Using Quantitative Image Analysis Techniques to Improve Electron Microscopy Image Quality

Thomas Ma, Shao Electron Microscopy Lab
Chadwick School, Class of 2027
USC Viterbi Department of Material Science, SHINE 2024

Introduction
Shao’s Electron Microscopy group is currently researching to understand the interactions between different variables in quantum materials most importantly, how a material's atomic structure would affect the bulk properties. The lab that I worked in focused on electron microscopy techniques. Scanning Transmission Electron Microscopy (STEM), using an accelerated electron beam, allows imaging at a spatial resolution up to a picometer (1 x 10⁻¹² m). With structural information on the atomic scale, many physics phenomena could be better understood and this could potentially help other technologies advance.

Method
The first method we used includes RigidRegistration. This method helps improve the image's resolution by having a higher signal-to-noise ratio (SNR). RigidRegistration provides better SNR because it stacks all photos based on the shift before each fast-acquired image. After we acquired the images, we used Atomap to identify the positions of each atom. Atomap works by finding the intensity difference in the image. The atomic positions are then further corrected by the center of mass refinement (COM) and 2-D Gaussian. We used a customized Python script to find how much atoms deviate from theoretical positions.

Research & Learning Process
I researched by reading many scientific papers on electron microscopy and different simulators. Once I read these, I applied that knowledge to the simulators I tried to run. The first program I tackled was MATLAB. I completed the tutorial and tested it after. Next, I tried to understand and run an electron microscopy simulator called μSTEM. Although I couldn’t figure out how to run μSTEM, I still tried my best. After this, I moved on to another simulator called Atomap and successfully ran tests on it.

Skills Learned
I learned how to thoroughly read scientific papers like Image Registration of low signal-to-noise cryo-STEM data by Benjamin H. Savitzky, using MATLAB, and Atomap. I’ve grown to appreciate the many hours researchers put into scientific papers and how detailed they have to get.

Results
Fig(a) shows the RigidRegistration method and how it stacks images based on the shift. Fig(b) shows the shifts of all the images to determine the best alignment. The abnormal pixels show the incorrect shifts being caused by low SNR(left). These pixels are then corrected(right). Fig(c) shows the Defocused Image Contrast Index (DCFI) before it was enhanced using RigidRegistration. The DCFI method is not favored because it will always stack the photos onto each other. Fig(d) shows the result of RigidRegistration and how effective this method is. The image is much clearer and the individual atoms can be recognized. Again, fig(e) shows the DCFI method and how it’s blurry. Although it may be hard to tell at first, fig(f) has a better quality to it, and the atoms are more defined, hence showing the effectiveness of the RigidRegistration method.

Fig(g) shows the processing steps for locating and fitting 2-D Gaussians to every atomic column. Fig(h) is the final result after using Atomap and then using the customized Python script to find the deviated atom placement. The picture shows tiny arrows. Each arrow is stretched in the direction where the deviated atoms deviated to.

How This Relates to Your STEM Coursework
In the future, I want to work in the engineering field because I enjoy the hands-on aspects of it. This project relates to my STEM coursework because it expanded my knowledge of the material science field. I also learned to apply my computer programming skills.

Advice for Future SHINE Students
Once I started my very first day at SHINE, I was excited and nervous about what I was going to do. I ended up learning a lot about electron microscopy and the different simulators used for them. My advice to future SHINE students is probably to remain focused on your task and always ask your mentor for future tasks so you can prepare yourself. Don’t stress too much about the learning curve because, at the end of the day, you are doing college-level work.

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Citations