

A mixed reality-enabled guidance system for nuclear facility decommissioning engineer - a prototype and preliminary findings

Arnab Chakraborty^{1,†}, Udayanto Dwi Atmojo^{2,*} and Valeriy Vyatkin^{2,3}

¹ Independent Researcher

² Dept. of Electrical Engineering and Automation, Aalto University, Maarintie 8 02150 Espoo Finland

³ Dept. of Computer Science, Electrical and Space Engineering, Luleå University of Technology, SE-971 87, Luleå 97187 Sweden

Abstract

Nuclear decommissioning requires the safe dismantling of radioactive facilities and handling of contaminated materials while minimizing radiation exposure to nuclear decommissioning engineers. Despite recent technological advances, nuclear decommissioning practices rely on IAEA's guidelines which usually require engineers to rely on printed notes and drawings to obtain information they need, which may contain outdated or inaccurate artifacts. This paper presents a mixed reality enabled guidance system that enables decommissioning engineers to receive on-demand information such as task instructions and their physical positioning in real time in the environment. The paper proposes the architecture of the system, a laboratory prototype, and preliminary evaluations. Future work will include more comprehensive evaluations of the system and further workflows for augmenting the technicians with robotics-based technologies.

Keywords

Mixed reality, Nuclear decommissioning, Guidance systems, Real-time positioning, XR

1. Introduction

Nuclear decommissioning involves dismantling facilities and handling radioactively contaminated materials under demanding safety constraints. Engineers must execute planned activities while limiting radiation exposure and maintaining an accurate understanding of their working environment. Access to reliable facility information, such as drawings, equipment records and task instructions, is essential for performing decommissioning operations. The International Atomic Energy Agency (IAEA) recognizes the need for the reliability and availability of supporting information, including drawings and records of modifications. When the task relies on printed notes and drawings, engineers

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* Corresponding author.

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✉ arnabjoy177@gmail.com (A. Chakraborty); [udayanto.atmojo\(at\)aalto.fi](mailto:udayanto.atmojo(at)aalto.fi) (U. D. Atmojo); vyatkin@ieee.org (V. Vyatkin)

 0000-0002-6865-0806 (U. D. Atmojo); 0000-0002-9315-9920 (V. Vyatkin)



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often have to manually relate documented information to physical equipment and locations. This can become more challenging when records are incomplete, outdated or inconsistent with the current facility or equipment configuration. Consulting separate documents also requires engineers to shift attention between instructions and their surroundings. These challenges motivate approaches that enable relevant information accessible at the point of work and help engineers associate guidance with the physical environment.

Mixed reality (MR) offers a technological means of presenting digital information alongside the user's view of the physical environment. In nuclear decommissioning, digital modelling and immersive visualization have already been explored to support planning, familiarization and training. IAEA publications show applications of augmented and virtual reality for nuclear decommissioning. Following these developments, this paper investigates the integration of on-demand task instructions and real-time indoor positioning with an MR-enabled guidance. The intended outcome is a technology that can help engineers access real time information while maintaining awareness of their location in the working environment.

Existing studies provide some foundation related to this area. [1] applied extended reality to the dismantling of large radioactive components as training, while [2] showed an AR-based system for visualizing radiation fields in decommissioning environments. The work [3] developed a digital twin prototype integrating AR visualization, QR-code management, demonstrating how digital information can be associated with physical waste containers. The work in [4] developed an AR-based framework enabling technicians to connect with remote experts through real-time visual feedback. [5] reviewed UWB indoor positioning technologies and their implementation challenges, and [6] conducted an experiment to compare UWB and ultrasonic localization under static and dynamic conditions in an industrial test environment.

Building on these existing research works, the paper's contributions include architecture that integrates QR-triggered task instructions with UWB-based technician real time positioning through an edge computing platform. This paper then presents the proof of concept based on this architecture and evaluates the implementation in a laboratory setting.

2. Proposed System Architecture

The proposed architecture, illustrated in Fig. 1, integrates ultra-wideband (UWB) sensing, edge computing and a mixed reality (MR) interface to provide positioning information and on-demand procedural guidance for nuclear decommissioning technicians. It comprises UWB anchors installed at fixed, known locations in the working environment, a UWB tag carried by the technician, an edge computing node and a Wi-Fi-capable MR headset. The architecture supports two complementary functions: tracking the technician's position through UWB ranging and displaying task instructions selected through QR code scanning.

The fixed anchors exchange UWB signals with the wearable tag to obtain ranging measurements representing the distances between the tag and the anchors. One anchor serves as the communication gateway, forwarding the ranging data to the edge node over Wi-Fi. The edge node aggregates these measurements and supports the estimation of the

tag's position relative to the known anchor locations. The resulting position represents the location of the technician's tag within the monitored environment and is made available to the MR application over the local wireless network.

The MR headset provides an interface for the technician to access information. By scanning a QR code associated with a designated task or item of equipment, the technician accesses the corresponding step-by-step instructions through the headset. QR codes establish an explicit association between the scanned identifier and the relevant guidance, while the UWB subsystem supplies positioning information independently. The MR application brings these information streams together, allowing the technician to consult task instructions and be able to receive their physical position information within the same interface.



Figure 1: System architecture of the MR-enabled guidance system with ultrawideband based real-time positioning

During operation, the UWB subsystem updates the ranging measurements as the technician moves, while QR code scanning initiates access to the relevant real time guidance content. This allows positioning and task guidance to operate as complementary functionalities. The architecture is intended to improve access to information at the point of work.

3. Preliminary Results

A prototype of the MR-enabled guidance system is implemented. The prototype considers Microsoft Hololens 2 Industrial Edition for the MR device. The UWB localization considers MakerFabs' MaUWB_ESP32S3 UWB devices. Preliminary laboratory evaluation examined the indoor localisation and QR-triggered instruction-display components of the augmented reality guidance system. Ultra-wideband localisation was evaluated using 40 positioning measurements, with ten measurements at each of four anchor locations. The overall median positioning error was 6.3 cm, with a mean of 7.58 cm and a maximum

observed error of 28.3 cm. The estimated position was displayed on a floor map alongside destination markers and directional guidance. These results demonstrate real time positioning accuracy at the tested locations.

The QR-triggered instruction panels achieved median application-level spawn latencies of 17.9 ms and 14.9 ms for the two tested markers, based on ten measurements per marker. QR detection itself was separately observed to take approximately 2.2 s. Repeated panel placements exhibited different levels of positional variability, with per-axis standard deviations reaching 47.4 mm for one marker. The results support the technical feasibility of combining position visualisation and location-associated instructions shown via a wearable MR interface. This experiment does not evaluate navigation performance, the level of accuracy of the instructions shown to the user, or the technical physical or mental workload upon long term usage. These require further evaluation of the prototype and the workflow with more users. Fig.2 shows the display shown via the MR device, showing an example of the QR code reading and the instructions shown to the user.

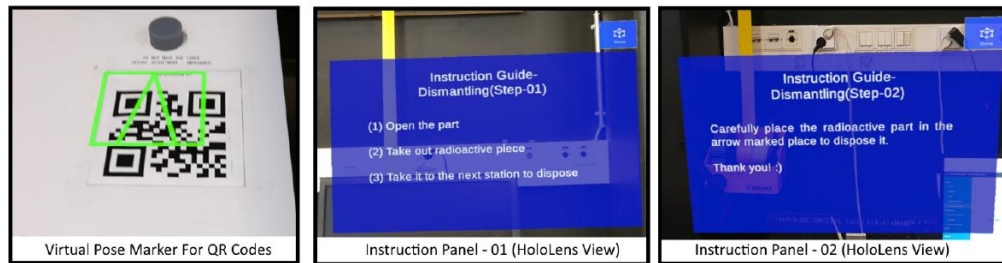


Figure 2: Instructions displayed in the MR device upon QR code scanning

4. Conclusions and Future Works

This work presented a prototype of mixed-reality guidance that combines UWB-based indoor localisation with QR-triggered real time instructions for nuclear decommissioning applications. Preliminary laboratory evaluations demonstrated the feasibility of the concept and the proof of concept's functionality. Future work will evaluate the localisation under obstruction of objects and the combination of this technology with robotics to enhance the decommissioning work' efficiency and overall technician' safety. Additional future work can include comparative user studies that assess task completion time, procedural errors, and workload against conventional guidance methods.

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Declaration on Generative AI

ChatGPT and Grammarly are used as tools to support the proof reading and editing of this paper, in particular for rephrasing and grammar checks.

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