**Self-Directed Femtosecond Laser Machining of Microscale Patterns using Deep Learning**

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Femtosecond lasers enable highly precise machining, due to the extremely short time scales. However, the process is highly nonlinear, and hence can be time consuming to optimise due to the high sensitivity to underlying parameters such as laser pulse energy and spot size. There is therefore great interest in the development of automation techniques for real-time control to further improve femtosecond laser machining [1].

In general, to laser machine a complex structure, the laser focus is scanned across the sample. This can be achieved through a variety of methods, such as motorised stages or galvanometer mirrors. However, in all cases, calculation of the optimal set of coordinates for laser energy delivery is critical, as even a single incorrect coordinate may result in a defective product. This calculation becomes even more important for microscale femtosecond machining, as the desired structure may be only slightly larger than the laser focus itself and hence the laser spatial intensity profile must also be considered.

Reinforcement learning is a technique that allows a neural network to discover a solution to a task through self exploration. The neural network is given a reward when it completes a task, and it can be provided with additional rewards for discovering faster or more accurate solutions. Recent important demonstrations include learning to play the boardgame called Go (where the network discovered an entirely new strategy) [2] and learning how to fold proteins (and predicting their resultant 3D structure) [3].

In this work, we show that reinforcement learning can be applied to identify the optimal coordinates, in real time, for femtosecond machining of a desired microscale structure. The neural network controls the laser and the movement stages in real-time and can automatically laser machine any desired microstructure, whilst simultaneously compensating for fabrication errors.

[1] Mills, Benjamin, and James A. Grant-Jacob. "Lasers that learn: The interface of laser machining and machine learning." IET Optoelectronics 15.5 (2021): 207-224.

[2] Silver, David, et al. "Mastering the game of go without human knowledge." nature 550.7676 (2017): 354-359.

[3] Jumper, John, et al. "Highly accurate protein structure prediction with AlphaFold." Nature 596.7873 (2021): 583-589.