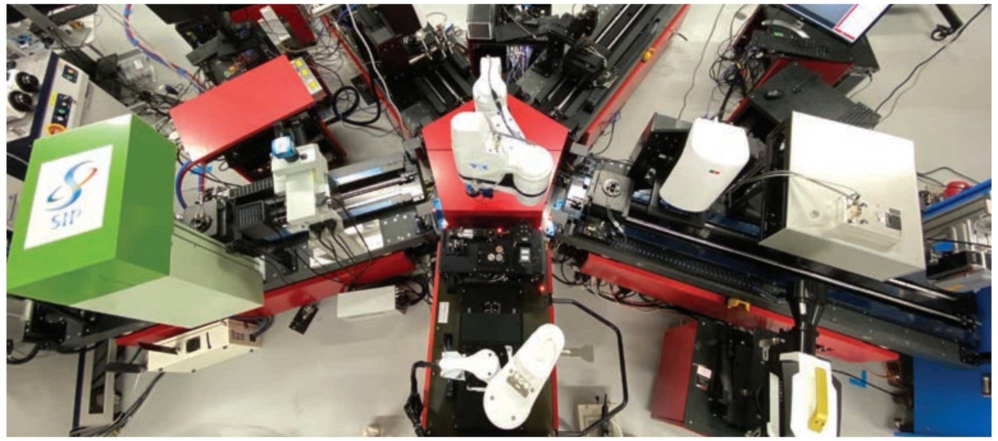
AI AND LASERS LIGHT THE WAY TO A MANUFACTURING REVOLUTION

The union of basic science, laser technology and machine learning at the University of Tokyo are SHINING A PATH TO PERSONALIZED MANUFACTURING.



▲ The Meister Data Generator and smart laser system developed at the University of Tokyo.

With an ageing population and a declining labour force, Japan has an urgent need to improve the efficiency of industry, making gains for sustainability along the way. Personalized manufacturing could provide a solution through the combination of artificial intelligence and cutting-edge laser technology being developed by Yohei Kobayashi and Hiroharu Tamaru, at the University of Tokyo.

By using artificial intelligence (AI) to better understand the complex physics underlying the way lasers cut, weld or drill materials, these researchers hope to make possible internet-based control of laser production systems, so that we can manufacture the things we want, on-demand, from home.

The nineteenth-century industrial revolution, powered by water and steam, saw a giant leap forward in manufacturing and mass production. A second technological jump came through harnessing electricity, while computers and digital innovation enabled a third. The fourth industrial revolution is now underway with the combination of digital and physical technologies to allow production and control on demand: an industrial internet of things.

LASER VERSATILITY

A crucial component is likely to be so-called cyber-physical systems, where computation, networking, and a physical production process are integrated, with a built-in feedback mechanism allowing for fully automated control. Additive manufacturing, perhaps better known as 3D printing, is a prime example, which often uses lasers for the physical processing part. But lasers can do so much more.

Since their development in the 1960s, lasers have offered exciting manufacturing possibilities. The applications are diverse and their properties are near perfect. They can focus a lot of optical energy on a small spot, generating a great deal of heat at a precise point on a target. So, unlike many conventional mechanical and chemical industrial process, laser processing is super-efficient and doesn't require any additional chemicals.

Lasers can be pulsed at extraordinary rates, and the duration of each pulse can be as short as a few tens of femtoseconds (10^{-15} seconds). This is faster than rate that energy can dissipate, allowing for microscopic processing of materials at scales of less than a millimetre, without causing heat damage. And with the correct choice of laser wavelength, the light can destroy one type of material, while leaving others intact.

Furthermore, laser power can be used in a blunt way, such as welding parts together, cutting sheets of metal or drilling holes. Or lasers can be applied more subtly, such as to polish or texture a surface.

HIGH-QUALITY DATA

Because lasers are electrically driven, they are easier to integrate into computer-control systems, making them ideal for cyber-physical systems. But the array of laser properties that make this wide range of applications possible, also causes a major technical question: how to find the best parameters for a specific job?

Traditionally, the solution would be user intuition based on trial and error, but optimizing a laser system in this way can take months, which is simply not viable at the scale required to realize truly useful cyber-physical systems. To complicate matters further, even when the best configuration is identified for a specific system to perform a specific task, what works well for one type of material might not work for another.

Researchers at the University of Tokyo are tackling this problem using AI and machine learning. However, "due to the complexity of the laser and light-matter interactions, it wasn't clear whether even artificial intelligence was powerful enough to offer a solution," says Hiroharu Tamaru, a professor at the Institute for Photon Science and Technology. "But now we have seen that it can, and it relies on having good data."

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▲ Lasers are allowing for smart manufacturing and enabling a new industrial revolution.

High-quality data is crucial because AI machine-learning systems need to be trained. A few thousand to a few tens of thousands of data points are often required for the algorithm to start making useful predictions. "We have constructed an all-automated and autonomous data acquisition system, called the Meister Data Generator," says Yohei Kobayashi, a professor at the University of Tokyo's Institute for Solid State Physics. "We don't even need to go to the lab to take data: it keeps working 24 hours a day, 7 days a week."

The researchers have applied their idea to many laser production processes including, very recently, laser ablation: using a short pulse of light to remove a small amount of material from a surface. In this case, they created a high-quality dataset by firing light pulses of controllable duration at a solid target. A three-dimensional microscope then provided images for the corresponding surface changes at a rate of about one per minute, or a 1,000 data points in a day.

This big-data driven approach is proving very fruitful, and the University of Tokyo collaborators at Kyushu University in Fukuoka are already exploiting the method to serve the semiconductor manufacturing industry.

TREMENDOUS POTENTIAL

Once the data is gathered, a deep-learning algorithm could simulate the 3D topology created after irradiation by multiple laser pulses at arbitrary positions and with arbitrary pulse energies. And the team have applied this system to a variety of materials, including dielectrics, semiconductors, and organic polymers.

Currently, the Meister Data Generator system can search autonomously thorough the various laser parameters with advanced algorithms, such as Bayesian optimization, which determines the next parameters to test while the experiments are running. Such a high-quality data will have the potential to further change the laser manufacturing processes.

And while the practical, real-world potential of this technology is tremendous, Kobayashi and Tamaru are also excited by the implications for basic research. The interaction between light and matter at such high intensities is complex. The physics of laser ablation, for example, needs further clarification before it is completely understood. The strength of vv at the focus of the laser can be akin to that holding an atom together, so simple models based on melting and vaporization are of little use. Sophisticated molecular dynamic simulations offer hope, but the processing power required is immense because the physical processes that take place during laser ablation are so varied — the laser pulses are as fast as a few femtoseconds, while melting might take place over microseconds.

The massive, high-quality data sets gathered by the Meister Data Generator will be useful in understanding high-intensity interactions of light and matter. And with a better understanding of the fundamental science underlying laser processing comes more control over the technology and a greater potential for it to be even more transformative. ■

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