Platform for Adaptive Integration of Beam Shaping on Demand in Ultrashort Pulse Processing Systems

Moritz Kröger*, Paul Buske**, Matthias Greiber***, Leon Gorißen*,Martin Kratz ***, Thomas Kaster*
Chair for Laser Technology LLT, RWTH Aachen University
***Chair for Technology of Optical Systems TOS, RWTH Aachen Univsity*
**** Fraunhofer Institute for Laser Technology ILT*
mailto:moritz.kroeger@llt.rwth-aachen.de

The usage of microservices in ultrashort pulse (USP) ablation systems allows for a flexible integration of process evaluation sensors which can be used to enable in process optimization loops. These optimization loops and the underlying system could be expanded to not only optimize traditional processing parameters but also the beam shape through the utilization of diffractive neural networks.

1 Introduction

Current USP processing systems adhere to a well-defined sequence of steps. The workflow commences with the preprocessing of a workpiece's ablation geometry, converting it into a process path that incorporates specific parameters. This process path is subsequently loaded onto the manufacturing system, the USP laser is configured, and the process is initiated. In the context of Industry 4.0, the integration of sensors such as confocal sensors or white light interferometers enables the assessment of product quality, which in turn allows for dynamic adjustments of the process. Additionally, the incorporation of optimization techniques permits autonomous parameter searching.

A critical factor influencing all USP processes is the beam shape. The combination of diffractive neural networks as a phase mask design method with spatial light modulators provides precise control over the laser beam shape, allowing for the adjustment of the beam shape on demand. Nevertheless, current software systems impede the adoption of these advancements due to their lack of flexibility, which hinders the integration of neural networks, optimization techniques, and adaptive measurement analysis. In this paper a software architecture is proposed which allows the beam shaping on demand and process optimization coherently.

2 Proposed software architecture

The proposed architecture is based on the microservice concept, where loosely coupled subsystems interact through request-response communication patterns. Each service operates as an encapsulated unit, fulfilling a distinct function within the manufacturing system. These services are autonomous and decoupled from the rest of the system, offering significant flexibility. This decoupling ensures that microservices can be adapted and modified on demand without impacting other subsystems, thereby enhancing the system's overall adaptability and resilience. [1]

Additionally, this architecture facilitates easier resource allocation, driver management, and dependency management. By isolating services, resources can be allocated more efficiently according to specific needs. Driver updates and modifications are managed independently, reducing the risk of system-wide disruptions. Dependency management is streamlined, as each service maintains its own dependencies, further simplifying maintenance and upgrades. As discussed in our previous work [2] the system is split into multiple microservices types which are catagorized into Control Services, Information Services and Application Controllers. This work also showcases the flexibility of this architecture for experimental manufacturing workflows.

3 Autonomous Process Optimization

The microservice system architecture can be used to inject Bayesian optimization into the manufacturing system. An example use case for an autonomous execution system is autonomous process optimization. In this use case, an industrial USP laser machine was reprogrammed using a Microservice based architecture. The Control Services used in this use case are:

The Movement Service (Aerotech A3200) is responsible for moving the workpiece in 3D space. The Scanner Service (Scanlab RTC6) is responsible for controlling the USP Scanner System. The Laser Service (Edgewave FX Series) is responsible for controlling the parameters of the laser source. The Distance Measurement Service (Keyence CL3000) is responsible for line measurements on the workpiece surface substrate. A Cavity Information Service can generate a productivity performance index from these measurements for a given cavity. The

DGaO Proceedings 2024 – http://www.dgao-proceedings.de – ISSN: 1614-8436 – urn:nbn:de:0287-2024-A003-6
submitted: 31.07.2024 – published: 12.08.2024

Metrology Service (GBS Smart WLI) is responsible for 3D metrology measurements on the workpiece surface. A Metrology Information Service can generate a quality performance index from these measurements for a given cavity.

The Bayesian optimizer controls the parameter search and is responsible for proposing experimental parameter sets. Afterwards, the Application Controller is responsible for loading these parameters into the control services and coordinating the ablation of example cavities. It autonomously analyzes these cavities through the Metrology and Distance Measurement Services. The data from these measurements are automatically saved in the specialized Information Service and autonomously analyzed. Afterwards, the resulting quality and productivity parameters of the just proposed and analyzed cavity are sent to the optimizer. Preliminary results show that a standard material characterization (optimization of fluence and pulse/line overlap for specific ablation efficiency and quality defined by SA) for metals can be automatically generated in 14 subsequent experiments.

4 Integration of Diffractive Neural Networks

Diffractive Neural Networks have proven to be a reliable method to efficiently generate phase masks for arbitrary beam shapes [3]. Preliminary benchmarks have shown that GPU-accelerated algorithms can generate phase masks for arbitrary beam shapes in minutes. The integration of such an algorithm is the example at hand of the usage of microservices in a manufacturing system. The system explained above can therefore be expanded with a Spatial Light Modulator (SLM) Control Service and an SLM Oracle Service, which allows the application controller to generate phase masks on demand and hides the needed GPU infrastructure and dependencies. At LLT, in cooperation with TOS and ILT, an SLM is integrated into the mentioned Pulsar system and the Diffractive Neural Network software is incorporated into the microservice architecture. First tests show promising results, as seen in Fig. 1.

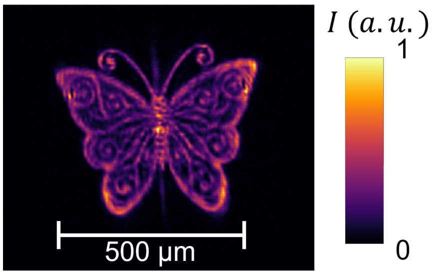

Fig. 1 *Picture of the laser focal point of the experimental setup shaped by an SLM phase mask calculated by a Diffractive Neural Network*

In the next step, the described use case will be expanded to not only optimize laser and process parameters but also the beam shape. For that, an algorithm will be used which allows the definition for a parameterized beamshape. Fig. 2 shows example beam shapes that can be generated from these continuous parameter sets.

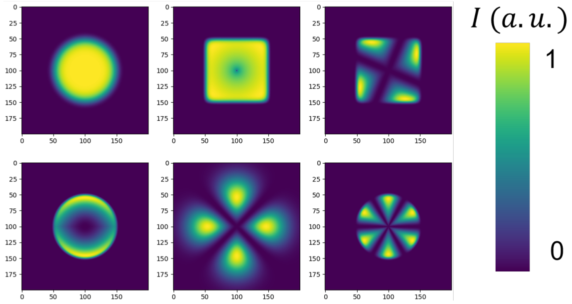

Fig. 2 *Examples of possible parameterized beam shapes that can be generated on the fly through diffractive neural networks*

5 Summary and Outlook

The proposed microservice architecture shows advantages when using it as a platform to integrate modern optimization techniques into manufacturing systems. Algorithms like diffractive neural network can leverage this architecture and allow the integration of new on demand calculation concepts into manufacturing systems which can be used for very sophisticated optimization loops. This optimization loops can in the future be extended to include even more manufacturing paramaters.

6 Acknowledgments

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).

References

[1] E. Wolff, *Microservices* (Dpunkt.Verlag GmbH, 2018).

[2] M. Kröger, C. Lasogga, M. Kratz, C. Hinke, and C. Holly, "Platform for Adaptive Integration of Data-Driven Models And Simulations Into Ultra Short Pulse Manufacturing Systems." Journal of Laser Micro/Nanoengineering **19**(1) (2024).

[3] P. Buske, A. Völl, M. Eisebitt, J. Stollenwerk, and C. Holly, "Advanced beam shaping for laser materials processing based on diffractive neural networks," Opt. Express **30**(13), 22798–22816 (2022).