Phase Identification and Bespoke Beam Shaping for Coherent Beam Combination via Deep Learning

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Abstract: Practical application of coherent beam combination of multiple fibres necessitates phase identification and optimisation in real-time. Here, we solve this mathematical challenge via deep learning, and hence demonstrate the potential for real-time bespoke beam shaping.

Coherent beam combination (CBC) of multiple fibres offers the potential to overcome the power handling capability of single fibre configurations [1]. In the practical application of CBC, the focal intensity profile is critically dependent upon the relative phase of each fibre, and so precise control over the phase of each fibre channel is required. However, identification of the phase compensations from the intensity profile at the focus (as measured by a camera), is extremely challenging as the phase information is not directly available. Whilst iterative methods exist for phase retrieval, a real-time corrective process is a requirement for effective practical application. This work builds upon recent applications of deep learning for CBC, including using iterative gradient descent [2], interference analysis [3], and reinforcement learning [4]. Here, we show how a neural network can be used to identify the phases of each fibre in a simulated 3-ring hexagonal close-packed arrangement directly from the focal intensity profile, in a single step taking ~10 milliseconds. The neural network is then shown to be capable of enabling bespoke beam shaping, even in the presence of simulated experimental noise. In addition, we show that two neural networks in combination can be used to determine whether a desired intensity profile is physically possible for a given CBC fibre configuration. The concept of the approach is shown in Fig. 1, which shows how a beam propagation simulation is used to produce pairs of randomly chosen phase profiles and associated focal intensity profiles. When the neural network is trained on these pairs of images, it is then capable of identifying the phase profile from any focal intensity profile.

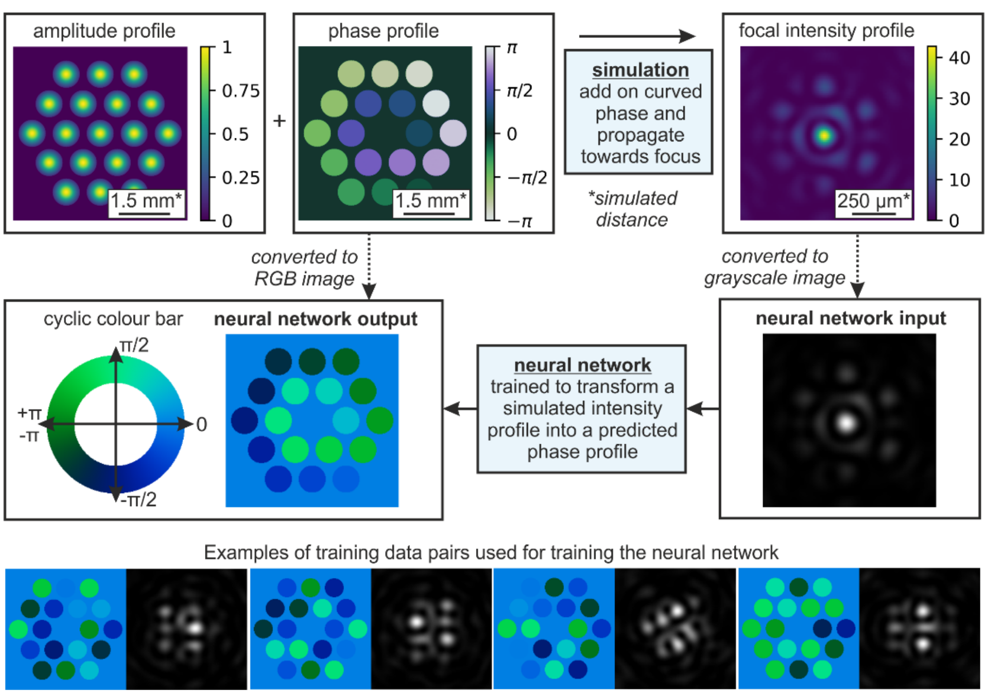

Fig. 1 Concept of using a neural network to identify the phase profile from a simulated focal intensity profile

Figure 2 shows that the neural network is capable of the identification of the phase profile from any given focal intensity profile, as highlighted by the similarity between the 'current phase' (i.e. the experimental and hence unknown phase profile) and the 'predicted phase' (i.e. the phase predicted by the neural network directly from the simulated focal intensity profile). When this predicted phase is subtracted from the current phase, the result is the creation of a flat phase profile (labelled 'corrected phase'). Whilst in some applications the flat phase may offer the desired intensity profile, this flat phase profile could indeed be augmented with a bespoke phase profile, as shown by the creation of a 6-fold ring intensity profile. In practice, the phase subtraction and phase addition could be managed in a single step via direct control of the phase actuator of each fibre. Whilst here the transformation of a random phase profile into the phase profile corresponding to a 6-fold ring intensity profile in presented, in practice, the bespoke intensity profile could be any physically possible spatial intensity profile.

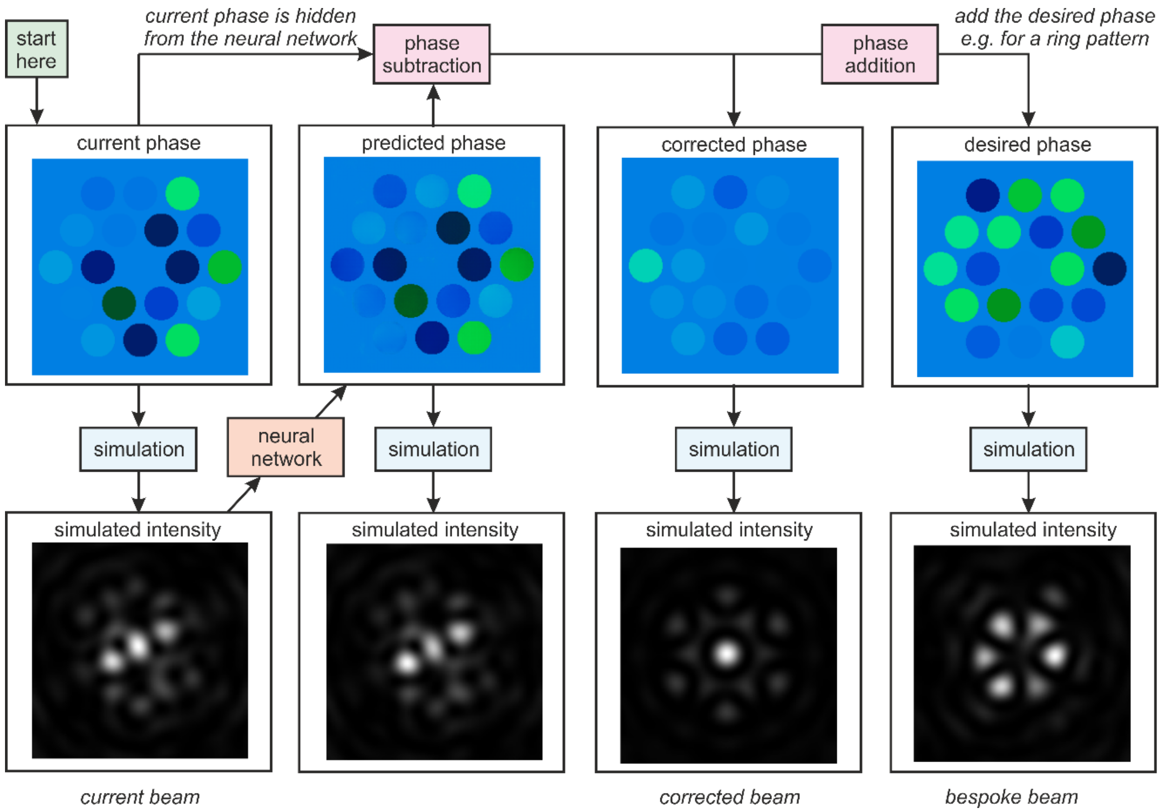

Fig. 2 Application of a neural network for bespoke beam shaping for any phase that is unknown to the network. This whole process only requires knowledge of the focal intensity profile and hence is possible without knowledge of the current phase.

In conclusion, deep learning was shown to be capable of enabling the single-step phase identification of nineteen fibres arranged in a hexagonal close-packed array, directly from the simulated focal intensity. The approach used a neural network to transform an image of the simulated focal intensity profile into the associated image of the simulated phase profile at the exit of the fibre array. Through subtracting the predicted phase from the current phase, the resultant phase was flattened, which could then be used as a basis for augmenting with a custom phase profile, hence enabling the potential for single-step bespoke beam shaping in a CBC system.

References

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