Automatic Operation of Conventional and Innovative Hardware for Electron Microscopy

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Meeting-report

Automatic Operation of Conventional and Innovative Hardware for Electron Microscopy

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New developments in TEM instrumentation and methodology have improved quantitative and high-throughput analysis together with sub-Angstrom spatial resolution, meV energy resolution and femtosecond temporal resolution. However, these new capabilities strongly depend on the skill of the user for both alignment and routine operation.

In addition, a new generation of hardware components based on MEMS technology and miniaturised phase plates is emerging, and will allow for a plethora of new experiments. For instance, through innovative electron optical components, it is now possible to generate vortex beams [1] angular momentum [2] and other state analysers [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.

Artificial Intelligence (AI) has clearly demonstrated its ability to automate a variety of complex systems ranging from large industrial machines, through vehicles, to small appliances in our homes. Automated control of instruments based on AI, promises to change the way in which electron microscopy is performed, facilitating the preparation of experiments and appears as a natural solution to this problem.

We have previously demonstrated that artificial neural networks (ANN) [4], a class of AIs able to autonomously learn from a large set of training examples, are able to govern electron optical devices within a transmission electron microscope.

In these regards, remarkable examples are the automatic alignment of orbital angular momentum (OAM) sorter [5], and the ability of an ANN to provide a real-time estimation of the lenses' aberrations, reported in figure 1.

The OAM Sorter is a novel type of miniaturised electron optics that performs a conformal mapping on the electron beam in order to measure its OAM state spectrum. An ANN, connected to both the electron microscope and Sorter control unit, is able to automatically and 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 1, top row).

Similarly, the information contained in a single ronchigram, is sufficient for an ANN to provide a real-time estimation of the microscope's objective lens aberrations which can be redirected to aberration corrector. Such correction is in line with state-of-the-art aberration diagnostic software (see figure 1, bottom row), but much faster requiring just a single image.

Building on these results, we will explore if AI can be exploit to beat traditional methods and autonomously govern the microscopes in more complex experimental situations, such as:

- Beam shaping experiments with MEMS-based adaptive optics.
- Bayesian approach to the image acquisition where partial measurements are used to optimise the final result in terms of dose and signal-noise ratio.
- Reliable and automated control of complex experimental workflows (autonomous discovery)
- High speed and reliable data analysis of the information flux from *in-situ* experiments.

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

The general approach is described in figure 2). A series of AI models are directly connected to different devices on the microscope and to different part of the microscope itself. These are able to autonomously collect data from the available detectors and provide real time feedback to the microscope in order to improve the performances of experiments that require very precise alignment or long-time stability, at the same time increasing the reproducibility, accessibility and throughput of the microscope [6].

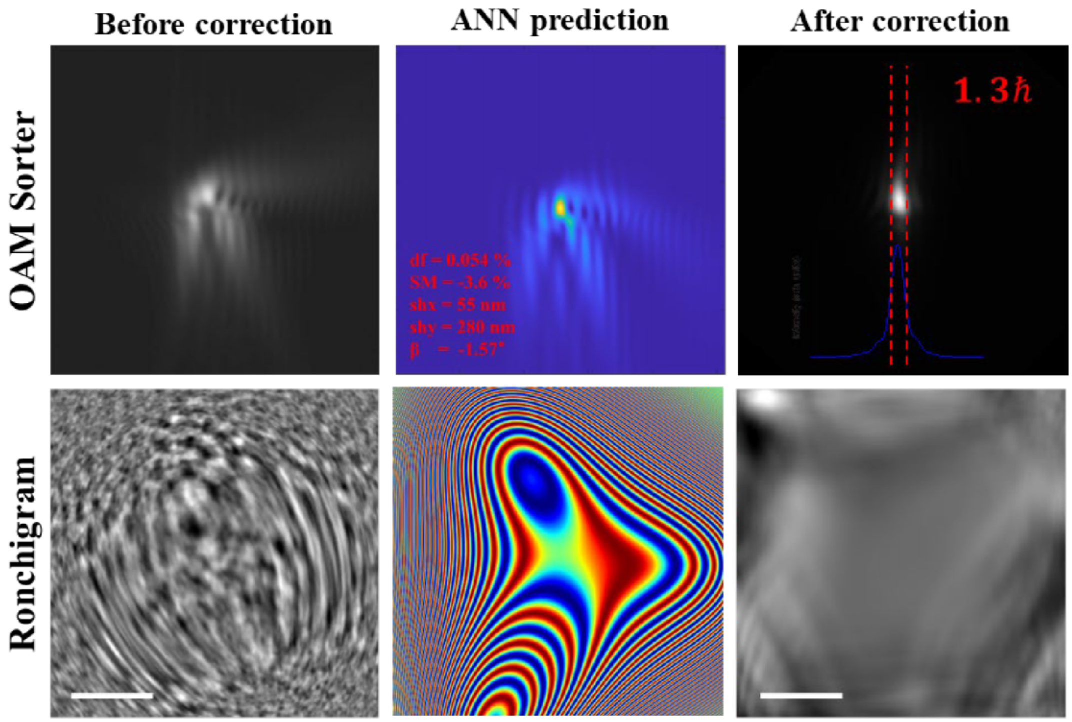

Fig. 1. Key application of ANN. Top row: alignment of the OAM sorter. Bottom row: fine tuning of a Cs corrector.

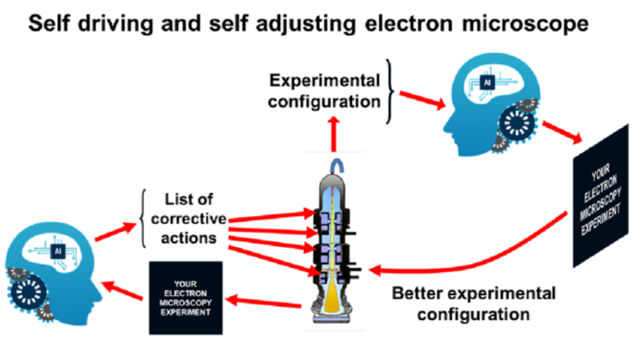

Fig. 2. Scheme for the application of AI to the real time optimisation of the electron microscopy experiments

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