Coherent beam combination with phase and amplitude control using deep learning

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Coherent Beam Combination (CBC) addresses the power scaling limits of high-power fibre lasers (HPFLs) by combining outputs from multiple lasers. The combined beam quality and efficiency, however, is degraded by random phase noise introduced during the amplification of each individual output and other environmental contributions. Consequently, precise phase correction is crucial for CBC performance. Additionally, amplitude fluctuations in HPFLs further complicate phase information extraction by varying primarily the visibility of interference fringes. With CBC systems already involving hundreds of fibres [1] phase alignment becomes increasingly complex and costly. Recent deep learning methods [2, 3], have demonstrated single step phase correction using camera observations of the combined beam, potentially providing economically viable solutions.

In this work, we simulate the combined laser output from a 7-channel CBC system, using a spatial light modulator and a HeNe laser to control the phase and amplitude of each simulated fibre. A Convolutional Neural Network (CNN) is employed to infer both the phase and amplitude information from a single camera observation of the combined output at the far-field. Our results demonstrate that including amplitude information during CNN training stage significantly improves the accuracy of phase prediction, even for amplitude fluctuations as high as 50%. Moreover, we explore the scalability of the CNN approach. The initial findings indicate that the number of training pairs scales linearly with the number of CBC channels (rather than exponentially). This finding provides new insights that deep learning could be used for real time phase locking control of 100s or even 1000s of fibres.

[1] H. Chang, et al., "First experimental demonstration of coherent beam combining of more than 100 beams," Photon. Res. **8**, 1943-1948 (2020).
[2] B. Mills, et al., "Single step phase optimisation for coherent beam combination using deep learning," Scientific Reports **12**, 5188 (2022).
[3] Y. Xie, et al., "Single-step phase identification and phase locking for coherent beam combination using deep learning," Scientific Reports **14**, 7501 (2024).