Deep Learning for Control of Light-Matter Interactions

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The interaction of light and matter is extremely complex, particularly for short laser pulses where nonlinear effects can become the dominant mechanisms. Consequently, even a small, unexpected change in the underlying experimental conditions can result in a severe negative effect on the outcome of the experiment. In practice, the sheer variety and number of experimental parameters that must be monitored means that a human-operator is simply not an effective approach. There is therefore great interest in the development of systems that can provide automated control of laser-based experiments.

In recent years, exciting developments in software and hardware have enabled a revolution in the field of artificial intelligence known as deep learning. Relevant to this presentation, there have been key breakthroughs in the application of deep learning for rapid and precise processing of multiple data streams. An obvious example here is the recent developments in autonomous driving, where multiple neural networks monitor visual data from multiple directions, in real time, and decisions are made on millisecond timescales.

The team at Southampton are applying the technology that supports "self-driving" cars to the control and optimisation of a wide range of light-matter interactions. The analogy here is that the team are solving the scientific and engineering challenges that will enable the "self-driving" lasers of the future that can control and optimise experiments and make critical decisions in real-time, without the need for input by a human operator.

This presentation will provide an overview of recent activity at Southampton in the application of deep learning for a range of light-matter experimental setups, namely:

The real-time application of neural networks in femtosecond laser machining for i) the identification of the laser machining parameters and materials parameters, ii) correcting unexpected beam aberrations, and iii) automatically ceasing laser machining at task completion in the case where the task length is not known prior to machining (see figure for details) [1]. The real-time control of the optical tweezers effect, where reinforcement learning is used to control a laser to translate single particles through a maze [2]. Real-time control via reinforcement learning of the spatial position of laser pulses, via automated control of translation stages, to machine specific and bespoke patterns in a target substrate [3]. The potential for using deep learning for real-time beam shaping in a coherent beam combination arrangement [4].

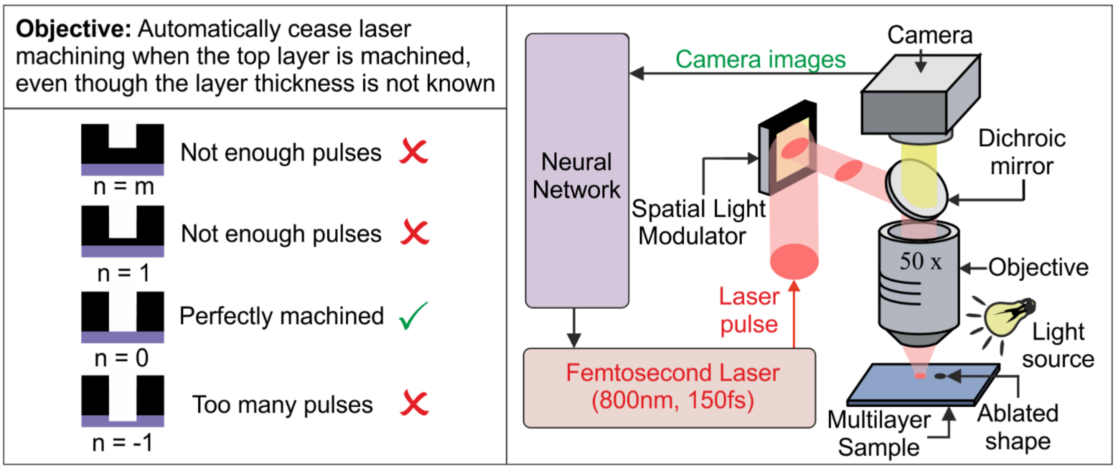

Fig. 1 Example application of deep learning for solving a practical laser machining challenge..

References

[1] Xie, Yunhui, et al. "Deep learning for the monitoring and process control of femtosecond laser machining." Journal of Physics: Photonics 1.3 (2019): 035002.
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[3] Xie, Y., Praeger, M., Grant-Jacob, J. A., Eason, R. W., & Mills, B. (2022). Motion control for laser machining via reinforcement learning. Optics Express, 30(12), 20963-20979.
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