Information recovery in ptychographic coherent diffraction imaging

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Ptychographic coherent diffraction imaging has been used to overcome the finite space-bandwidth product in classical lens-based microscopy and solve the phase problem in lens-less imaging. While ptychography harnesses data redundancy to recover information about object, illumination and coherence with theoretically unlimited field of view, practically this ability is limited by the computational memory available. Here we present data compression strategies that allow for data reduction by an order of magnitude and promise to find application in memory-limited ptychograpy.

1 Introduction

Ptychographic coherent diffraction imaging (PCDI) [1] is a scanning microscopy technique that has been driven by the need for lensless imaging modalities especially in the EUV [2] and x-ray [3] spectral range. In a PCDI experiment a specimen is scanned across a stationary coherent illumination beam, referred to as probe (Fig. 1). The scattered wave is recorded on a detector and contains information about the sample. Since optical sensors are too slow to measure the rapid phase variations of the diffracted wave, only intensity information is measured. The missing phase information has to be recovered to invert the diffraction data. To this end, the specimen is scanned in overlapping regions providing data redundancy for phase retrieval [4]. Although theoretically unlimited, practically in PCDI the field of view (FOV) is limited by the computational memory available. It is therefore of practical interest to investigate compression strategies while preserving the ability for phase recovery [5]. Here we provide a data compression strategy that allows for extension of the achievable FOV in PCDI.

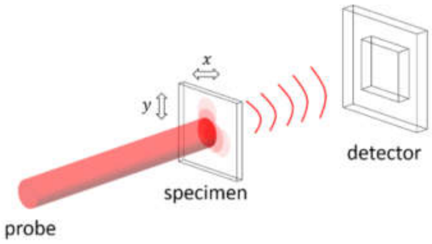

Fig. 1 *Experimental setup. A specimen is scanned by a finite illumination in overlapping regions and the scattered signal is recorded on an optical detector. The redundancy resulting from scanning in overlapping regions is used to recover phase information and invert the diffraction data.*

2 Compression algorithm

Let the diffraction data be denoted by $I \in R^{MxN}$, where *M* is the number of detector pixels and *N* is the number of scan positions. Then the diffraction data can be approximated by a rank-K truncated singular value decomposition (SVD), i.e.

$$I \approx USV', \tag{1}$$

where $U \in R^{MxK}, S \in R^{KxK}$, and $V \in R^{NxK}$; the apostrophe denotes the conjugate transpose. Redundancy in the data set due to the overlap in scan position should result in an effective lower rank in the SVD, which thereby provides an orthogonal basis to approximate the data [6]. In what follows we refer to the compression rate by the ratio *K / N*.

3 Experimental setup

In a ptychographic experiment the detector is typically placed in the optical far-field. While this condition is naturally satisfied for x-rays for illuminations of small lateral extent, it is achieved for visible radiation by employing a lens and placing the detector in the plane where the source is imaged [7]. In our experimental setup a HeNe laser (632.8 nm) is focused by a converging lens (*f* = 10 mm). Immediately downstream the lens a specimen (spokes target) is placed and translated using a microscopy xy stage (~50 nm resolution). Far-field diffraction patterns are recorded on a 12 bit CMOS detector (2048², 5.5 µm pixel pitch). Multiple exposures are stitched to increase the dynamical range to 20 bit using

$$I_{hdr} = \frac{\sum_k W_k I_k}{\sum_k W_k t_k} t_{max}, \tag{2}$$

where I_{hdr} is the stitched intensity, W_k is 0 where I_k is overexposed and 1 elsewhere, I_k is a diffrac-

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tion intensity with recording time t_k, and t_{max} is the maximum recording time.

4 Reconstruction algorithm

We reconstructed the specimen using both the extended ptychographic iterative engine (ePIE) [7] and the difference map [8] which did not show significant deviations. Further details on the reconstruction procedure can be found in [2].

5 Results

A PCDI data set of a spokes target was obtained with an overlap of approximately 80% between adjacent scan positions [4]. The data was compressed by means of Eqn. (1) to yield data sets between 100% and 10% of the size of the original data set. Figure 2 (a) shows the ePIE reconstruction after 1000 iterations without compression. Figure 2 (b) shows the reconstruction with a moderate compression rate of 80%. Only minor differences to the lossless reconstruction can be found. Figure 2 (c) shows the reconstruction result with only 20% of the original data amount. Most of the original features are still preserved. Figure 2 (d) shows the reconstruction result for a compression rate of 10%. In this case the spokes target could not be reconstructed with high fidelity.

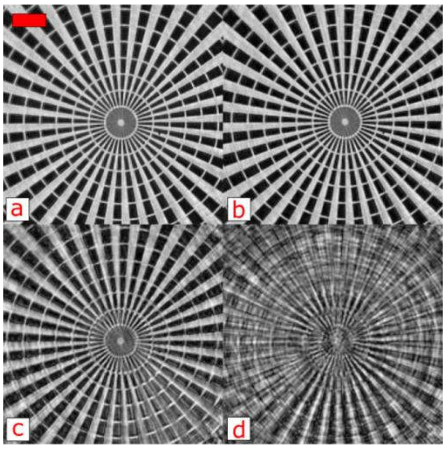

Fig. 2 *Reconstruction with varying compression rates. (a) 100%, (b) 80%, (c) 20%, and (d) 10% of the size of the original data set was used for reconstruction of the test object. The scale bar on the top left shows 100 µm.*

6 Discussion and conclusion

We have presented a data compression strategy technique that achieves ptychographic data sets reduction by up to an order of magnitude. Similar to image compression strategies such as JPEG [10], the SVD-based approach presented here orthogonalizes the data and finds a sparse approximation. A few further comments have to be made. First, since approximation of the diffraction data by the truncated SVD results in systematic errors, a small feedback parameter (β=0.1 [8]) was used for the ePIE algorithm. We observed this strategy to consistently yield more robust reconstructions than for high feedback parameters which may be due to an averaging effect that small feedback have on the specimen estimate at the cost of fast convergence. Second, it is noted that the compression procedure reported here was able to achieve even better compression rates for objects that are intrinsically sparse in structure. For sparse objects and small illuminations, many diffraction patterns resemble each other (an extreme case of which is scanning transmission x-ray microscopy [11]). Finally, it is noted that the SVD compression strategy reported here lends itself to multigrid implementations. The data can be orthogonalized on a CPU by means of a full rank SVD and then be transferred to a GPU in pieces using only significant coefficients of the SVD. We expect the method reported here to be useful for tomographic ptychography experiments, where the size of diffraction data reaches the tera byte range.

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