Digital Photonics for Next Generation Laser Material Processing

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Laser technology's industrial use has grown due to lower costs and improved optics. To stay competitive in context of laser system technology, five enablers - actuators, control, sensors, algorithms, and digitalization – have been identified and must be advanced. *Digital Photonics* addresses this by photonics-requirements-driven wholistic development of system technology.

1 Introduction

In recent years, the laser has developed from a specialized tool into a tool used in many parts of industry. One of the reasons for this is the falling cost of laser beam sources [1], as well as new developments in the field of laser optics [2, 3]. Furthermore, the laser itself is a unique tool that is used for various processes in a wide range of applications [4]. In particular, the ability to manipulate the laser beam quickly by using scanners or acousto-optidial c deflectors (AODs) and processes without force transmission between the tool and workpiece are further important advantages [5].

Laser system technology must adapt to changes, especially those in the laser market, to remain competitive and systematically exploit the advantages of laser technology.

To meet this challenge, five enablers have been defined. The respective further development of these enablers, but also their systematic combination, will lead to digitized system technology for the next generation of laser material processing (LMP). This will be referred to below as *Digital Photonics*.

2 Enablers of Digital Photonics

Actuators: Further development of existing systems with new actuators as well as research and development of new kinematic concepts.

Control: Use of new approaches in control technology to reduce error tracking and process time.

Sensors: Development of new sensor technology to improve the status determination of system technology.

Algorithms: Improving path accuracy, for example through new reinforcement learning approaches for motion planning or Bayesian optimization for parameter development.

Digitalization: Consistent digitalization of all process steps and use of new approaches in the software architecture.

3 Research Examples

High-precision and highly automated laser micro structuring:

Combining a 2D galvanometer scanner head with an XY servo stage creates a system where the high dynamics of the scanner are available across the entire working field of the stage. Simultaneous motion of both devices has been shown to enhance production by improving accuracy and reducing processing time. A key factor in this success is the strategy used to distribute the motion between the devices. Ref. [6] proposes a trajectory planning approach that optimally utilizes the kinematic limits of the system, resulting in feasible trajectories for both the scanner head and the stage such that the simultaneous motion is capable of achieving high laser processing speed.

In order to be able to utilize the flexibility of the laser in the entire Ultra-short pulse (USP) laser system, it is necessary to integrate various measurement technologies. This allows process results to be evaluated directly and any errors to be responded to immediately. A flexible software architecture is necessary to be able to use different use cases flexibly. This makes it easy to integrate new sensor technology quickly. A software architecture based on microservices has proven to be useful for setting up such a flexible USP laser system. This provides the basis for further applications in the field of automated parameter generation or a closed-loop laser system. [7]

Cost-effective and flexible 3D laser material processing:

Also due to the lighter process optics [3], cheaper and smaller robots can be used for the LMP in the future. However, these have the disadvantage that the path accuracy of the robots is currently not sufficient for LMP. One approach to improving accuracy is to train the kinematic model of the robot using AI approaches. The kinematic freedoms of the laser process can also be taken into account. [8]

Insofar as the path accuracy is not sufficient due to improvements in the modeling of the robot, the fast and highly dynamic deflection of the laser beam can also be used here. However, the exact robot position must be known to set up a control loop.

To achieve this, new approaches in the field of sensor data fusion and the development of new, laser-based speckle sensors are being researched. The overall aim is to improve the status determination of robot systems. [9]

Cost-effective large-area laser material processing:

Until now, the paradigm for processing large-area components has been that the machine size is proportional to the component size. With the use of mobile robots equipped with laser welding optics, large-area components can be processed more efficiently [10]. Here, the path accuracy could be increased by using a new sensor system, as direct LMP is almost possible [11].

4 Conclusion

The conditions of the laser market are changing - In order to remain competitive and fully exploit the advantages of laser technology, laser system technology must adapt to market changes. Five key enablers have been identified for this purpose: Actuators, controls, sensors, algorithms and digitalization. These enablers are to be systematically further developed and combined to realize the next generation of laser material processing, known as *Digital Photonics*.

5 Outlook

The future of laser material processing will be characterized by the consistent further development and integration of the defined enablers. There are already concrete examples in research, such as the highly automated USP system using a new software architecture. In addition to laser material processing, issues from the entire research field of laser technology, such as self-learning laser beam sources, will also be addressed in the future. The aim is to meet global challenges from the perspective of laser technology.

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