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Bots2ReC - Analysis of Key Findings for the Application Development of Semi-Autonomous Asbestos Removal

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Abstract

The removal of asbestos from existing buildings is a socially important and challenging renovation process due to the handling of hazardous materials. The EU project Robots to Re-Construction (Bots2ReC) has developed a robotic system for semi-autonomous asbestos removal for apartment buildings. The removal of plaster and tiles and the associated tile adhesive is implemented as a semi-autonomous construction task by mobile manipulators and integrated into the existing construction process. The development is based on a test-driven approach in order to obtain information about the achievable performance and the acceptance of the human operators as early as possible. The identification of the control variables for the respective tools and the embedding in the on-site process flow are named as the main reasons for the test-driven approach. The analysis of selected key findings of the project shows for the developed semantic mapping via mobile robot that a minimal, application-specific data format favours an efficient overall process control via task planning up to execution. In the development of mobile bases for the application, it can be shown that a holonomic drive is preferable to a differential drive due to the partly narrow and angled parts of the building. To carry out the intended processes and to guide the automated power tools, the in-house development of serial manipulators is necessary, since the combination of the required working space with the occurring weight and process forces cannot be solved within the requirements by an industrial manipulator. Finally, the main benefit of this papers contribution is seen in the transferable outcomes to other on-site automation projects.

Keywords
On-Site Automation; Mobile Manipulation; Asbestos Removal

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1 Introduction

The motivation for automating the asbestos removal process is high, as both societal and economic goals converge due to the potential health burden, the repetitive work for human workers and the immense prevalence in buildings of the 1960s and 1990s. During the peak of asbestos use, the harmful material was used in millions of European apartments. The most reliable figures of 15 million contaminated apartments come from France [1], although similar figures can be assumed in other European countries such as Germany, Italy and the UK due to similar asbestos consumption [2]. Nowadays, the removal of asbestos is done manually with abrasive power tools. Construction workers are protected from the asbestos dust by protective suits and breathing masks. The protective measures make the work considerably more difficult, require regular breaks and only allow short shifts. Despite the protective measures, illness due to asbestosis, for example, cannot be completely ruled out. As a result, the manual removal process is dangerous as well as time-consuming and costly.

An automation solution developed in the "Robots to Re-Construction" (Bots2ReC) research project, aims to protect workers and increase productivity. The following process requirements and prerequisites shape the project as a challenge: no digital data basis of the buildings, narrow and winding rooms, high safety requirements in the form of air locks and foil covers, irregular processing surfaces and the need of a removal process that is as dust-free as possible. The solutions developed and the underlying process are presented in the following with its guiding decisions.

An analysis shows an excerpt of the key findings along the development process with the respective influences on the overall system. This includes the developed process of robot-based semantic mapping to generate an application-specific environment representation for the subsequent task planning. The analysis justifies the necessary development of special machines for the components of the mobile base, the serial arm, and the automated power tools. A discussion of the results with a concluding summary rounds off the article. The contents presented here and further details that go beyond them are summarized in the freely available project book [3].

2 Test-Driven Development Process

A test-driven development process was selected for the development, as many requirements from the construction industry were difficult to validate by simulation and many assumptions determined the development, especially in the area of controlling the abrasive process. For this reason, a first prototype to validate the assumptions made was to provide as much clarity as possible within the first year of the project, in order to develop a second, more mature prototype. The process flow is shown graphically in Figure 1.

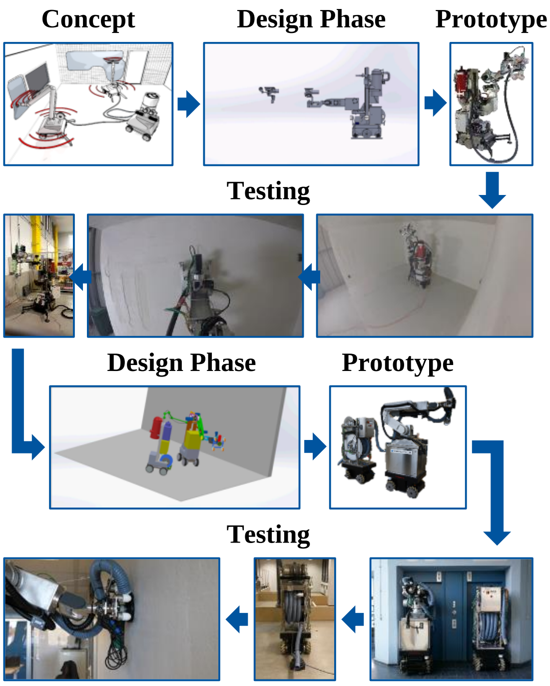

Figure 1: Test-Driven Development Process

The basis for the process was a comprehensive list of requirements, in which the risky assumptions in particular were identified. Test scenarios for validation were defined for these assumptions and the design of the first prototype aimed for the enabling of all identified test scenarios.

The tests were performed on the list of scenarios, sorted according to the uncertainty of the assumption from low to high. Various assumptions were falsified which led to fundamental architectural changes in the robotic system. The most significant is the centralisation of the aspiration unit, so that the second prototype was designed as a tandem. The front unit performs the removal process while the rear unit handles the supply cable and hose. Figure 2 shows both developed systems.

The structural change was necessary to meet the performance requirements and especially the process requirements of the construction industry. The two key points for centralising the extraction were as follows:

- Due to the given installation space, an on-board aspiration unit cannot provide the necessary power to ensure almost 100% extraction of the asbestos dust produced. The centralisation allows the industrially common over-scaling of the extraction capacity in order to make load peaks manageable.
- An on-board aspiration unit means that the contaminated waste generated has to be handled by the robot. This would be possible, for example, by depositing sealed film bags.

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The resulting challenges in ensuring navigation capabilities were great. Accordingly, a centralized aspiration unit solves this problem elegantly and decouples the logistical removal of the waste from the process.

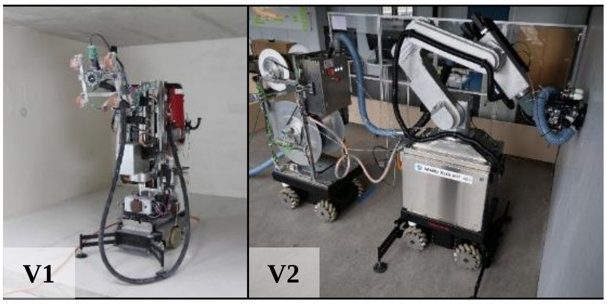

Figure 2: Developed Robots

The choice of the test-driven approach was accordingly a success, as the early concretisation of risky assumptions enabled major changes such as the required structural change.

3 Key Findings

In addition to the key findings at the system level, various key findings can also be named at the level of process steps or subcomponents. An excerpt is given in the following.

3.1 Application-Specific Environment Model

Since the process of asbestos removal takes place in existing buildings from the mid-20th century, the data basis for the environment is usually poor. Accordingly, a collection of the fundamentally required data is necessary. Within the framework of the project, a customised semantic mapping process was developed, which is shown in Figure 3.

On the basis of a holonomic mobile robot, the floor plan of the object is determined with two 2D lidar sensors and a common Simultaneous Localization an Mapping (SLAM) procedure. Based on the localisation within the floor plan, the point clouds of an array of three RGB-Depth cameras are transferred into a global point cloud. A subsequent segmentation and semantic classification yields the representation of floor, wall, door and window objects based on 3D polygon representations. The generated semantic map can be used directly for task planning for the deployment of the mobile manipulators. The detailed implementation of the developed methods can be found in [4-6].

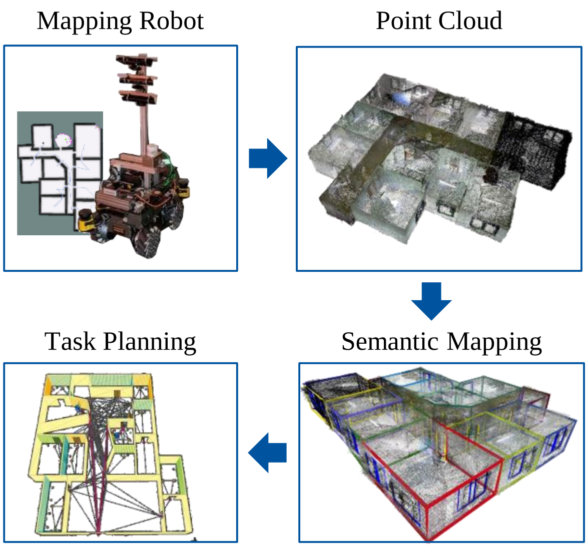

Figure 3: Environment Cognition Workflow

3.2 Special Machines Required

The analysis of various asbestos removal renovation projects clearly showed that the development of a robotic system for the application case had clear conflicts of objectives between the targeted performance and the available installation space. For this reason, industrial series products could be used in very few cases. A few excerpts for self-developed subcomponents are given below.

3.2.1 Mobile Base

The use of mobile robots in residential buildings is already technically possible and is demonstrated, for example, in the form of private service robots. The challenge in this project was the stability of the overall system to support the total weight of 300kg and to enable the processing of ceilings beyond 2.50m height. Figure 4 shows both models developed. According to these requirements, variant A relied on a differential drive whose stability was ensured by four additional omni wheels. The robust design was convincing and the mobility was found to be sufficient. However, the change to the structure of a coupled tandem required holonomic movements, so the drive concept for variant B was changed to meconium wheels.

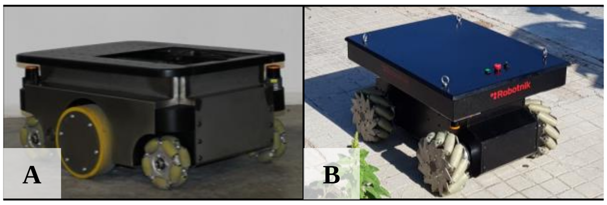

Figure 4: Developed Mobile Bases

3.2.2 Serial Robotic Arm

In order to ensure the execution of the process, a serial chain with at least 6 degrees of freedom (DOF) was required. Numerous geometric investigations within realistic application situations showed that an additional redundant DOF was required for angled and narrow corridor areas. For the first prototype, this was solved with a 1P-6R chain, which was the fastest in design and realisation and met the goal of gaining insights fast. During the first tests, it became clear that the centre of mass and the additional dynamic loads operated the mobile manipulator partly outside the stable range of the supporting polygon. Accordingly, the

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arm for the second prototype was designed as a 7-R chain, which has a much more stable basic configuration due to an optimised distribution of the link lengths and thus the centres of mass. The developed serial robots are shown in Figure 5 with their kinematic structure and the design methods can be found in [7] and [8].

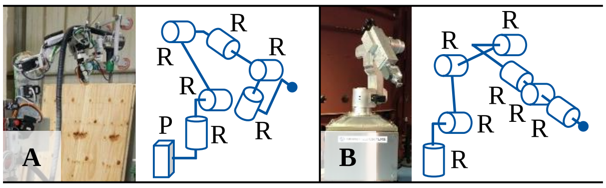

Figure 5: Developed Manipulators

3.2.3 Automated Power Tools

Analogous to the development of the mobile bases and the serial manipulators, three variants of the required grinding tool could be created. The variants are listed in Figure 6.

The concept of the grinding tools is strongly linked to the envisaged control concept. Variants A and B rely on a position control of the manipulator, in which three compliant DOF generate the compensation with respect to the wall in question in case of alignment errors. The associated positioning forces are introduced via support wheels on the tool, so that the tool aligns itself with the wall surface. During the tests, it was found that the dynamic process forces during the grinding of plaster interfere with the precise alignment of the tool and thus do not achieve qualitatively acceptable results. As a consequence, the compliant DOF for pan and tilt were removed and only the nominal wall distance was realised by a spring-loaded DOF. In combination with a force-torque sensor and an array of 1D radar sensors, a satisfactory closed loop control was finally found in the form of a hybrid control approach. Detailed information on the control methods evaluated can be found in [9-12].

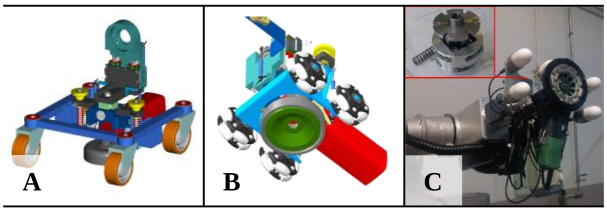

Figure 6: Developed Grinding Tools

4 Discussion and Conclusion

The paper presents the test-driven development process of an on-site construction robot for the removal of asbestos from apartment buildings. The authors limited themselves to the presentation of decision-making processes and the associated findings. A quantitative presentation of the respective performance data is deliberately avoided in order to focus on the general development methodology.

Overall, the development processes presented here reinforce the known methods of targeted development of on-site construction robots. The greatest added value lies in the presentation of the adaptation to the use case of asbestos removal and the processing of the key findings determined therein. The transferability to other applications that make use of mobile manipulators is given.

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