Large area high-speed atomic force microscopy with arbitrary scan path playback

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Abstract

A novel control system for a two-axis flexure stage, with 100 µm × 100 µm scanning range, has enabled large area High-speed Atomic Force Microscope (HS-AFM) scanning. By combining this stage with a coarse stage and data stitching, a system capable of imaging both large areas and high resolution is demonstrated.

Introduction

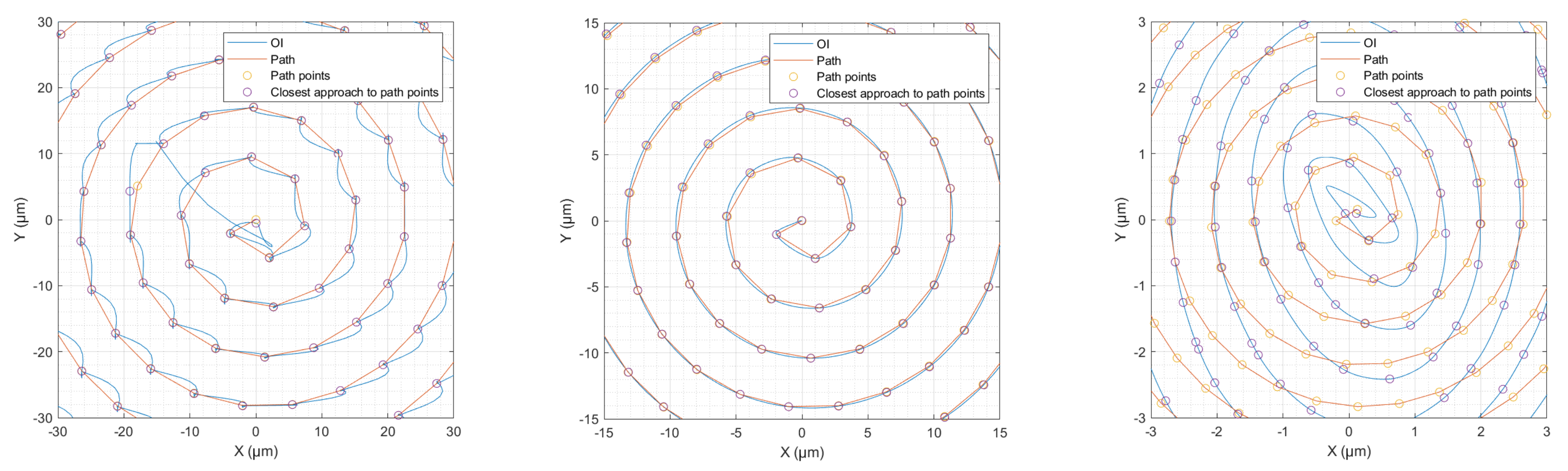
Atomic force microscopy (AFM) is traditionally a slow method, but in recent years numerous high-speed AFMs (HS-AFMs) have been developed [1,2,3].

To aid faster scanning, alternative scan paths have been adopted such as spiral scanning [4], Lissajous and rosette scanning [5]. Each of these paths has its own advantages, however, a common element of all is that there is no sudden change in motion direction and no abrupt change in acceleration which allow a higher scan speed to be maintained.

Previous work [6] showed the potential of replacing the short range 4.5 µm × 4.5 µm flexure stage on the NPL HS-AFM with an XY-100D stage manufactured by Queensgate with a 100 µm × 100 µm scan range. This resulted in the generation of high-quality, distortion-free images. However, scanning patterns were limited to those it was possible to generate using constant velocity ramps. In this work we demonstrate the use of arbitrary paths on this stage for large area HS-AFM scanning.

Methods

To generate arbitrary scan paths suitable for HS-AFM, a new approach to stage control was required. Stage control traditionally has controlled each axis individually, or has cared only about reaching the target point. Arbitrary scan paths require "contoured motion" where a 2D path towards the target point must be followed. For HS-AFM, an additional requirement is "PVT motion" (position, velocity, time) where a smooth curved path is interpolated between points with smooth control over the speed along this path. Motion controllers can achieve this, but require analogue outputs to the stage controller which can reduce the fidelity of control, and are significantly more expensive and complex. New firmware was written by Queensgate that allows a series of points for a PVT motion path to be pre-programmed into the stage controller, with the controller then running a smooth curved path between these points in real time.



a) Individual axis control *b) PVT control* *c) PVT control (sped up)*

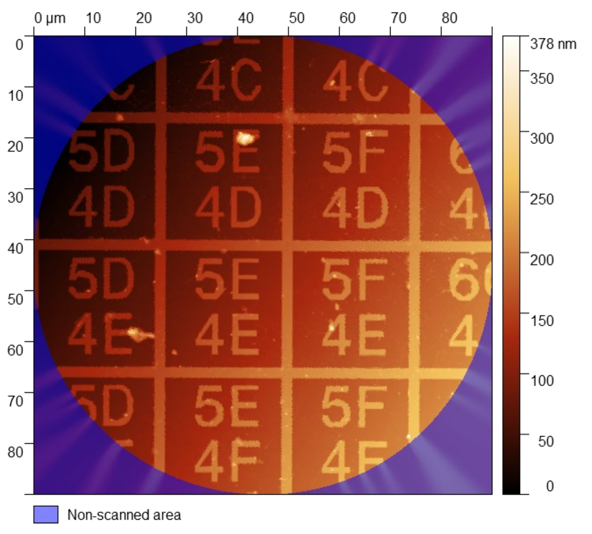
Figure 1: Stage rig results for spiral scan path.

Results

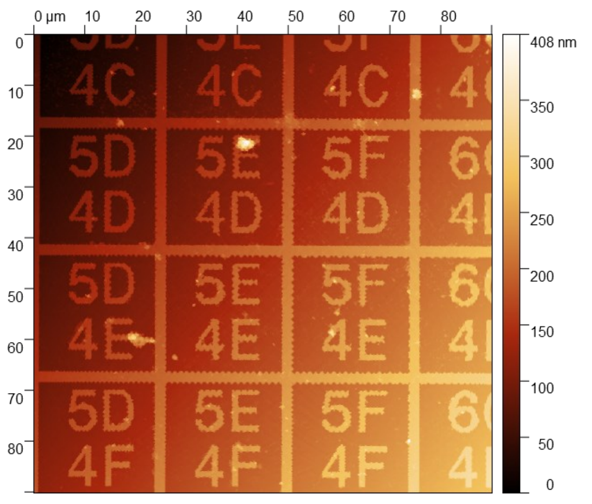
Before using the new scanning techniques for HS-AFM, they were tested using the NPL stage rig [7]. Figure 1 shows the same spiral pattern realised using traditional independent axis control, by contoured by PVT motion (both 0.1 s per point) and by a sped up (0.5 ms per point) PVT motion. As expected the path playback resulted in much smoother motion compared to the traditional approach.

It can also be seen that, at lower speeds, all approaches result in a final motion passing close to the specified points (maximum observed error 0.2 µm). Faster speeds result in scanning that misses some or all of the specified points. However, the path playback methods continue to produce a smooth motion that is usable for HS-AFMs with real-time metrology even if it "misses" the nominal path.

To illustrate the range of scales at which this scanning strategy is applicable to HS-AFM, several images were recorded (figures 2 & 3). Two scan paths were used for HS-AFM scanning, the rosette and Lissajous patterns [8,9]. These were chosen as they are cyclical. This allows these paths to be looped, which is important for this HS-AFM as the tip sample interaction breaks down if the speed drops or the stage stops [10].



a) Rosette (scans circular area)



b) Lissajous

Figure 2: HS-AFM scans of numbered grating.

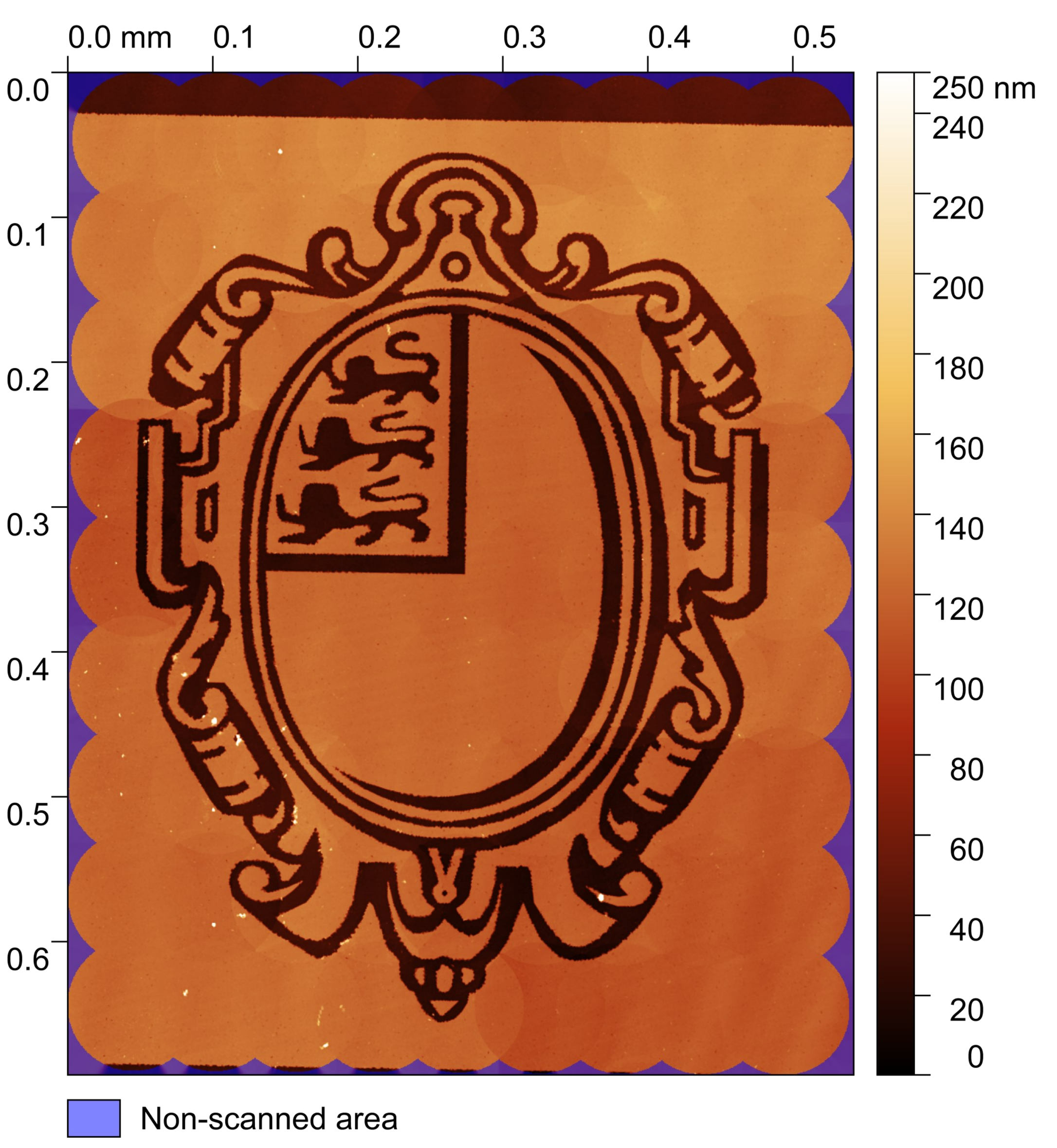


Figure 3: HS-AFM scans of NPL crest. The full image is formed of 82 individual frames of data.

Conclusions

Using the Queensgate XY-100D stage allows the HS-AFM to scan across larger area high-speed scans, resulting in less stitching being required. This allows high quality images of topography to be produced more quickly and with less error than is possible with the shorter-range stage.

Imaging a similar area using a larger stage is quicker than using a smaller stage and stitching because time is saved not moving the coarse stage between frames and because there is no need to image any overlap between frames. Using arbitrary paths also gives more flexibility to choose different resolutions. The overall error is reduced as data stitching always introduces some errors around the frame edges [11].

The increase in scan range has not sacrificed resolution; it is still possible to image small scale features using the longer-range stage. As such this imaging set up is particularly suitable for applications that require a large area to be imaged in order to locate a feature of interest as well as detailed measurements.

There is also the potential for similar scan methodology in applications other than AFM such as other imaging systems or lithography.

References

[1] Yang C *et al* 2023 *Surface Science and Technology* 1 7
[2] Marchesi A *et al* 2021 *Scientific Reports* 11 13003
[3] Fukuda S and Ando T 2023 *Biophysical Reviews* 15 2045–2058
[4] Mahmood I A and Moheimani S O R 2009 *Nanotechnology* 20 365503
[5] Nikooienejad N *et al* 2019 *Review of Scientific Instruments* 90 073702
[6] Bartlett G *et al* 2021 *euspen's 21st International Conference & Exhibition*
[7] Yacoot A *et al* 2019 *Measurement Science and Technology* 30 035002
[8] Sun X *et al* 2021 *Measurement Science and Technology* 32 115010
[9] Sun X *et al* 2024 *Measurement Science and Technology* 35 117003
[10] Heaps E *et al* 2020 *Measurement Science and Technology* 31 074005
[11] Klapetek P *et al* 2024 *Measurement Science and Technology* 35 125026