FRAUNHOFER INSTITUTE FOR LASERTECHNOLOGY ILT

PRESS RELEASE

AI has the potential to close control loops

Whether in laser material processing, additive manufacturing and repair processes, laser weed control or the automated design of optical systems: Artificial intelligence has enormous, sometimes disruptive potential in photonics. With around 50 international experts in attendance, the 3rd "AI for Laser Technology Conference" took place at the end of November at the Fraunhofer Institute for Laser Technology ILT in Aachen, and clearly showed that the AI-driven transformation is in full swing.

"When we design optical systems, our AI implements in seconds what classic algorithms previously needed hours or days to do or could not do at all," reported conference director Prof. Carlo Holly at the 3rd "AI for Laser Technology Conference", hosted by Fraunhofer ILT on November 23 and 24, 2023.

As Head of the Data Science and Metrology Department at Fraunhofer ILT and chair of the Technology of Optical Systems TOS at RWTH Aachen University, Holly deals with data-driven innovations on a daily basis. However, he believes that the current innovation process based on artificial intelligence (AI) is also breaking new ground. "The potential of AI goes beyond just monitoring and controlling laser processes: We can use it to pave the way for first-time-right production," he said. If the instruments of modern measurement and sensor technology are cleverly combined with AI methods, machines can be trained to produce without errors right from the start or to react autonomously to changes in the process. "AI has the potential to close control loops. Learning machines that readjust themselves in the process based on continuous data evaluation are moving into the realm of the feasible," says Holly.

More and more AI players and applications

Microsoft specialists Ansgar Heinen and Marcel Franke also addressed the dynamic nature of the AI market: "Never before have we seen a new technology being adapted so quickly – even in more conservative industries," they reported. And never before has a digital solution spread as rapidly as ChatGPT. Just five days after its launch, the AI, which is based on a large language model (LLM), had one million users worldwide; barely two months later, it had over 100 million. For its development, state-of-the-art mainframe computers scanned many petabytes of text data from books, articles or software code for generalizable grammatical and semantic patterns and rules. Generative AI has integrated these into its language system and can now generate

Press contact
Petra Nolis M.A. | Head of the Communications Group | Telephone +49 241 8906-662 | petra.nolis@ilt.fraunhofer.de
Fraunhofer Institute for Laser Technology ILT | Steinbachstraße 15 | 52074 Aachen, Germany | www.ilt.fraunhofer.de

code or communicate like a human. For such tasks, LLMs must be highly variable and make decisions between a large number of parameters. "The number of these parameters is an order of magnitude higher than the number of stars in our galaxy," explained Marcel Franke, at the Aachen conference. Nevertheless, AI is very easy to use. For the first time, humans no longer have to learn the language of the machine. "Because our language serves as an interface, AI becomes a communicative co-pilot," he said. At the same time, LLMs can be used in a variety of ways and trained for specific applications in industry, administration, the legal sector and research and development. And, according to Heinen, AI is finding its way into more and more corporations and medium-sized companies in the automotive, mechanical engineering, electrical, chemical and pharmaceutical industries.

His observation is in line with forecasts by the US market research company Gartner. Its analysts see AI as a paradigm shift that will be accompanied by completely new forms of collaboration between humans and machines. The impact on modern life will be similar to that of the introduction of the internet and the smartphone. According to Gartner, 80 percent of all people will interact with smart robots on a daily basis by 2030. As early as 2025, AI will contribute to the development of one in three new medicines and materials. And for the current year 2024, Gartner is forecasting that three quarters of all companies will increase their investments in AI.

Wide range of photonic applications

In twelve presentations and a guided tour of the Fraunhofer ILT laboratories, the conference illustrated how AI is also advancing photonics. Dr. Volker Rominger, Head of Machine Learning & Simulation in Laser Applications at TRUMPF, presented a wide range of AI applications relating to laser cutting, bending and welding. These included "optimate", its automated component optimization program that analyses conventional designs, suggests alternatives made from laser-bent and laser-cut sheet metal and delivers the resulting cost savings at the same time. As a rule, this system eliminates work steps, reduces the amount of material used and, thus, the weight as well. The “optimate”-team has trained the AI on thousands of labeled component data. "It predicts the optimization potential with 96 percent accuracy," he reports.

TRUMPF also provides an AI solution to counteract disturbances, such as when laser-cut sheet metal parts catch, jam or twist – interference that can cause fully automated process chains to come to a standstill. TRUMPF’s AI determines the optimum cutting strategy for each component, taking into account numerous parameters from the starting point and optimum position of the sheet metal to the distribution of gas pressure in the laser cutting process. In this case, the machine knowledge is trained on hundreds of thousands of practical examples. And it also helps in the next process step: AI optimizes the fully automated recognition and sorting of the cut parts. Indeed, conventional machine vision algorithms reach their limits in this task given the amount of data, the sheets of up to eight square meters in size made of different materials, the varying lighting conditions, component geometries and randomized human intervention in the process. "That's why we use many millions of parameters from a deep neural network and let the data work for us," explained Rominger. The large amount of input data makes the solution increasingly robust. The number of detection errors decreases with each new generation of neural networks and with each data set since the system learns and improves.

Experience available at any time for quality assurance

Rominger reported on other AI applications. These included the laser welding of so-called hairpins on copper windings of electric motors. "The camera-monitored process is very robust in itself. However, there are often changes in our customers' production environment, be it lighting conditions or inaccurately paired hairpins," he explained. This is remedied by an AI filter that minimizes interference in the camera data and classifies the condition of the hairpin pairs in real time. "By using AI we were able to significantly increase the reliability of quality control to 99.8 percent," says Rominger. AI helps TRUMPF interpret the complex spatial information quickly and precisely and, in conjunction with real measurement technology, paves the way for learning systems that build up empirical knowledge, learn quickly, do not forget, and are not affected by fatigue or how they feel on a particular day.

Rominger concludes: "Machine learning is no longer a vision, but a reality. We can use it to significantly increase the productivity, reliability and quality of laser processes and, what’s more, this is only the tip of the iceberg". He advised companies that are not yet involved in this field to put aside their scepticism and explore the possibilities in practical pilot projects. After all, the technology is developing rapidly and is already giving competitors who use AI a productivity advantage.

Making the invisible visible

He did not have to convince the conference participants. It was clear from the presentations and questions from the audience that they had long been dealing with how to use AI. Dr. Markus Kogel-Hollacher from the Precitec Group, for example, reported that AI is proving its worth for more and more applications. "Whether laser cutting, laser welding or 3D measurement technology: Wherever we generate process data, there are ideas for obtaining valuable information from it using AI," he said. This now extends so far that invisible information on the tensile strength or electrical contact resistance of welded joints can be derived from data from optical sensors. The company lays the foundation for this by training neural networks with elaborately labeled image data and findings from destructive weld seam analyses.

According to Dr. Michael Ungers, Scansonic MI GmbH takes a similar approach to AI applications in inline-monitored laser soldering and welding processes. Reliably detecting the smallest irregularities in the weld pool, such as pores and spatter, is based on extensive training of neural networks, as well as on validation and verification in extensive test series. The company intends to ensure that the AI can also detect irregularities in unknown image data during customer use. Supplied by optical sensors integrated into the processing heads, the data are analyzed close to the line by an edge computer and visualized for human users. Here, too, AI takes on the role of co-pilot. And it also starts with the laborious, manual labeling of thousands of data records. But the effort is worth it. This is because the combination of online sensor technology and AI results in more robust, more precise error detection, and, according to Ungers, should significantly reduce inspection costs in production in the medium term.

Potential everywhere – including in the field

The combination of photonics and AI unlocks its potential not only in industrial laser material processing. Dr. Peter Fuhrberg, managing director of Futonics Laser GmbH, presented an AI application in Aachen that aims to significantly reduce the use of pesticides in agriculture. At its heart is an AI-supported camera system that can distinguish between young crops and weeds within milliseconds. This enables it to detect unwanted plants as it passes over the field, determine their exact position and direct a near-infrared (NIR) laser at the growth centers of the individual plants using a scanner while compensating for all vibrations. One laser pulse is enough to kill the weeds. Before it sprouts again, the neighbouring crop plants have won the growth race to the sunlight.

Futonics is systematically advancing this pesticide-free weed control. As, according to Fuhrberg, this will probably be carried out by battery-powered, autonomously navigating vehicles, energy and space efficiency and reliability are high on the agenda. Here, too, AI in conjunction with modern simulation tools can help. These show that fast-switching 2-µm thulium lasers achieve the highest area efficiency per unit of energy used. With an 800-watt system, a laser pulse lasting 2 milliseconds is therefore sufficient because the NIR light is well absorbed by the plants. According to Fuhrberg, the beam quality, system reliability and service life also speak in favour of NIR technology. The example shows how AI can inspire photonics and, at the same time, help to ground innovative ideas from the outset. At the Aachen conference, Fuhrberg showed that even the selection of lasers is highly complex in view of the large number of design variants with wavelengths ranging from ultraviolet (UV) to mid-infrared (MIR), different pulse durations and beam guidance approaches. AI helps reliably preselect the most efficient and robust system designs and thus provides a solid basis for development.

On the home straight to the closed loop

However, as TRUMPF expert Dr. Volker Rominger said in Aachen, we can only see the tip of the iceberg at the moment. At Fraunhofer ILT, Prof. Carlo Holly is already diving deeper to get an idea of the future possibilities of AI with his team. Photonics is getting better and better at using sensors to make processes and measured variables visible. At the same time, it is a driver of progress in hardware development, which now enables data analysis in real time. "The findings of the data analysis in turn expand our options for predicting process sequences and optimizing parameterization," he explained. This provides a basis for realizing autonomous and adaptive production and closing control loops in the future through real-time monitoring and adjustment of parameters during the running process.

Fraunhofer ILT is conducting tests to explore these possibilities for additive processes, laser material processing from welding and soldering to polishing, as well as for the fully automated design of optical systems. The latter, in particular, is a highly complex, time-consuming process that requires a great deal of expertise. "We are asking ourselves how far we can get with automated AI-supported design," said Holly, who presented research in which he and his team are training a neural network for the design of optical systems. The long-term goal is to use modern modelling and AI-supported design – based on an optimal temperature distribution on the workpiece – to determine the design of the beam guidance all the way back to the beam source.

A clever trick for the diffractive deep neural network

To achieve this, Holly's research group uses the physical realization of a virtual neural network, so-called diffractive deep neural networks. At the heart of these optical neural networks are cascaded phase masks, i.e. diffractive optical elements (DOEs), which diffract the radiation differently and thus shape it. "If we position several DOE layers one behind the other, the diffractive deep neural network is created. The light serves as a transmitter of information," he explained. The light beams pass through all the DOE layers one after the other and are modulated according to the phase shift set by the pixels. "We interpret this structure as a neural network and use algorithms from the field of artificial intelligence for the optical design," he explained. This enables the team to adapt complex beam shaping specifically and robustly to the respective application. With conventional design approaches, this plan would be doomed to failure owing to the large number of degrees of freedom – several thousand in typical systems. With the help of AI, they can be easily optimized.

Metrological basis still indispensable, but closed loops are getting closer

According to Holly, measured values from real experiments will remain indispensable in the future in order to hone strategies for AI-supported process control. However, AI can help identify measurement points and parameters that are actually relevant, and contribute to significantly reducing measurements and experiments by computationally extrapolating the less relevant ones. What should enable efficient process control based on real-time analysis and prediction in the future is already helping researchers at Fraunhofer ILT to conduct more selective experiments. "AI analyzes the measured values from one experiment and provides us with the path for the next and all others. This strategic support significantly reduces the total number of experiments and therefore also the costs and time required," he reported.

In the next step, the collected values – then classified in a metamodel – can be used to optimize the process parameters. "We derive parameters for the data input in the production process from the data output of the measurements in the experiment," says Holly. Gradually, this AI landscape will be able to manage without human control. The more it learns, the closer it gets to "first-time-right production" and autonomous reaction to process deviations. The ongoing process can then be aligned with the pre-calibrated ideal process and guided along the experimentally validated production strategy.

Photonics has created the conditions for this over decades: Digital systems in which every sensor and every camera can be identified via their own IP addresses, as well as inline measurement technology, simulation solutions and metamodels for inverting experimentally determined output data into process-controlling input data. "With these components, the automatically calibrated, closed control loop can be implemented: This is effectively the blueprint for an autonomous machine," summarized Holly. With this outlook, the 3rd "AI for Laser Technology Conference" in Aachen outlined a roadmap to autonomous production in smart factories: via the convergence of photonics and AI.

Artificial Intelligence @ AKL'24

The Impact of digitalisation and AI on value creation and business models in laser technology will be addressed by the GERD HERZIGER SESSION as part of the AKL'24. Chairman Prof. Constantin Häfner will host an expert panel with Dr.-Ing. E. h. Peter Leibinger, Chairmen of the Supervisory Board, TRUMPF Group, Ditzingen (D), Dr. Christopher Dorman, Executive Vice President, Lasers Business, Coherent, Glasgow (UK) und Dr. Christoph Rüttimann, CTO Bystronic Group, Niederönz (CH), on April 18th, 2024. In-depth presentations on digitalization in photonic production will follow later in the morning. Find the full AKL`24-Program here.

Image 1:
"If you close the control loop, you can build a machine that regulates itself. That is the roadmap we are following." Professor Carlo Holly, Head of the Data Science and Measurement Technology Department at Fraunhofer ILT.
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Image 2:
A practical example: Sven Linden from Fraunhofer ILT shows how in-situ white light interferometry based on semantic segmentation helps users analyze and classify the quality of laser-polished components pixel by pixel.
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Image 3:
"If we add AI to our inline sensor technology for welding processes, then it's no longer just a question of good or bad. Instead, we can use it to obtain information about invisible physical properties such as the strength or contact resistance of a weld seam." Dr. Markus Kogel-Hollacher, responsible for research and development projects at the Precitec Group.
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Image 4:
"Machine learning is no longer a vision, but a reality. We can use it to significantly increase the productivity, reliability and quality of laser processes and, what's more, this is only the tip of the iceberg," explained Dr. Volker Rominger, Head of Machine Learning & Simulation in Laser Applications at TRUMPF.
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Professional contact

Prof. Carlo Holly
Head of the Data Science and Measurement Technology Department
Telephone +49 241 8906-142
carlo.holly@tos.rwth-aachen.de

Peter Abels
Group Leader Process Control and System Technology
Telephone +49 241 8906-428
peter.abels@ilt.fraunhofer.de

Fraunhofer Institute for Laser Technology ILT
Steinbachstraße 15
52074 Aachen, Germany
www.ilt.fraunhofer.de