Automated and Robust Nano-Assembly with Atomic Force Microscopes

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Atomic Force Microscopes (AFM) have become a useful tool not only for imaging at the nanoscale resolution, but also a useful tool for manipulating nanoscale objects in nanoscale device prototyping and for studying molecular and cellular mechanisms in biology.

In this project, we have developed a method, called sequential parallel pushing (SPP), for efficient and automated nanoparticle manipulation [1]. Instead of using tip scanning to fully locate the particle center, this method uses one scan line perpendicular to the pushing direction to determine the lateral coordinate of the particle center. The longitudinal position of the particle is inferred from the position where the tip loses contact with the particle through real-time analysis of vibration amplitude of the cantilever. The particle is then pushed from the determined lateral position along the current push direction toward the baseline of the target. This process is iterated until the particle reaches the target position. Experimental results show that the SPP algorithm, when compared with simple target-oriented pushing algorithms, not only reduces the number of scan lines but also decreases the number of pushing iterations. Consequently, the manipulations time has been decreased up to 4 times in some cases. The SPP method has been successfully applied to fabricate designed nanoscale patterns that are made of gold (10 ~ 15nm diameter) particles and of 170 latex (50nm diameter) particles.

Because of the presence of thermal expansion and contraction, the relative position between the AFM (atomic force microscopy) tip and the sample undergoes drift with respect to time. Such drift contaminates the AFM images as the time taken to acquire a complete AFM image is in the range of minutes. As the AFM image is used as a reference for most manipulation mechanisms, the drift-contaminated image will cause problem for AFM based manipulation because the displayed positions of the objects under nanomanipulation does not match their actual locations. The drift during manipulation, similarly, will further deteriorate the mismatch between the displayed positions and the actual locations. Such mismatch is a major hurdle to achieve accurate and efficient AFM based nanomanipulation. Without proper compensation, manipulation based on a wrong displayed location of the object often fails. In this project, we have developed an algorithm to identify and eliminate the thermal drift contamination in the AFM image by applying a strategic local scan method [2]. Briefly, after an AFM image is captured, the entire image is divided into several parts along vertical direction. A quick local scan is performed in each part of the image to measure the drift value in that very part. In this manner, the drift value is calculated in a small local area instead of the global image. Thus, the drift can be more precisely estimated and the actual position of the objects can be more accurately identified. In this paper, we also present the strategy to constantly compensate the drift during manipulation. By applying local scan on fixed features in the AFM image frequently, the AFM image with the most current position can be obtained. Starting from a drift-clean image at the beginning, the AFM based nanomanipulation can be more accurate and efficient when drift can also be compensated during manipulation in real-time.

[1] Kangmin Xu, Arash Kalantari, and Xiaoping Qian. "Efficient AFM based nanoparticle manipulation via sequential parallel pushing." Accepted by IEEE Transactions on Nanotechnology, (2011).

[2] Guangyong Li and Liming Liu. "Strategic Local Scan for Drift Compensation in AFM Based Nanomanipulation." Submitted to IEEE/ASME Transactions on Mechatronics, (2011).