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PRESS RELEASE

Making photonics more efficient with AI

How can artificial intelligence (AI) contribute to value creation in laser manufacturing technology and optical design? What approaches are there and what is missing to leverage the potential? A conference organized by SPECTARIS and supported by Fraunhofer ILT and the German Association for IT-SMEs in Berlin on October 1 and 2 provided answers.

It was perfect timing: SPECTARIS organized the conference "AI in Photonics – More Value Creation in Laser Manufacturing Technology & Optics Design" right when the division "DWII2 – Artificial Intelligence" was inaugurated at the new Federal Ministry for Digital Transformation and Governmental Modernisation (BMDS). For Evelyn Graß, head of the Artificial Intelligence Division at BMDS, October 1 marked a double departure. "We want to become an AI nation!" she quoted from the coalition agreement. AI will revolutionize many things; by reshuffling the deck, it will alter how companies and countries compete. That is why AI must become a top priority. Graß is optimistic about the starting point: "We have high-quality data from our industrial processes, the value of which must be recognized and exploited." She is pleased that photonics is tackling this task with determination.

First comes the data strategy – then AI

The conference then showed how complex and multidimensional the challenge of making data usable for AI applications is. According to Stephan Kiene, head of the Azure business for public sector clients at Microsoft Germany, the first step must be a data strategy. Data silos are still widespread, and the data they contain is not only inaccessible, but difficult to combine. He advocated for central data platforms where manufacturing and sensor data converge with lifecycle management or manufacturing execution data. In addition, sufficient computing power is needed for simulations, digital twins, and computationally intensive AI processes.

The overarching goal is close-meshed, preferably 360° quality monitoring. Many speakers described the need for this, including Martin Stambke, TRUMPF product manager for sensor technology. Whereas a car door has 70 weld seams, batteries and fuel cell stacks have hundreds. Not one of them can be defective. And while a production error in car doors costs less than 100 euros, a battery is already worth several thousand euros when the welding process begins. Dr. Jan-Phillip Weberpals,

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AUDI expert for laser beam processes, sensor technology, and machine learning, and Konstantin Ribalko, Key Account Manager at Precitec, described a similar situation: "Not one of the many hundreds of weld seams per component may be defective when cells are connected to make battery modules, despite a wide range of material thicknesses and welding depths."

Getting costs and data volumes under control

A deep understanding of processes and systematic quality control are required to minimize waste. The welding processes are monitored with emission-based sensor technology, 3D imaging via triangulation, camera and OCT systems, and even computer tomography (CT) scans both on and off the production lines. Process monitoring generates vast amounts of data and results in high costs. Both are problematic, especially in regulated industries, as Christoph Hauck, Chief Technology and Sales Officer at toolcraft AG, reported. He formulated specific demands for AI: It should determine the ideal parameter configuration for predictive process planning in order to prevent errors. "Real-time error detection in the process, which minimizes the need for expensive CTs, would also be very helpful to the industry," he explained. For additive processes, he would like to see automatic parameter adjustment to new powder batches, geometries, and machine variants, adaptive real-time control, and first-time-right production so that all quality requirements can be met right away, even for a batch size of 1. And in order to implement load-optimized designs in powder bed processes, companies need process strategies that create perfect structures along the load paths and otherwise operate in speed mode to produce AM components faster and more cost-effectively.

The examples show that applications are becoming more complex, components more valuable, and the variety of processes in which AI is used to optimize processes based on data is increasing. At the same time, traceability is in demand in industrial applications. Hauck was not the only one to hint at how unsatisfactory the status quo is: companies generate large amounts of data, but too often this data ends up in silos. When it is used, the insights gained are often minimal. Causalities remain unclear; errors are assessed manually and subjectively. The effort involved in testing and process qualification is getting out of hand. AI comes in handy in this problematic situation.

Data strategy and cloud platforms

However, a common theme throughout all of the presentations was that adapting to the respective processes is a challenging, interdisciplinary task that requires care and strategic clarity. This begins with the IT infrastructure. Having their own data centers and storage hardware is hardly profitable or practical for companies. Cloud-based high-performance computing and cloud-based data platforms make process, sensor, machine, and test data usable where it is needed – in cloud-based simulations or on production-oriented edge computers. The coexistence of centralized and decentralized infrastructure and heterogeneous data formats must be managed strategically so that the added value hidden in raw data can be exploited. AI tools help to harmonize the raw data, thereby making it useful. "The more this generated data can actually be used for AI and machine learning models, the better and more realistic they become. It is a self-reinforcing process in which the data platform becomes the central driver of innovation in the company," said Kiene. But this process has not yet caught on in data silos.

Photonics is a case in point. It faces unique challenges: heterogeneous processes, expandable data availability, and process understanding limited to specialists. Thomas Koschke from BCT Steuerungs- und DV-Systeme and Max Zimmermann from Fraunhofer ILT described them vividly at the conference. In order to train AI for the parameterization and control of robotically supported laser metal deposition (LMD) processes, they had to create the data basis themselves. "For good LMD results, you have to set many parameters, which often interact with each other. If, for example, the feed rate and laser power are not matched, there is a risk of overheating or the powder not melting properly. Both of these factors affect quality," explained Koschke, referring to two of the many parameters. Since testing all variants for optimal parameterization is not practical, AI should support process setup, and then also inline process monitoring.

When it comes to the details, the exact time stamp counts

However, the road to series production readiness has been rocky. The AI needed to learn error detection and process control, and when this data was generated, the devil was in the details. To visualize the data, BCT software assigned images, temperature measurements, laser power, voltage, and other sensor data to the topology of the component. However, problems became apparent as soon as the data was processed into uniform formats, scales, and standards. Time stamps were incorrect, a misaligned nozzle distorted the data, and there were other inconsistencies. "It all comes down to the details when collecting data," Koschke warned. "You can't expect good prediction results with poor data," Zimmermann added.

There was another problem: Some anomalies were not caused by process errors, but by faulty sensor configurations. "Before the data model can be constructed using in-situ and ex-situ data from metallographic analyses and CT scans, all inconsistencies must be clarified," Zimmermann explained. However, once all data has been precisely assigned in terms of time and space, the AI model performs excellently. Because labeling is also time-consuming, the partners had AI and process experts work together on this. The latter then labeled a few images. The AI trained with this data then evaluated entire data sets, which the process experts corrected as necessary. Using a human-in-the-loop approach, the team created the necessary database to further develop the AI for series production.

Timing is everything

Optimizing early is important to increase the complexity of the data models later on. The precise timestamps and exact coordinates of variances occurring in the process form the basis for the AI model to predict how laser power, melt pool, and the physical and mathematical variables interact, and vice versa, to infer laser power from melt pool images. In this way, the model learns to determine the laser power required to keep the melt pool constant. The result: more homogeneous structures in the LMD process. "With data-based predictions, we build more cleanly, get closer to the target geometries, and have more stable processes – without any regulatory intervention," reported Zimmermann. This is important because every regulatory intervention influences the process and impairs stability.

Stambke also reported on AI series applications. TRUMPF relies on user-centered solutions to introduce employees – those in manufacturing who have not previously had anything to do with AI – to its potential and convince them of its added value. Conventional image processing and its algorithms often reach their limits in photonic manufacturing. This is also the case when lasers connect hairpins in electric motors. Their copper surfaces reflect incident light very strongly. Varying part quality further complicates imaging based on conventional gray value algorithms. To align the laser spots, which are only 50 to 500 µm in size, the optics control system still needs precise position information about the hairpins. This is where TRUMPF comes in with neural networks. An "AI filter" separates the component from the background based on semantic segmentation: It reduces the grayscale image to a binarized black-and-white image in which the grayscale algorithm reliably recognizes the hairpins. "We create robustness by separating the component from the background and filtering out interference," said Stambke. The results remain transparent and the measured values verifiable, as they are based on coordinates determined by the established algorithm. Tests on 9,500 hairpin pairs prove the process is robust: The combination of gray value algorithm and AI filter ensured a first-pass yield of 99.8 percent. The missing 0.2

percent was due to pairs that were actually defective. Rejected parts were, therefore, detected before the welding process even began.

Do-it-yourself AI

TRUMPF consciously involves users. After initial projects with pilot customers, the developers realized that it was suboptimal to train the models using only images provided by customers. "Why? Because our customers know their components much better than we do," he explained. That's why they now offer do-it-yourself AI. TRUMPF is building a training system that enables users to train their own models. For example, when commissioning a production line, TRUMPF's users can program the system to automatically save an image after each welding process. The images can be utilized in cloud-based software to train the model. The user interface is simple and code-free. After training with just a few images, the system suggests labels, which can also be corrected by a human-in-the-loop. The AI becomes more accurate with every correction, every image replacement, and every further classification. It is also possible to define limit values in the training model instead of first on-edge at the machine – practical hands-on AI instead of abstract AI metrics.

TRUMPF is now working on making such solutions usable for complex applications and multi-sensor systems, such as welding bipolar plates in fuel cell stacks. Joining the plates made of high-alloy steel is a challenging joining task since their shapes are complex, material stresses are high, and the plates have film-like thickness of only 75 to 100 µm. The task is to apply several meters of absolutely tight seams per plate for several hundred pieces per stack. "If just one connection leaks, the entire stack cannot be used," explained Stambke. The required 100 percent inspection takes two to three minutes. This is not practical in series production, however. That is why Trumpf is promoting AI-supported, multi-sensory process control. To achieve this, many sensor signals must be merged into a coherent quality statement. The combination of a high-frequency short-wave IR camera and a microphone in conjunction with AI has already shown in tests that it detects leaky seams very well. Bipolar plates that the system deemed to be tight were indeed tight. False alarms are at the same level as previously used, significantly more complex measurement methods. AI and photonics could soon trigger a productivity boost in fuel cell production.

Data-driven innovations in photonics

Prof. Carlo Holly, head of the Chair of Optical Systems Technology at RWTH Aachen University and head of the Data Science and Measurement Technology Department at

Fraunhofer ILT, looked further into the future in his presentation. His Computational Optics Group focuses on optical neural networks and automated optical design. "At Fraunhofer ILT, we have firmly established data-driven innovation in our overall research," Holly reported. For example, it is common practice in LMD processes to use digital twins or to work with process simulations to solve inverse problems in material processing with ultra-short pulse lasers. The trend is moving toward using self-learning solutions and neural networks in quality assurance. Holly is exploring the extent to which optical design can be automated using AI methods in order to adapt laser radiation to manufacturing processes quickly, efficiently, and cost-effectively.

The expert outlined the path from pure data-informed machine learning to data & physics-informed machine learning. "Pure language models that extract physical content solely from language – in other words – often fall short in photonics," he stated, "because we often already have explicit knowledge about the physics of the processes." Ignoring this and starting from scratch is a detour. Instead, he advocates direct interaction between the models and the real physical world. This, he says, is the methodical path to autonomous, self-learning laser systems for materials processing. This path has four stages. The first is design and modeling using multiphysical models, ray tracing, and CAD tools, processes that are increasingly being supported or optimized by AI in areas such as optical design and component design. The second stage comprises process monitoring and quality inspection. However, inline observation has so far only detected errors and physical deviations retrospectively. Predictive control is, obviously, desirable. Stage three, therefore, involves forecasts based on an ever deeper understanding of the causes of errors. "Once we have reached that point, the fourth step – active, corrective intervention in the process – is close at hand," he said. Holly concluded that data science provides photonics with very powerful tools that can be applied to a wide range of photonic processes. The future of AI-supported photonic manufacturing has long since begun!

Image 1:
Prof. Carlo Holly, Head of the Chair of Optical Systems Technology at RWTH Aachen University and Head of the Data Science and Measurement Technology Department at Fraunhofer ILT, at the conference "AI in Photonics – Adding Value in Laser Manufacturing Technology & Optical Design."
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Image 2:
Evelyn Graß, head of the "DWII2 – Artificial Intelligence" department at the new Federal Ministry for Digital Transformation and Government Modernisation (BMDS), quotes the coalition agreement: "We want to become an AI nation!"
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Image 3:
Stephan Kiene, Head of Azure Business for Public Sector Customers at Microsoft Germany, emphasizes the need for a clear data strategy and centralized data platforms for the success of AI applications.
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Image 4:
Martin Stambke, TRUMPF Product Manager for Sensor Technology, at the conference "AI in Photonics – Adding Value in Laser Manufacturing Technology & Optical Design."
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Image 5:
Konstantin Ribalko, Key Account Manager at Precitec: "When connecting cells for battery modules, despite a wide range of material thicknesses and welding depths, not even one of the many hundreds of weld seams per component may be defective."
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Image 6:
Dr. Jan-Phillip Weberpals, AUDI expert for laser beam processes, at the conference "AI in Photonics – Adding Value in Laser Manufacturing Technology & Optical Design."
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Image 7:
Christoph Hauck, Chief Technology and Sales Officer at toolcraft AG: "Real-time error detection during the process, which minimizes the need for expensive CT scans, would be a great help to the industry."
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Image 8:
Max Zimmermann, Fraunhofer ILT: "Before starting to build the data model with in-situ and ex-situ data from metallographic analyses and CT scans, all discrepancies must be clarified."
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Image 9:
Thomas Koschke from BCT Steuerungs- und DV-Systeme emphasizes the importance of accurate data: "When it comes to data collection, every detail counts."
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Image 10:
Successful start to the conference “AI in Photonics – Adding Value in Laser Manufacturing Technology & Optical Design on October 1, 2025, in Berlin.
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