Lasers in Manufacturing Conference 2025

Improving Remanufacturing with Cobots: Sensor-Enhanced Path Planning for Automated Laser Cleaning

Thomas Kaster[a,1], Jan-Niklas Schneider[a], Leon Gorissen[a], Christian Hinke[a]

[a]*RWTH Aachen University - Chair for Laser Technology LLT, Steinbachstr. 15, 52064 Aachen, Germany*

Abstract

This paper presents a novel conceptual two-step approach for automated laser cleaning in the remanufacturing process using collaborative robots (cobots) and sensor-enhanced path planning. Remanufacturing is a key enabler of the circular economy, but current processes, especially cleaning, remain labor-intensive and inefficient in the context of individual and small series production. The integration of flexible robotic systems with advanced sensing and control architectures enables precise and adaptable surface treatment. Our system leverages the Robot Operating System (ROS) for modular, real-time integration of laser control, sensor fusion, and motion planning. The proposed method significantly reduces manual involvement, increases repeatability, and opens up new possibilities for sustainable and intelligent manufacturing, making the approach accessible to small- and medium-sized enterprises (SMEs) with limited automation capacity.

Keywords: Remanufacturing; Circular Economy; Robotics; Laser; Laser Cleaning

1. Introduction

Remanufacturing plays a crucial role in achieving sustainable production, a key pillar of the United Nations Sustainable Development Goals (United Nations, 2023). It involves returning used components or products to like-new condition through processes such as disassembly, cleaning, repair, and reassembly. The cleaning stage, while essential for quality assurance, also has a significant environmental footprint when performed manually or with abrasive chemicals. Laser cleaning is frequently used in this context for removing contaminants, coatings, or oxidation. Despite its effectiveness, laser cleaning is often hindered by manual steps, particularly in defining the path of the laser beam and adjusting process parameters based on part geometry and condition. These limitations, especially in digitalization, reduce scalability and increase costs (Schöggl, 2023). This paper addresses this gap by proposing a cobot-based system that combines human-robot collaboration with intelligent sensor feedback to automate laser cleaning tasks. The primary goal is to enhance efficiency and adaptability while lowering the barrier to adoption for small and medium-sized enterprises (SMEs).

2. Related Work and Problem description

Previous research in laser processing has demonstrated the benefits of automation and robot integration, particularly in structured production environments. Conventional industrial robots are widely used for laser welding, cutting, marking and additive manufacturing (Boldrin, 2024; Bremer, 2021). However, in remanufacturing applications, the high variability of parts and unknown surface conditions pose significant challenges. Several studies have proposed machine vision systems for part recognition and guidance in structured environments. For instance, vision-guided robotic inspection in remanufacturing has demonstrated automated path planning based on reconstructed 3D part geometry (Khan, 2021). However, few works

* Corresponding author. Tel.: +49-241-80-40420
E-mail address: thomas.kaster@llt.rwth-aachen.de

address the integration of real-time sensor feedback with flexible robotic manipulators operating in dynamic, unstructured environments (Ghofrani, 2019). This gap hinders broader application of automation in remanufacturing environments characterized by variability and uncertainty. The use of collaborative robots has gained traction due to their safety features and ease of use, especially in human-centric settings. In the context of laser-based manufacturing, however, it must of course be mentioned that this combination gives rise to new safety requirements. Moreover, ROS has emerged as a popular platform for robotics research due to its open-source nature, active community support, standardized communication patterns and modularity (Robinson, 2022). Our approach builds upon these advances, applying them in the underexplored domain of remanufacturing-specific laser cleaning.

3. Cobot-based Approach

The proposed cobot-based approach is structured as a two-step process: (1) rough positioning of the cobot by a human operator and (2) precise alignment and path generation using sensor feedback. In the course of further research, the system is to be expanded with a combination of sensors in order to obtain detailed 3D data of the component's surface. For example, a laser triangulation sensor (Micro-Epsilon scanCONTROL), a depth camera (Intel RealSense D435i), and a CMOS camera (Allied Vision) could be used for this purpose. The collected data will then be processed within ROS, which coordinates path planning, sensor calibration, and laser power control modules. This modular design allows the system to adapt to part-specific features and automatically generate individual laser cleaning paths.

4. Prototype

The physical setup (see Fig. 1) consists of a lightweight cobot arm (Universal Robots UR5e) equipped with a galvanometer scanner (Scanlab ScanCube7) as the laser optics. The laser used is a nanosecond laser from Tyo redENERGY® G4 SPI Lasers UK Ltd with a maximum laser power of 100 W. In the version shown, the sensors described as an approach are not yet integrated.

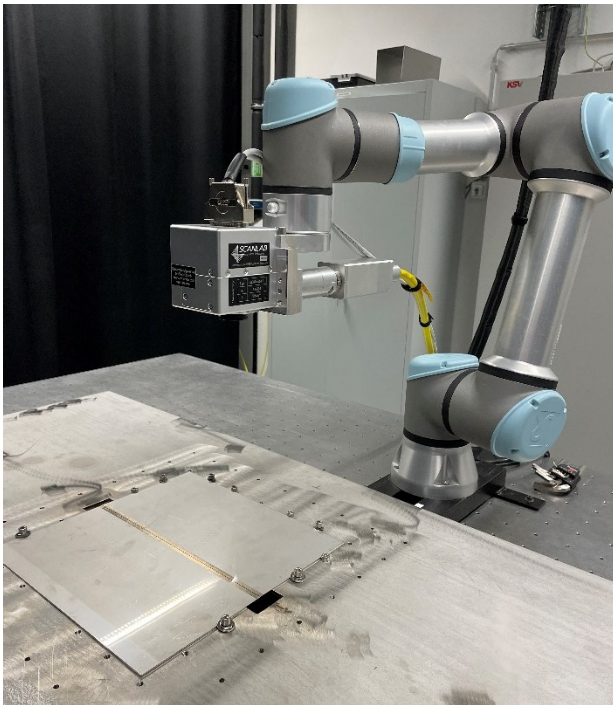

Fig. 1. Prototype laboratory setup for cobot-based and automated laser cleaning. Cobot (UR5e) and galvo scanner (Scanlab ScanCube 7) during laser cleaning as weld seam preparation.

Once the integration of sensors on both the hardware and software sides is complete, the prototype should function as follows: The ROS-based software stack includes nodes for sensor data acquisition, preprocessing (e.g., noise filtering, segmentation), surface modeling, and motion planning. The path planning algorithm uses point cloud data to identify areas to be cleaned, taking into account accessibility and optimal laser alignment. Operators can visualize the sensor data and intervene if necessary via a graphical user interface. The entire process, from initial positioning to cleaning, is designed to be intuitive and robust, enabling quick changeovers and minimal training.

5. Results

As this work presents a conceptual approach rather than a fully realized implementation, no experimental data is available at this stage. However, preliminary simulations and feasibility assessments indicate that the proposed sensor-guided, ROS-integrated system is well-suited for adapting to diverse geometries commonly found in remanufacturing. The focus lies on demonstrating the potential of modular sensor integration with cobots to address known bottlenecks in the laser cleaning process chain.

6. Discussion

By outlining a feasible architecture for integrating collaborative robots with sensor-enhanced path planning in a ROS environment, this paper contributes a flexible and scalable concept for automating laser cleaning. The proposed system emphasizes adaptability to various component shapes without the need for highly structured environments. Potential challenges include sensor calibration, latency in sensor fusion, and the development of standardized software modules for different laser processes. While practical validation is pending, the concept has strong potential for application in small- and medium-sized enterprises aiming to digitalize and automate remanufacturing processes. The modular nature of ROS and the use of off-the-shelf components enhance the transferability of the proposed concept from research to industrial applications.

7. Conclusion and Outlook

This conceptual paper introduced a modular, ROS-based approach for automating laser cleaning tasks in remanufacturing using collaborative robots. By leveraging a combination of depth and vision sensors, the system is designed to overcome the limitations of manual path definition and enhance flexibility and repeatability. Although experimental validation is a subject of future work, the outlined framework establishes a foundation for further development. Next steps include the hardware setup, system integration, and real-world testing. Ultimately, this work aims to contribute to an open-source, adaptable framework for smart laser manufacturing aligned with circular economy goals. In the long term, we envision a community-driven ecosystem of ROS packages dedicated to laser-based (re)manufacturing.

Acknowledgements

Funded by the Deutsche Forschungsgemeinschaft (DFG, German Research Foundation) under Germany s Excellence Strategy – EXC-2023 Internet of Production – 390621612.

The authors acknowledge the financial support by the Federal Ministry of Education and Research of Germany in the framework of Research Campus Digital Photonic Production (project number: 13N15423).

This manuscript was reviewed for spelling grammar and clarity using the AI-based tool ChatGPT.

References

Boldrin, D., Tosatti, L., Previtali, B., Demir, A., Seam tracking and gap bridging during robotic laser beam welding via grayscale imaging and wobbling, in Robotics and Computer-Integrated Manufacturing, Volume 89, 2024, https://doi.org/10.1016/j.rcim.2024.102774.

Bremer, J., Walderich, P., Pirch, N., Schleifenbaum, J., Gasser, A., Schopphoven, T., Effects of path accuracy on additively manufactured specimens by laser material deposition using six-axis robots, in J. Laser Appl., 2021, https://doi.org/10.2351/7.0000308

Ghofrani, J., Kirschne, R., Rossburg, D., Reichelt, D., Dimter, T., Machine Vision in the Context of Robotics: A Systematic Literature Review, 2019

Khan, A., Mineo, C., Dobie, G., Macleod, C., Pierce, G., Vision guided robotic inspection for parts in manufacturing and remanufacturing industry, in Journal of Remanufacturing, 2021, DOI: 10.1007/s13243-020-00091-x

Robinson, M., 2022. From Academia to Industry and Beyond: ROS Is Advancing Robotics for Tomorrow's Challenges. Accessed July 19, 2025. https://ifr.org/post/from-academia-to-industry-and-beyond.

Schöggl, J., Rusch, M., Stumpf, L., Baumgartner, R., 2023, Implementation of digital technologies for a circular economy and sustainability management in the manufacturing sector, in Sustainable Production and Consumption, p. 401 – 420, DOI: 10.1016/j.spc.2022.11.012

United Nations Department of Economic and Social Affairs (DESA), 2023, The Sustainable Development Goals Report 2023: Special edition, Towards a Rescue Plan for People and Planet, https://unstats.un.org/sdgs/report/2023/The-Sustainable-Development-Goals-Report-2023.pdf. Accessed July 28, 2025.