Imaging Distortion Correction in Panorama Stitching in Scanning Electron Microscopy

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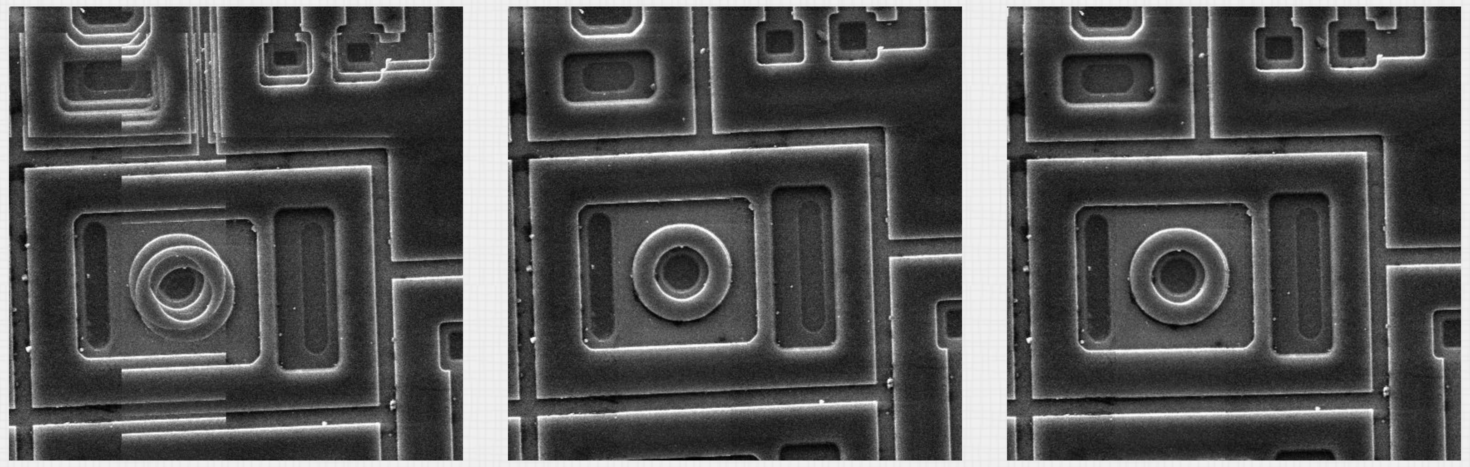
Introduction

When acquiring panoramic images using Scanning Electron Microscopes (SEMs), a geometric distortion (fig. 1a) is generated by the optical system and the stage mechanics of the microscope. Images of captured objects in panoramas obtained by using ordinary stitching methods (fig. 1b) can have incorrect shape and size.

This work describes the distortion model generated in SEMs in order to obtain metrologically more precise images (fig. 1c), and proposes a method to find the parameters of the model, given preliminary estimates for distortion parameters and a set of partially overlapping image tiles.



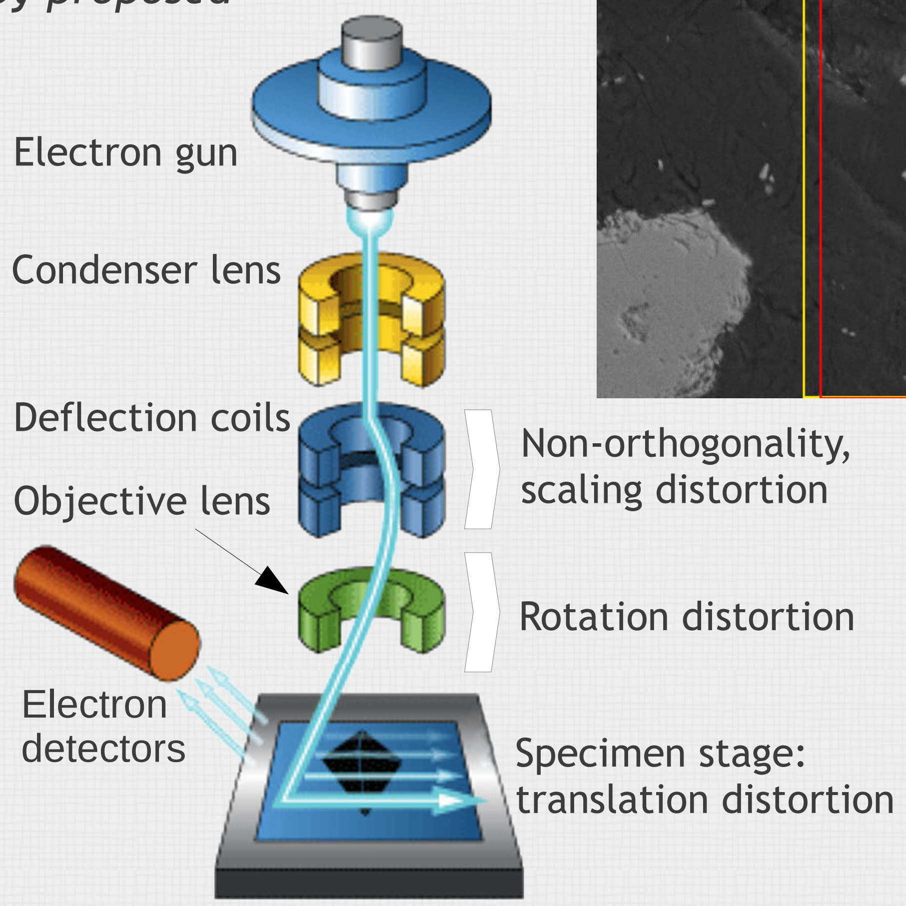
(a) (b) (c)

▲ *Figure 1: Part of panorama (a) with visualised misalignment in overlaps, (b) stitched by homographies, (c) stitched by proposed method.*

Distortion in SEMs

Distortion generated in the optical system of SEMs is dominated by non-orthogonality, scaling and rotation distortions (fig. 2). Because the optical system does not change while acquiring a panoramic image, the distortion is global across the acquired image tiles. It can be modelled by an affine transform with 5 parameters.

Distortion generated by the specimen stage has a form of simple translation and can be unique for all stage shifts. The number of parameters depends on the size of panorama.

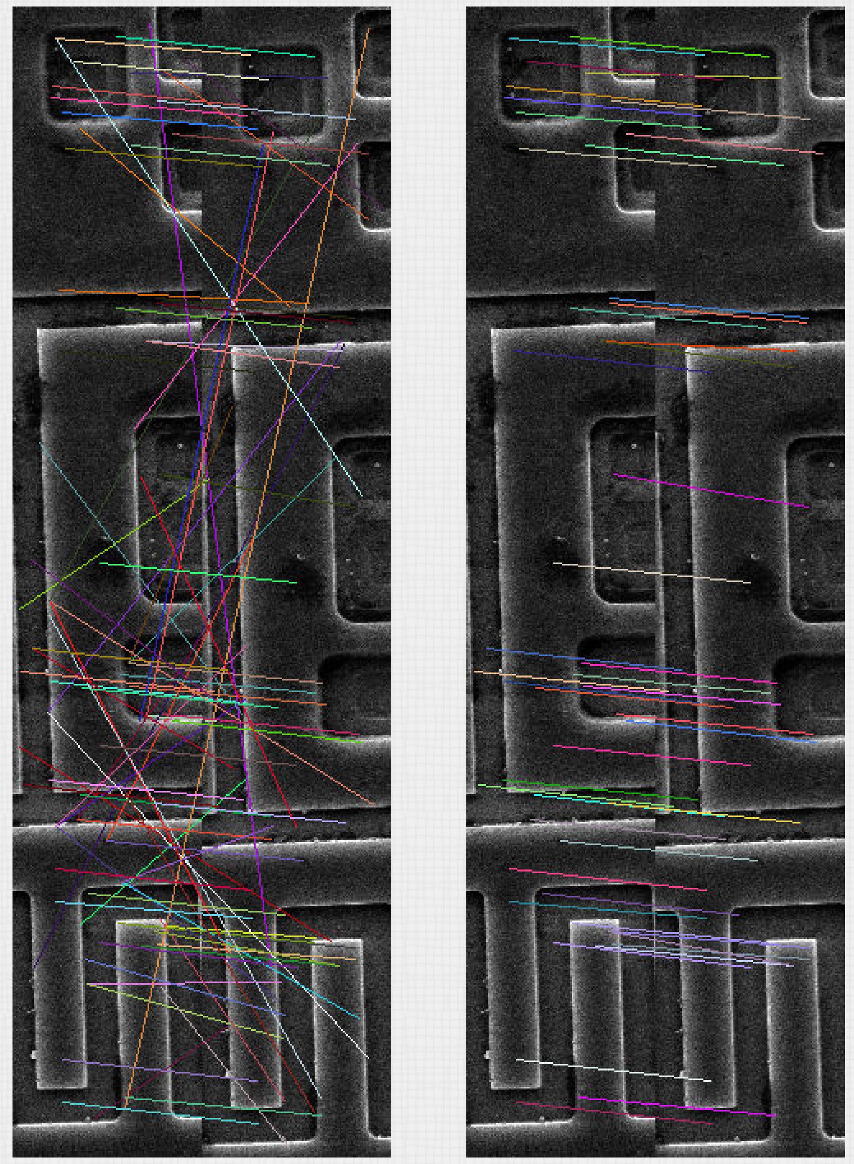


▲ *Figure 2: SEM layout [1].*

Estimating distortion parameters & stitching

After applying the distortion correction, it is required that all corresponding points in the overlaps of neighbouring image tiles have the same coordinates. The parameters were found by minimization of the cost function defined as a sum of squared distances between all corresponding points in all overlaps in the panorama. The algorithm has three main stages:

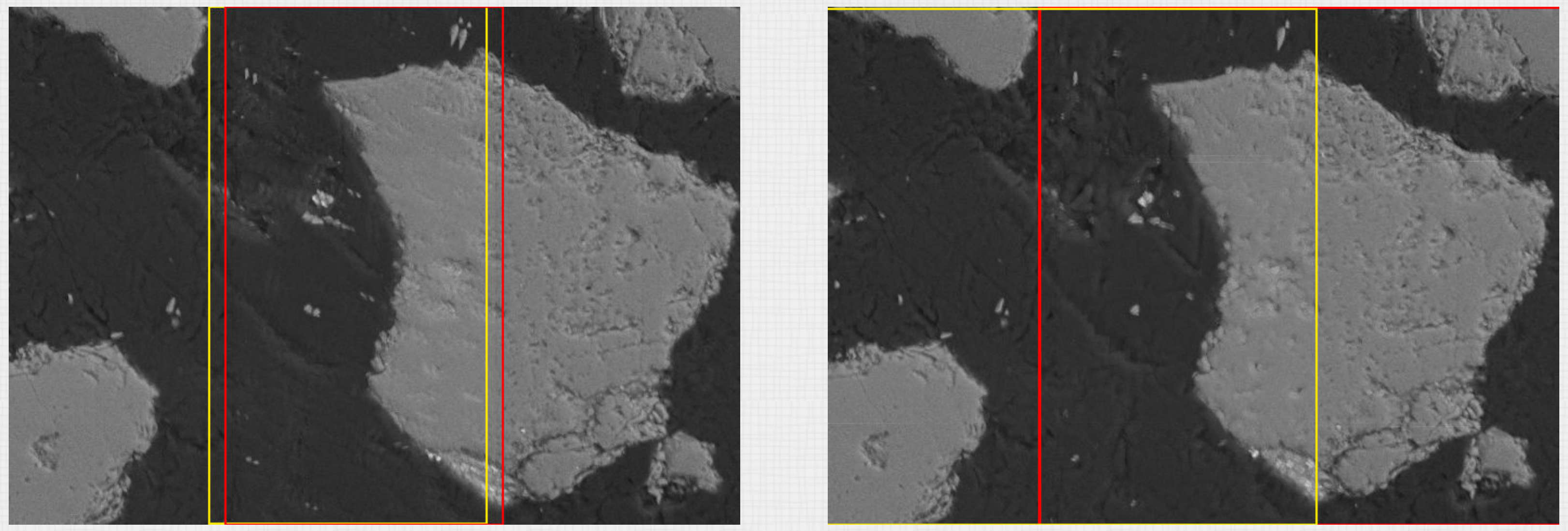
1. Establishing corresponding points:
   - Keypoints detected by using SIFT [2] or ORB [3] keypoint detectors,
   - Brute-force matching (fig. 3a) with RANSAC [4] filtering (fig. 3b).
2. Minimization of the cost-function:
   - Estimate of global minimum obtained by utilising simulated annealing [5],
   - Actual solution determined by non-linear programming [6].
3. Stitching:
   - Starting with the tile in the centre, proceeding in breadth-first search manner.



(a) (b)

▲ *Figure 3: (a) Brute-force matched SIFT keypoints and (b) RANSAC filtered matching.*

Results



(a) (b)

◄ *Figure 4: Visualised overlaps in (a) misaligned neighbouring tiles, (b) tiles aligned using the proposed method. Example in (b) has higher SSIM index and is of better quality.*

The obtained panoramas showed high visual quality, which was evaluated by using Structural Similarity Index (SSIM) [7] computed between the overlapping regions of image tiles prior and after inserting them in the panorama. Preliminary estimate of the distortion parameters (1% scaling error, 1° non-orthogonality and rotation error) were confirmed. Stage shift errors exceeded the expected all bounds and their expected normality and randomness properties were rejected by statistical tests. It was also found that modelling non-orthogonality before scaling gives better results. Performing optimization on the subsets of datasets converged to different minima of similar quality, indicating that the cost function might be flat and redefining it might lead to more stable results.

References:

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