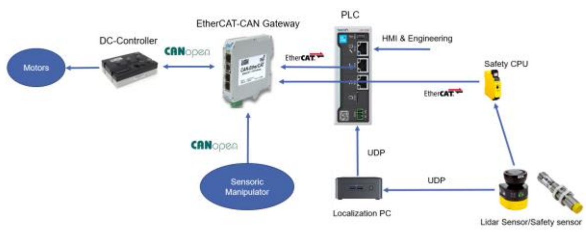

Fig. 3. integrated electronics on DekontBot [10,11,12,13]

3. GUI, HMI, Visualisation and Data transfer

The decontamination system is designed to operate in both teleoperation and automatic modes. To facilitate user interaction, a user-friendly interface has been developed, enabling operation of the system without requiring deep technical expertise. The decontamination process relies on the contamination map generated by the GammaBot. Using this map, the DekontBot can identify contamination positions and position the necessary tools for decontamination or clearance measurement. This information is automatically transmitted from the GammaBot to the DekontBot via a TCP server/client architecture. Through the user interface (Figure 4), users can select or delete available maps. Additionally, users can control the DekontBot, either initiating or halting its operation, and switch between teleoperation mode and automatic mode. Safety signals, collision risk, and other key parameters such as manipulator joint positions, battery voltage and localization status are displayed on the user interface. The selected contamination map is visualized using RViz2 on

ROS2, allowing users to view both the 2D map and the 3D point cloud of the building, overlaid with a dynamic URDF model of the DekontBot (Figure 5). Furthermore, the platform is equipped with two cameras: one for monitoring the vehicle and another for observing the manipulator, ensuring enhanced situational awareness during operation.

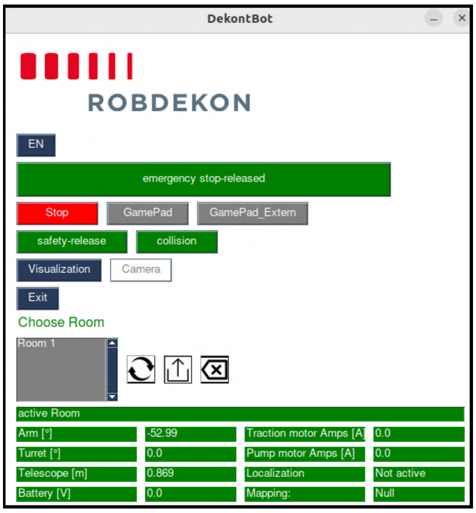

Fig. 4. GUI

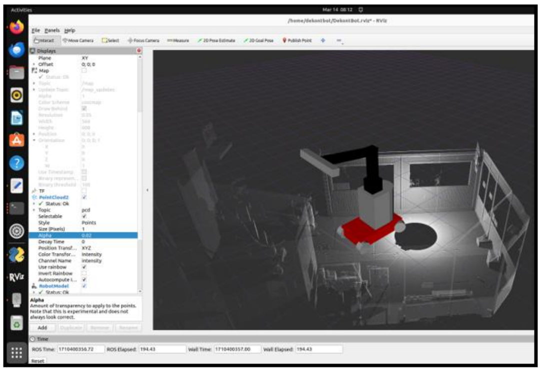

Fig. 5. Visualisation of point cloud and URDF model

4. Results and Further Developments

The mechanical and electrical expansion of the DekontBot has been successfully completed, and the platform is now fully operational for teleoperation. All degrees of freedom of the original platform can be controlled using the implemented electronic components. The necessary values for system operation can be measured through selected sensors, and the safety hardware of the DekontBot is fully integrated.

With the developed GUI and visualization tools, the platform can be operated without any prior knowledge of robotics or programming, making it highly user-friendly for its intended user group.

The next phase involves integrating path planning and control algorithms to automate the platform. Additionally, for more precise tool positioning, essential for the decontamination and clearance measurement of inclined walls, floors, and ceilings, further degrees of freedom will be added to the end effector. The safety system also requires improvement to meet TÜV (Technical Inspection Association) testing and verification standards.

Further optimizations are needed, including enhancing the quality of point clouds, refining details in the URDF model, and ensuring robust communication between the DekontBot and the control center. These developments will prepare the DekontBot for initial testing within a nuclear facility.

5. Conclusions

It has been demonstrated that automation and robot-based solutions hold significant potential in decontamination processes. These solutions serve not only to alleviate the physical burden on decontamination personnel but also to minimize the generation of secondary waste. Consequently, the DekontBot was developed for the decontamination and clearance measurement of concrete walls in nuclear power plants.

With the integration of the DekontBot, the effort and associated risks of these tasks can be substantially reduced. There is considerable interest from operators of nuclear power plants in adopting autonomous solutions or robotic systems for decontamination operations.

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