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Pivot Point: The Key to TEM Automation

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Since its inception, transmission electron microscopy (TEM) has been considered one of the most site-specific sample analysis techniques; with regions of interest on the order to nanometers to micrometers. The advent of aberration C_s probe correction has further pushed the resolution of the scanning TEM (STEM) to the picometer scale, thereby minimizing the desired field of investigation further. Combined with the addition of other factors such time-consuming sample preparation, this trend has minimized the utilization of statistical analysis in extremely high-resolution scenarios. The phrase, "n equals 1" has been a longstanding statement espoused by electron microscopists in reference to experimental replication. The development of on the fly data analysis techniques, such as few shot analysis[1], coupled with integrated control of microscope platforms (e.g., PyJEM) is providing advancements to overcome these statistical challenges[2]. For such programs[3,4] to be integrated into all microscopes, it is necessary to fully understand the limitations of sample positioning through goniometer and stage movements. Until newer, more sophisticated stage/goniometer designs can be developed that circumvent many of the previous generation's drawbacks (e.g., large hysteresis) only a deep understanding of sample movement will tightly controlled automation at the nano or even picometer scale be achieved.

With current automated control of the microscope stage, it is possible to investigate how the stage responds to requests to move to a target location. Empirically, we have observed that the stage has backlash when creating montages over a wider sample area. Fig 1a illustrates this phenomenon in a simple example. There is significant discrepancy between the target positions and the reported positions in the y-direction, potentially due to the discrete nature of the stepper motor. However, the x-direction also shows a hysteresis style effect when the direction switches near target positions (1500, 500) and (-1500, 0). To verify that this backlash was present in both axes, a similar test was performed on the y-axis and this is shown in Fig 1b. Next, we tested to see if moving in the orthogonal axis would impact the backlash of the other axis. In other words, this tests the independence of the axes with respect to hysteresis and the results are shown in Fig. 1c and 1d. There does not appear to be any effect on the reported x-position when moving in the y-direction, and vice versa. However, there does appear to be variability in the reported position of the microscope, even for identical target positions. This can be clearly seen in Fig 1d, for the two X locations about the target position of (500, 1000). Future work will investigate the repeatability of these types of movements to see if this variance can be meaningfully quantified to give an idea of the accuracy of the stage motion.

We will discuss protocols to understand existing stage limitations with respect to stage motion. In order to elicit discussion on both the practicality of current stage designs on full automation as well as how to design next generation microscopes to better accommodate advanced microscopy algorithms it is necessary to bring forth these underappreciated microscopy topics and discuss them in detail [5].

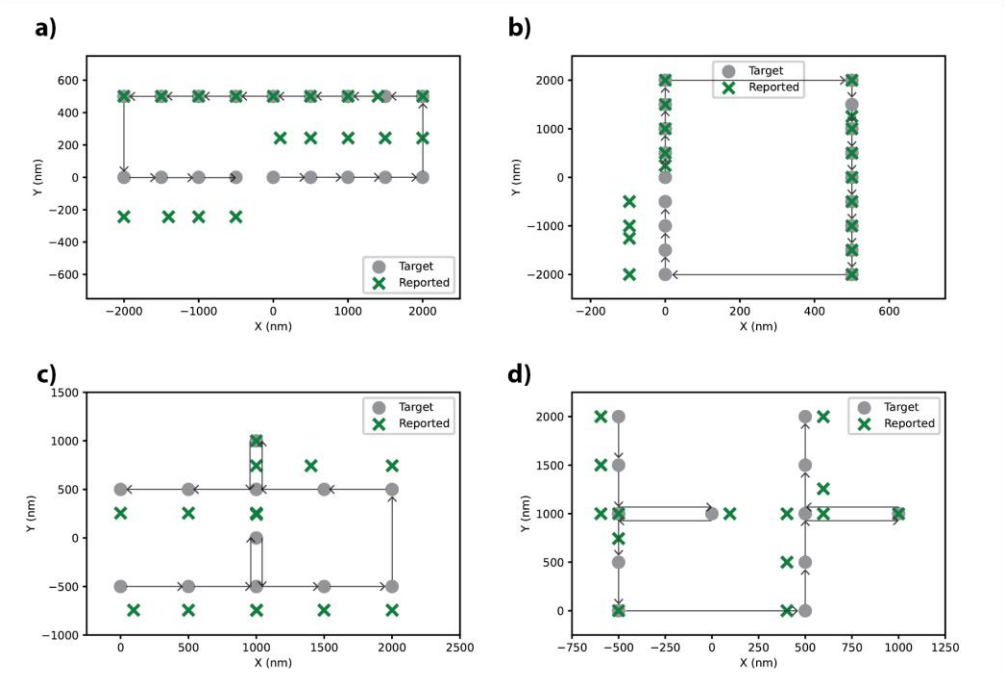

Figure 1: a) Stage movement pattern showing backlash in the x-direction on the first step in a given direction. b) Stage movement pattern showing backlash in the y-direction on the first step in a given direction. c) Stage movement pattern showing that y-direction motion does not influence x-direction motion. d) Stage movement pattern showing that x-direction motion does not influence y-direction motion.

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