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doi:10.1017/S1431927622011278

Microsc. Microanal. 28 (Suppl 1), 2022

Artificial Neural Network for Automatic Alignment of Electron Optical Devices

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Modern electron microscopes are very complex machines and in spite of many automatic procedures their optimal operation mainly depends on the skill of the user for both alignment and routine operation.

The complexity of the microscope has been steadily increasing with aberration correctors, monochromators, and energy filter and, in addition, a new generation of electron optics based on MEMS and miniaturised phase plates is emerging. Through electron optical components, based on microelectromechanical systems technology, it is now possible to generate vortex beams [1], angular momentum analysers [2] and many more ideas are still emerging [3]. However, as the instrumental research stretches beyond the standard use of the microscope, more challenges are found for real operations and this complexity could become the bottleneck of new instrumental development.

A natural solution to this problem is using Artificial Intelligence (AI). AIs have clearly demonstrated their ability to control a variety of complex systems ranging from large industrial machines, through vehicles, to small appliances in our homes.

Here, we make use of artificial neural networks (ANN) [4], a class of AIs able to autonomously learn from a large set of training examples, how to govern electron optical devices within a transmission electron microscope.

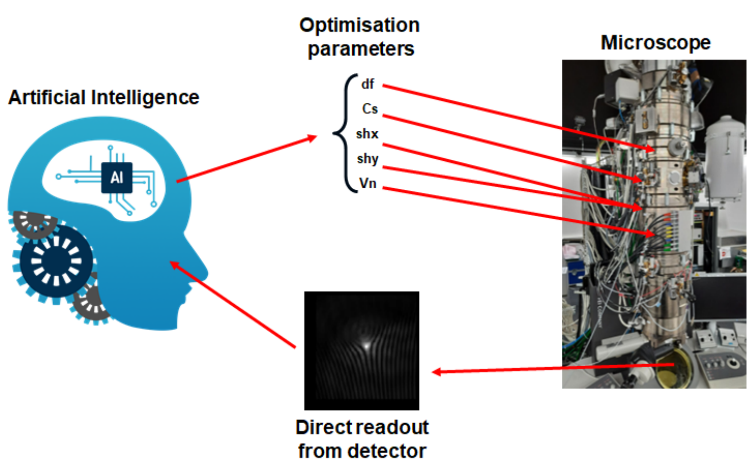

Figure 1: scheme for the application of AI to the real time optimisation of the electron microscopy experiments

The general approach is described in figure 1). The ANN is directly connected to the microscope and it is able to autonomously collect data from the available detector and provide real time feedback to the microscope in order to improve the performances of the running experiment.

In this contribution we will report on the first successful examples of AI driven experiment.

We will start from the specific case of an orbital angular momentum (OAM) sorter [5], a novel type of miniaturised electron optics that introduces a conformal mapping of the electron beam in order to measure its OAM state spectrum. An ANN, connected to the microscope, is able to reliably improve the alignment of the complex electron optical configuration of the OAM sorter from the observation of a single misaligned OAM spectrum, reaching the same resolution of a skilled user in few seconds (see figure 2, top row).

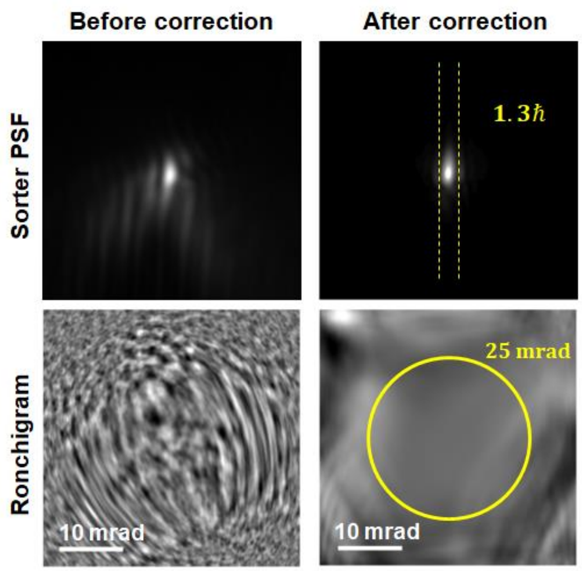

Figure 2: key application of ANN. Top row: alignment of the OAM sorter. Bottom row: fine tuning of a Cs corrector.

Similarly, we also demonstrate how the information contained in a single ronchigram, the image of a stationary STEM probe on an amorphous region, is sufficient for an ANN to provide a near real-time estimation of the aberrations in line but faster than state-of-the-art aberration diagnostic software (see figure 2, bottom row). The AI flexibility could be used to beat traditional methods and align the microscopes in more complex experimental situations for example during sample observation or while controlling MEMS-based phase plates.

Finally, we will discuss how the AI will make it possible one of the first Bayesian kind of approach in the image acquisition where the partial measurement results are used in near real-time to optimise the rest of the experiment in terms of dose and signal-noise ratio.

As an example, we will report on the first attempt of electron single pixel imaging and the role that AI can play in predicting optimal new patterns during the experiments.

These are the first, necessary steps eventually leading toward the realisation of a fully functional, automated, electron microscope [6].

References:

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[6] We acknowledge that this work has been conducted collaboration with Forschungszentrum Jülich, Thermofisher Scientific, and CNR-NANO personnel.