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High-speed computational imaging with path-corrected fly-scan ptychography

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Abstract. Ptychography is a powerful computational imaging technique that reconstructs both the complex object function and the illumination probe from overlapping diffraction patterns. While it provides high-resolution, aberration-corrected imaging, its reliance on stepwise mechanical scanning limits acquisition speed. In this work, we propose a fly-scan ptychographic approach that enables continuous sample translation along arbitrary trajectories, significantly reducing measurement time. To account for motion-induced decoherence, we incorporate an object mode decomposition model combined with automatic differentiation for accurate trajectory correction. This method enables diffraction-limited reconstructions without the need for high-speed tracking, allowing fast and precise measurements using standard ptychographic setups.

1 Introduction

Ptychography is an advanced computational imaging technique that enables simultaneous reconstruction of the complex object function (amplitude and phase) and the illumination probe from a series of intensity diffraction patterns collected at highly overlapping scan positions [1]. Compared to conventional imaging techniques, ptychographic measurements yield more comprehensive information about the object under investigation, without relying on a perfectly aberration-free imaging system. Additionally, the inherent redundancy in the measured data facilitates the correction of various experimental imperfections, including sample-detector distance inaccuracies, angular misalignments, and other systematic errors. However, its scanning-based nature makes it time-consuming, with a significant portion of acquisition time spent on mechanically moving and stabilizing the sample stage [2]. To address this, we introduce a fly-scan ptychographic approach that accelerates acquisition by translating the sample continuously along an arbitrary trajectory during exposure.

2 Arbitrary path fly-scan ptychography

In fly-scan measurements, continuous sample motion eliminates the overhead associated with movement and settling delays, thereby reducing measurement time by minimizing intervals

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when no data is collected. However, this motion causes averaging of high-frequency features in the diffraction patterns, leading to reduced contrast and degraded reconstruction quality compared to conventional step-scan methods. To preserve high resolution, the forward model must be adapted to account for motion-induced decoherence.

We address this by modeling the object as a superposition of identical modes shifted along the scan path [3], effectively capturing the continuous motion during exposure. Combined with automatic differentiation (AD), this approach enables accurate fly-scan reconstruction and simultaneous correction of the scan trajectory, significantly improving reconstruction quality without the need for high-speed or high-precision tracking hardware, which can be seen depicted in Figure 1. As a result, fly-scan measurements can be performed using standard ptychographic setups.

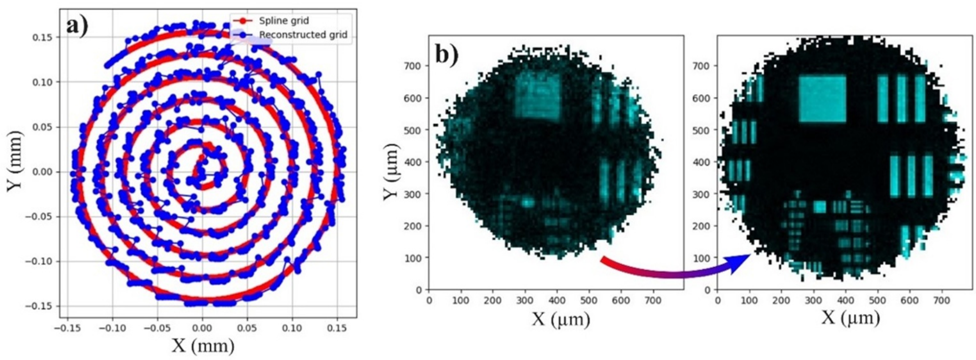

Figure 1. Experimental results from fly-scan ptychography: a) Comparison between the initial spline-approximated scan grid and the experimentally reconstructed scan grid obtained using the fly-scan object mode decomposition algorithm; b) Reconstructed object using the spline-approximated scan grid (left) versus the reconstruction using the corrected scan grid obtained through the proposed algorithm (right).

3 Conclusion and Outlook

With this reconstruction algorithm, we significantly increase the measurement speed by several times and up to an order of magnitude while preserving diffraction-limited resolution. Importantly, our AD-based approach also enables reconstruction of the fly-scan trajectory itself, allowing accurate image recovery even when the scan path is not precisely known. This eliminates the need for high-precision trajectory control, making fast and high-quality fly-scan ptychography feasible with standard step-scan experimental setups.

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