Survey

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ROBDEKON – competence center for decontamination robotics

ROBDEKON – Kompetenzzentrum für Dekontaminationsrobotik

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Abstract: There are still many hazardous tasks that humans perform in their daily work. This is of great concern for the remediation of contaminated sites, for the dismantling of nuclear power plants, or for the handling of hazardous materials. The competence center ROBDEKON was founded to concentrate expertise and coordinate research activities regarding decontamination robotics in Germany. It serves as a national technology hub for the decontamination needs of various stakeholders. A major scientific goal of ROBDEKON is the development of (semi-)autonomous robotic systems to remove humans from work environments that are potentially hazardous to health.

Keywords: decontamination, robotics, automation, artificial intelligence, autonomy, machine learning

Zusammenfassung: Es gibt immer noch viele gefährliche Aufgaben, die Menschen in ihrer täglichen Arbeit verrichten. Dies ist insbesondere bei der Sanierung von Altlasten, beim Rückbau von Kernkraftwerken oder beim Umgang mit gefährlichen Stoffen von großer Bedeutung. Das Kompetenzzentrum ROBDEKON wurde gegründet, um die Expertise hinsichtlich der Dekontaminationsrobotik zu konzentrieren und Forschungsaktivitäten in diesem Bereich in Deutschland zu bündeln. Es dient als nationaler Technologie-Hub für die Bedarfe unterschiedlichster Interessensgruppen bei Dekontaminationsfragestellungen. Ein wesentliches wissenschaftliches Ziel von ROBDEKON ist die Entwicklung (semi-)autonomer Robotersysteme, um den Menschen aus gesundheitsgefährdenden Arbeitsumgebungen herauszunehmen.

Schlagwörter: Dekontamination, Robotik, Automatisierung, künstliche Intelligenz, Autonomie, maschinelles Lernen

1 Introduction

Working conditions for people have been improving for centuries. Although work is generally much safer than it has been in the past, an ever-increasing understanding of health hazards creates new requirements for safe workplaces. This could be enhanced protective equipment, further reduction of human exposure, or asking for performing the work completely remotely. However, working with additional protective measures comes not for free: The net amount of work decreases, and work can become more exhausting requiring more breaks in turn. Classic teleoperation for working remotely can be clumsy and non-intuitive, which is why only the most skilled operators perform those tasks.

1.1 Requirements

This is where robots and digitalization come to the rescue. Some of the work may be executed fully autonomously, for other tasks semi-automated assistance functionality for efficient remote work is an important means to take humans out of the danger zone. Modern technology enables a much richer operator experience when operating remotely by increased immersion into the remote area.

However, taking humans out of the danger zone is no small task as human intelligence and perception capabilities still widely surpass what is currently possible for machines. But still, the capabilities of autonomous systems

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have strongly risen over the last years and some tasks can already be performed fully autonomously.

Three areas seem to be especially interesting for the application of robotic decontamination systems: The dismantling of nuclear power plants, the remediation of contaminated sites, and the handling of hazardous materials.

In the described scenarios, full autonomy is often neither easily achievable nor the primary target. Shortage of skilled workers makes it necessary to fully exploit the experience and knowledge of the human operator. By implementing autonomy functionality in the form of assistance functions, thereby providing semi-automation, the human operator can draw attention to those more difficult cases where AI-based robotic systems may be unable to find a suitable solution. That way, an operator could supervise multiple systems and hence support multiple tasks with his or her experience. As an example in the remediation scenario, this could happen in different levels of autonomy: The operator could be steering individual machine joints to solve the situation or could intervene on a higher level, e. g., point the system to an alternative dumping site. That way, each operator may supervise more than one autonomous system.

In order to fulfill such a supervision task, innovative operating concepts have to be envisioned that allow a full immersion in each task by providing intuitive interaction capabilities. This allows the operator to quickly switch between supervised systems and to have an immediate full three-dimensional view of the scene. As a result of this full immersion, the operator needs very little time to switch between different tasks.

Additionally, assistance and telepresence systems allow aging operators to continue to do work usually involving a high level of physical exertion and hence being able to continue to contribute their expertise.

1.2 Background

Classic remotely-controlled heavy machinery is an established means to handle situations with great danger for the human operator. In Jaseiskis et al. [22] in 1994, there was already a thorough discussion that robotic systems would be beneficial to reducing human risk in hazardous environments together with an overview of pilot systems. In 2014, OECD-NEA called in [27] for “robotic technologies coupled with current technologies for end-effector and material handling” and identified the current ways of decommissioning as inefficient due to the high safety measures.

Internationally, there are conceptually similar research activities going on. We will provide a non-exhaustive overview in the following. RACE [33] was established in 2014 as part of the UK Atomic Energy Authority (UKAEA) and belongs to the UK government’s £250 million Robotics and Autonomous Systems Strategy. RACE conducts R&D and commercial activities in the field of Robotics and Autonomous Systems in challenging environments. They have a strong background in remote operation and so far conducted more than 35,000 hours of remote operations on the reactor shutdown critical path. They focus not primarily on decontamination tasks, decommissioning however is a part of their activities. RACE is part of the more academic RAIN Hub [35] where also several UK universities are involved in the topic of AI applications on nuclear challenges.

Japan channels its research in the Collaborative Laboratories for Advanced Decommissioning Science (CLADS) [21] initiated by the Japan Atomic Energy Agency. This center is connected to other Japanese institutions covering research for safe nuclear use and decommissioning like the Nuclear Safety Research Association NSRA [29] and the Tokyo-based International Research Institute for Nuclear Decommissioning (IRID) [20].

In the US, research is more distributed across the country while the Florida International University (FIU) focuses on robotics for waste site operations [14]. Norway targets similar research tasks at the Institute for Energy Technology (IFE) in their recent HADRON group [18], while Switzerland like other countries pursues those activities in a larger context of civil security [1]. On an international level, OECD-NEA launched the Nuclear Education, Skills and Technology (NEST) Framework in 2019 to address multinational and multidisciplinary knowledge transfer and technical innovation [30].

Related research activities in Germany include the second national competence center similar to ROBDEKON but dedicated to rescue robotics called DRZ [11] with which ROBDEKON closely cooperates. The University of Kaiserslautern [36] also works on autonomous heavy machinery as well as the ETH in Switzerland [12]. The University of Bonn deals with assisting robots for disaster response, e. g., in the CENTAURO project [8]. This is also an important research topic at Fraunhofer FKIE [16]. The University of Bremen pursues AI research for robotic applications [19]. In the topic of dismantling nuclear power plants, the funding program FORKA [17] is an umbrella for many research projects. There are funded projects like ROBBE [34] with the topic of robot-assisted treatment of components in the dismantling of nuclear power plants or AuDeKa [3] where an automated decontamination cabin with documentation based on industry 4.0 features is developed. Robotics for asbestos removal has been researched in Bots2ReC [9].

Many companies already develop assistance systems for heavy machinery, but those solutions mainly target specific application cases, e. g., assistance in grading. Among them are (in alphabetical order) ASI Robots [2], Brokk Nuclear [5], Built Robotics [6], CAT [7], Framatome [15], John Deere [23], Komatsu [25], Leica Kobelco [24], Novatron/Doosan [28] and TopCon [38].

After the Fukushima incident in Japan, many different robotic systems were utilized but most of them were still teleoperated like the Teledyne FLIR (formerly iRobot, Endeavor Robotics) PackBot [37]. As an example of a robot-centric application, Toshiba and IRID created a robot (SunFish) that was small and hardened enough to reach the melted core [39].

2 Mission

To address the aforementioned technical needs, the German Federal Ministry of Education and Research (BMBF) launched the German competence center ROBDEKON [31] in 2018. ROBDEKON is part of the Federal Government's "Research for Civil Security" program.

The mission of ROBDEKON[1] is to protect workers from health hazards that are present in hazardous environments and to serve as a technology hub for users seeking advice on robotic decontamination tasks. For that reason, a collaboration of research and application partners was incentivized to concentrate the German work in decontamination robotics to create innovative approaches to risk mitigation. Each partner contributes its expertise and its lab to the competence center.

There are other research groups also looking into various aspects of those areas: In the project Bauen4.0 [40] the digitalization of the construction site is the main research focus which provides a basis for the use of robotic systems. In VIRERO [41] the focus is on VR technology for robotic radiometric material sorting tasks, e. g., for the dismantling of nuclear facilities. In LaDECO [26] the goal is to assess the process of laser-based decontamination regarding particle creation and safety.

In ROBDEKON however, we strive for a holistic take on robotic decontamination: modern AI-based solutions that allow for assisting human operators by (semi-)automation of tasks, modern concepts for telepresence and teleoperation as well as education of end-users to show technological advances.

1 https://robdekon.de

2.1 Robots in hazardous environments

Every place where humans are exposed to health risks (or even fatalities) at their workplace requires a lot of safety measures to keep the risk of injuries or poisoning as low as possible. We also consider long-term exposure to less concentrated hazardous substances an underestimated health risk. Autonomous heavy machinery can help by separating the operator from the hazard. Simple remote-controlling of machines helped in this regard, but undeniably has its limitations like limited immersion and loss of three-dimensionality due to classic screens showing a single camera view. Robots that carry out hazardous tasks autonomously open up completely new possibilities in how workplaces may look like [44, 45]. Even with semi-automation in the form of assistance systems, the worker can use the limited time in dangerous areas much more efficiently.

2.2 Application domains

ROBDEKON selected three application areas where robotic systems can help in decontamination tasks. These areas are showcases of the possibilities and should in no way be seen as a restriction of the underlying techniques.

Decommissioning of nuclear power plants — The task of decommissioning nuclear power plants is a very elaborate process where great care is taken to first measure the contamination strength of all walls, floors, and ceilings of the building to secondly conduct decontamination. This process typically comprises mechanically removing the contaminated surface parts while at the same time trying to keep the nuclear waste volume as low as possible. Automation can be a great help in mapping the inner areas of nuclear power plants and decontaminating large wall areas. Currently, human workers wear protective suits which prevent radiation exposure but are physically very strenuous to wear. Hence, the workers can only spend a limited amount of time in those suits, which makes the process quite inefficient. Automation helps to put the worker outside of the hazardous area where the machine can be remotely controlled by immersive telepresence technologies. A still unsolved problem is to retrieve unknown objects which lay unordered inside a box, e. g., to clamp them for cleaning.

Handling of hazardous materials — Humans often need to handle hazardous materials, which poses severe health risks, e. g., sorting battery waste. Especially lithium-polymer-based batteries can spontaneously ignite when mechanically stressed. Autonomous robots could reduce the health risks by employing AI methods to presort the batteries and keep humans out of the dangerous zone. This requires precise recognition of the specific battery type at hand which is often not an easy task as only small variances in the outer appearance define a different battery type. Assistance by robotic systems has the potential to perform many parts of the separation task autonomously, which allows the worker to concentrate on the fewer cases that are difficult to decide.

Contaminated sites and landfills — Remediation of landfills and contaminated sites is a process where the health risks for humans are more predictable. Nevertheless, long-term exposure to PBTs (persistent, bioaccumulative, and toxic substances) needs to be reduced as much as possible. Many of the tasks found in remediation operations could be automated already today: Digging a predefined area to a given depth, loading the diggings to a transportation platform, or carrying the material to a heap are very suitable for automation. By implementing telepresence capabilities, the system can ask the operator for help in unexpected situations. The operator then takes control and helps the system to continue the task.

ROBDEKON strives to establish technology in an enabling way for the whole community and to provide education on the possibilities of current technology. This facilitates technology transfer into practical systems that make use of what is currently possible.

3 Structure of ROBDEKON

3.1 The competence center

The competence center is a consortium of partners who bring together robotic expertise and domain knowledge to obtain relevant solutions. It features a coordination office that is the central point for any internal and external questions. The steering committee is responsible for the strategy and the research road map while also monitoring project execution. An advisory board from industry and science provides counseling to create relevant solutions in the project. Sub-projects deal with developing core technologies for robotic decontamination first, and afterward, in realization projects, demonstrators are built to showcase the methods. Additionally, working groups meet to address the needs of standardization, education, and teaching as well as public relations.

3.2 Partners

The ROBDEKON partners come from both academia and the application domains detailed in Section 2.2.

Fraunhofer IOSB — The Fraunhofer Institute of Optronics, System Technologies and Image Exploitation IOSB is the coordinator of the competence center. This includes organization and synchronization of activities and events internally and externally. At the same time, Fraunhofer IOSB works as a research partner on the development of an autonomous crawler excavator where an AI-assisted algorithm toolbox has been developed which enables many mobile robotic platforms to perform tasks autonomously.

ICP — The ICP Ingenieurgesellschaft Prof. Czurda und Partner mbH is an expert for hazardous waste sites and advises the research partners on questions of practical relevance and user requirements to the developed solutions.

KAH — Kraftanlagen Heidelberg GmbH advises the partners on all topics related to the decommissioning of nuclear power plants, including (but not limited to) regulatory requirements and release processes, characterization and handling of contaminated parts, and decontamination of walls.

KHG — The Kerntechnische Hilfsdienst GmbH has a long-lasting experience in remote operation of heavy machinery in nuclear environments and therefore brings to the consortium very valuable insights into the matter of decontamination in the nuclear context.

Götting — Götting KG is an industrial partner specialized in automation for series-production utility vehicles. By this capability, partners are enabled to algorithmically interact with utility vehicles and treat them like robots.

FZI — The FZI Research Center for Information Technology specializes in robotic solutions and AI and provides devices and methods for the handling of hazardous materials, e. g., wasted Li-ion batteries, where recognition and sorting can prevent incidents with human health risks.

KIT — The Karlsruhe Institute of Technology is represented by four research labs. *1) KIT-TMB:* The Institute of Technology and Management in Construction has great experience in technologies for the decommissioning of nuclear plants. They develop a robotic system to automatically decontaminate walls. *2) KIT-H^2T:* The chair of High-performance Humanoid Technologies specializes in affordance planning and allows robots to grasp and handle previously unknown parts of basically arbitrary shape. *3) KIT-IPR:* The Intelligent Process Automation and Robotics Lab develops a mobile robotic system that autonomously explores a building to create a three-dimensional map including the measured degree of contamination. *4) KIT-ISAS:* The chair of Intelligent Sensor-Actuator-Systems leads the development of the ROBDEKON interface that enables teleoperation of the systems and provides virtual/augmented reality (VR/AR) enhancements for the operator. In addition, they model the distribution of hazardous materials in the soil given as few samples as possible and compute a strategy where the next sample should be placed to obtain maximum information.

DFKI — The German Research Center for Artificial Intelligence automates a walking excavator which exhibits many degrees of freedom to move and to articulate. DFKI also provides a control room where full user immersion is possible due to an omnidirectional treadmill and VR-enhanced interaction with the robotic systems.

3.3 Associated partners

ROBDEKON also has associated partners who provide guidance to the partners and identify application opportunities and focus areas of practically relevant solutions. The associated partners are EnBW Kernkraft GmbH, Ministerium für Umwelt, Klima und Energiewirtschaft Baden-Württemberg (Referat "Entsorgung und Stilllegung"), SH-Management, Volvo Construction Equipment Germany GmbH, and Liebherr-France SAS. Additionally, expertise in hazardous materials is provided by Brandoberrat König of Feuerwehr und Katastrophenschutz Mannheim.

4 Robotic systems in ROBDEKON

The robotic systems in ROBDEKON are developed at each partner's lab, but in close cooperation of the partners so that specific domain knowledge is shared within the consortium. A major topic was the development of a suitable unified interface to connect the robotic platforms to a control station. That way, all the systems are compatible and can be operated by the same control stations. Hence, any collaboration between the systems has a technological basis. More detail is given in 4.2.

4.1 Robotic tasks to solve

The following tasks are of particular interest in ROBDEKON's research work. The developed methods are primarily AI-based methods, whether in the form of classical AI methods such as planning and reasoning, or machine learning (ML) methods such as deep learning.

Vehicle autonomy — To achieve (semi-)autonomy of mobile robotic systems for decontamination, it is necessary for the machine to perceive itself and the environment around it, interpret the environment and derive decisions from the interpretation. This in turn leads to the requirement that autonomous robotic systems must at least feature environment sensors, have a model of their own behavior, and have some sort of intelligence to decide what to do next. For most tasks in the context of decontamination, autonomous manipulation capabilities are necessary. These topics are detailed in the following sections.

Sensors and sensor fusion — Sensor types commonly found in mobile autonomous robotic systems are (stereo) cameras (also UV and IR), LiDAR (light detection and ranging, "laser scanner"), IMU (inertial measurement unit), GNSS receivers (global navigation satellite system), ToF (time-of-flight), wheel encoders, and ultrasonic sensors. In addition to those general-purpose sensors which apply in many robotic scenarios, specific decontamination tasks require further specialized sensors like chemical (pH value, concentrations) or physical (pressure, flow, radiation) ones. However, many quantities important to decontamination can currently only be performed by chemical analysis in a lab. Sensors that could output the contamination concentrations in real-time would be a very welcome addition to enable even more use of robotics.

As a foundation for any work done with the system, proper sensor fusion is a must. That is, all the sensory data needs to be assigned a proper timestamp and the sensor setup must be calibrated to be able to correctly reference measurements across sensors.

Localization and mapping — For mobile systems to operate in previously unknown environments, precise localization and mapping are key. In mobile robotics, this is often done simultaneously (SLAM). Using SLAM algorithms, the system tries to find evidence in the data, that a certain location has been visited before. On the second visit (and on further subsequent visits), a so-called loop-closure is performed, in which the robotic system corrects the understanding it has of its own position by comparing features perceived in the past and currently. By this reasoning, the system can reduce the error of the map it has created and can increase the accuracy of its current location. The recognition of being at the same place can be done by any of the exteroceptive sensors listed above or a combination thereof. A particular challenge in decontamination robotics is to consistently update a map under the premise that the decontamination robot itself changes the world around itself by manipulation. This makes the associations between past and current sensor data rather complex.

Path and action planning — To efficiently fulfill a decontamination task, a robotic system needs a plan of action. As humans should be involved as little as possible, it is of great importance to plan and control the action for autonomous execution. If the goal is mapping an environment, the system should not do so by exploring the area randomly (which eventually could also succeed) but there should be some logic to efficiently achieve full coverage of the mission area in a given precision. To explore in a meaningful way, the system needs to interpret the map it has created from the sensory data. The system might be confronted with many challenges: Is the surface even enough to drive on? Is the opening large enough to fit through? What is a clever way to go to point A in order to subsequently proceed to point B? What to do if there is an obstacle that was not there when the map was first created? Answering those essential questions is called path/trajectory planning. For mobile decontamination systems, we need not only planning for the platform as a whole but also for the mechanic actuator. One of the most challenging tasks in interacting with the world for a robotic system is to successfully grasp unknown objects (sometimes piled on a heap) without damaging or dropping them.

In most cases there are many possible plans that would fulfill the task, however, it is a difficult optimization problem, which solution should be chosen. The outcome can be widely different when given different prioritizations of safety, speed, accuracy, cost, or energy efficiency.

Robot control — Planning alone is still not enough to perform a task as there has to be also control of the planned execution to ensure that the system is actually following the plan even if disturbed. Especially heavy machinery often employs hydraulics which is notoriously hard to control and model algorithmically. The feedback loop to recognize the current state of the machine is done mostly visually in humans while the kinematic control algorithms typically rely on more precise sensor data.

Therefore, an important part of control is to employ control stations for human operators, which are primarily accustomed to visual impressions, but also to haptic feedback. As full autonomy is not always achievable nor even wanted, a human operator should be able to easily interface with the system. For this purpose, he is supported by semi-autonomous assistance systems. A wholesome immersion with rich visual information makes it much easier for the expert to assess a situation than being reduced to simple passive camera views on screens which are the default in classic remotely-operated machines. Especially, difficult tasks like tool change on an excavator could be assisted by a human remotely until those tasks work fully autonomously.

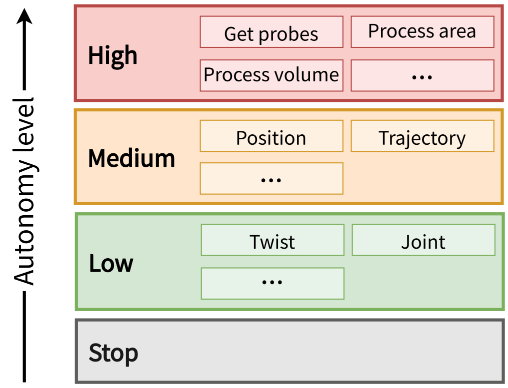

Figure 1: Schematic view of different autonomy levels for robotic tasks in the ROBDEKON interface, mainly developed by KIT-ISAS.

4.2 Robotic systems overview

In the following, there is a brief list of the systems available in ROBDEKON with a very short description per system. The systems are covered in much greater detail in the specific separate contributions in this issue.

ROBDEKON interface — The ROBDEKON interface is a programming interface that all partners in ROBDEKON use to allow teleoperation and VR/AR applications for the robotic systems [46]. Each system provides certain capabilities and the human operator can choose on which abstraction layer those should be used. For example, an autonomous excavator may provide a high-level option to autonomously dig a pre-defined area, a mid-level option to drive to a manually selected location in a map, and the low-level option of commanding individual excavator components (e. g., joints) manually similar to how a normal operator inside the excavator would, albeit using enhanced user interfaces. The stop level interrupts currently executing commands and prohibits issuing new commands via the interface. The communication of the systems also works without physical proximity as the communication is VPN-based. This allows a control station to be placed virtually anywhere.

Control stations — As ROBDEKON also deals with the creation of modern interaction methods for the robotic systems, control stations using the ROBDEKON interface are created which include VR, where the operator wears 3D glasses and uses VR controllers (Fig. 2), and AR, where a device like a tablet has the video of the real system overlayed with additional sensor data. Additional control stations give the operator the opportunity to walk on an omnidirectional treadmill while examining the scene on surrounding screens in 3D using lightweight polarized glasses. For interaction with the devices, a haptic feed-

Figure 2: VR telepresence system developed by KIT-ISAS as one example for the ROBDEKON control stations.

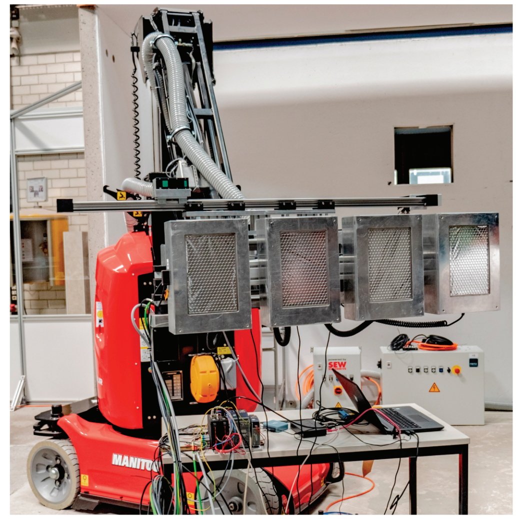

Figure 4: Decontamination platform and measurement array of KIT-TMB.

back system was created [13] which allows the operator to feel the mechanical restrictions of possible system actuations. Another challenge addressed in ROBDEKON is the latency between the control station and the real robotic system [10]. All control stations interact with the robotic systems via the ROBDEKON interface.

Gammabot — The Gammabot (Fig. 3) is a scanning platform for decommissioning nuclear power plants. The robot is equipped with a high-resolution LiDAR and sensors to detect radiation. The platform acquires the scan while it is stationary and then decides autonomously where the next scan would be most beneficial to obtain a full coverage map. The idea is to let the system create a map overnight and to afterwards provide this most recent map to the operator and to the decontamination platforms.

Decontamination platform and measurement array — The decontamination platform "Decont System" can be equipped either with a milling machine to remove a contaminated wall surface layer or a radiation detection array to measure successful decontamination [42, 43]. The system equipped with the measurement array is depicted in Fig. 4.

Cleaning of contaminated parts — For the cleaning of contaminated parts that have been separated from the building structure, like disaggregated pipe parts, currently, a manual decontamination process is used where fully protected humans clean the items, e. g., with a water jet. To automate this process, machine learning algorithms were developed to allow a robot to grasp a previously unknown object from a box and to determine a cleaning strategy for that object to reach all parts of the surface with the cleaning jet. Grasping of initially unknown and unorderered parts from a box is still an active research problem [32]. A robot executing those newly developed methods is shown in Fig. 5.

Walking excavator — A walking excavator (Fig. 6) is an extremely versatile platform, which has a large number of degrees of freedom to move. For this reason, such excavators usually require very experienced drivers to properly operate them without inflicting damage to the vehicle itself.

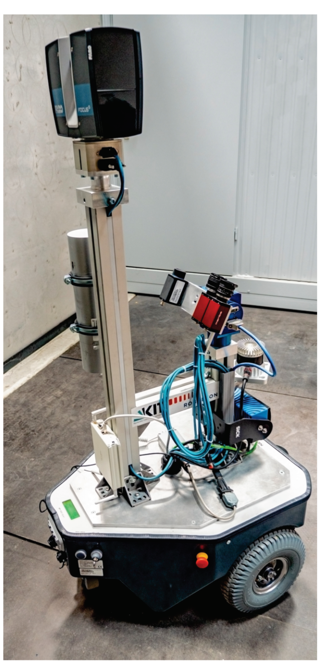

Figure 3: Gammabot system of KIT-IPR.

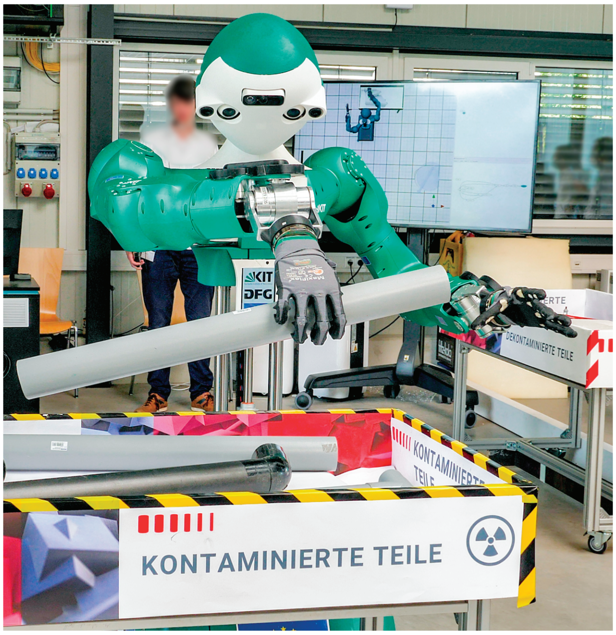

Figure 5: Grasping of contaminated parts for cleaning by the humanoid robot ARMAR-6 of KIT-H^{2}T.

Figure 6: Top: Autonomous walking excavator of DFKI. Bottom: Additional sensors like LiDAR scanner and cameras for various tasks. Photo credit: Felix Bernhard – DFKI Bremen.

The excavator was equipped with sensors and autonomy functions that allow it to autonomously drive even on sloping terrain [4] and have protection against overturning. This was achieved by reinforcement learning. The versatility of the platform is depicted in Fig. 6

Figure 7: Top: Autonomous crawler excavator of Fraunhofer IOSB. Bottom: Some of the added hardware (GNSS, LiDAR scanners, stereo cameras, WiFi) in greater detail.

Crawler excavator and autonomous dumper vehicle — A 24 t excavator (Fig. 7) was equipped with sensors, computing resources, and algorithms to be able to autonomously drive to a given target location, dig a predefined area to a given depth and load the excavated material to an autonomous transport vehicle (Fig. 8) while at the same time avoiding static and dynamic obstacles. The vehicles feature a combination of several machine learning methods for the sub-tasks like control and mapping.

The material is also autonomously transported to a dumpsite. For the whole duration of the task, the excavator avoids collisions with static or dynamic obstacles in the working area by carefully working around them or halting execution.

Hazardous material handling — For handling hazardous material, robotic systems have been developed that are able to grasp objects and classify them with high accuracy. The mobile system depicted in Fig. 10 can take hazardous items off the ground by a robotic arm and can put them into a basket to bring them to a safe destination. For sorting of batteries, the system in Fig. 9 can perform precise classification while the objects are moving on a conveyor belt and the robotic arm then sorts the hazardous items into the appropriate buckets.

Figure 8: Top: Combination of autonomous tractor and dump trailer of Fraunhofer IOSB. Middle: Additional sensors on the roof: Cameras, LiDAR scanner, GNSS. Bottom: UWB (ultra wide-band) localization system mounted on a frame on the trailer.

Figure 9: Sorting and classification system by FZI for hazardous waste handling.

5 Conclusion

ROBDEKON has created numerous technologies for sensor data fusion, mapping, planning, control, manipulation, interaction, and immersion. Those technologies were developed with decontamination robotics in mind such that

Figure 10: Husky system of FZI to retrieve hazardous materials.

using these technologies can reduce health risks for humans. The developed technologies provide assistance for humans in performing tasks (semi-)autonomously and by offering new concepts for telepresence which in turn enable operators to supervise more than one thread of action. ROBDEKON serves as the national knowledge hub for decontamination robotics.

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