Large area high-speed AFM with arbitrary scan path playback

Edward Heaps[1], Graham Bartlett[2], Jayesh Patel[2], Craig Goodman[2], Alison Raby[2], Andrew Yacoot[1], Petr Klapetek[3]

[1]National Physical Laboratory, Hampton Road, Teddington, TW11 0LW, UK

[2]Queensgate Instruments, 3-4 Fielding Industrial Estate, Wilbraham Road, Fulbourn, Cambridge, CB21 5ET, United Kingdom

[3]Czech Metrology Institute, Okružn´ı 31, 638 00, Brno, Czech Republic

edward.heaps@npl.co.uk

Introduction

Atomic force microscopy (AFM) has long been a vital tool for the measurement of surface topography and other surface properties at the nanoscale. Although AFM is traditionally a slow technique, that raster scans the sample with respect to the tip, in recent years there have been numerous high-speed AFMs developed (Yang 2023, Marchesi 2021, Fukuda 2023). These typically have a small flexure stage with a scan area less than 10 µm range in the *x* and *y* axes.

One approach to High-Speed AFM (HS-AFM) is to use a cantilever in contact with the sample surface that moves across it in open loop, relying on passive mechanical feedback to maintain tip-sample contact (Payton 2012). Previous work at NPL has focused on introducing metrology to this type of HS-AFM such that traceable dimensional images can be obtained directly, with the minimum of data stitching and manipulation (Heaps 2020).

Subsequently work was carried out to investigate the potential of replacing the short-range flexure stage used up to that point with an XY-100D stage manufactured by Queensgate with a 100 µm × 100 µm scan range. Use of this stage for sample scanning in the HS-AFM resulted in the generation of high-quality images using only the built-in stage sensors and timing data to provide information about lateral position. However, scanning patterns were limited to those it was possible to generate using constant velocity ramps (Bartlett 2021). In this presentation we report on the application of non-raster scans to the 100 µm × 100 µm scan range stage.

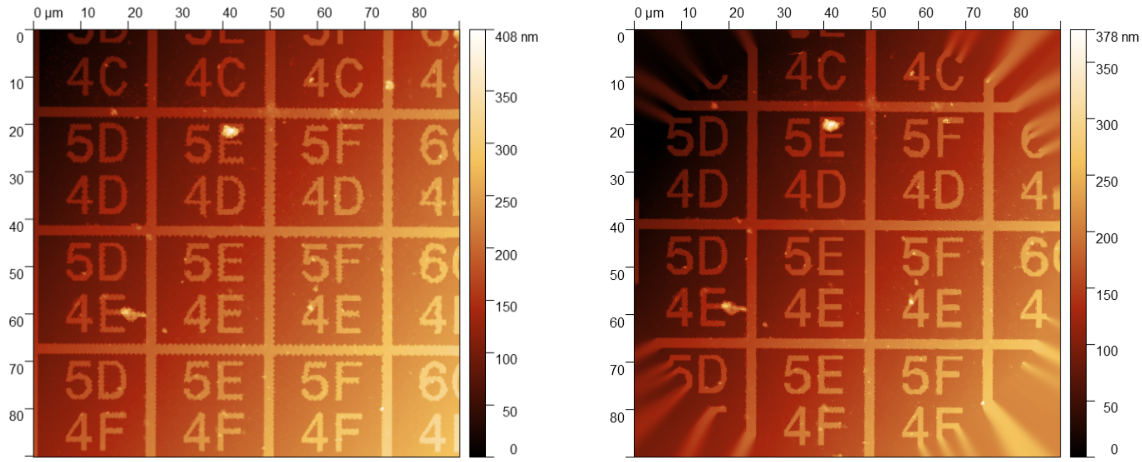
Method

To allow for arbitrary scan paths suitable for HS-AFM, a new approach to stage control is required. Stage control traditionally has only controlled one axis at a time or has only been concerned with 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. 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. The paths used in this work were generated using the GwyScan library (Klapetek 2017).

The Queensgate stage was mounted on the NPL HS-AFM and fitted with mirrors to allow its position to be measured using the HS-AFM's optical interferometers.

Results

To demonstrate the range of scales at which this scanning strategy is applicable a number of images were recorded.



(a) Lissajous path scan. (b) Rosette path scan.

Figure 1: HS-AFM scans of numbered grating. The rosette path scans a circular area. As such, the image has been extrapolated to the corners of the square axes.

To demonstrate the ability of the HSAFM to record data across the stage range a numbered grating structure was imaged across an area of 90 µm × 90 µm (Figure 1). The Lissajous path was made up of 53 360 points, the rosette path 81 224 points.

In order to demonstrate the ability of this technique to scan over large areas, an image of the NPL crest was captured (Figure 2). This crest formed part of a logo etched onto the border of an NPL produced calibration sample. The full image is formed of 82 individual frames of data. Each frame was a 90 µm × 90 µm rosette scan with 2400 path points spaced 1 µm apart.

An example of the HS-AFM's setup ability to scan small areas/structures is shown in figure 3; a collagen sample. In this image it is possible to observe thin structures of the order of 100 nm in width. The scan path was a rosette with 100 488 scan points. The rosette path scans a circular area. As such, the image has been extrapolated to the corners of the square axes.

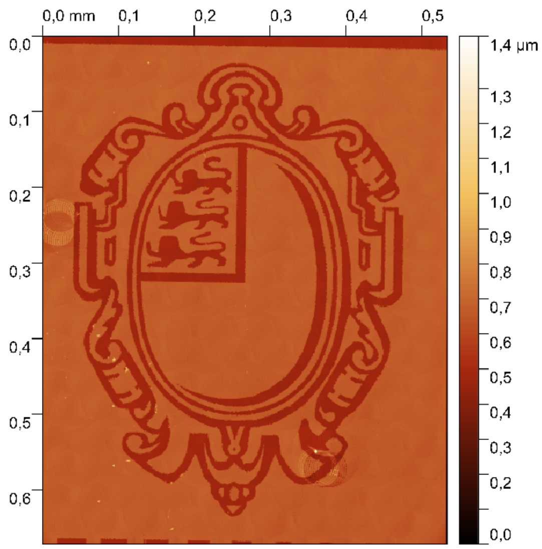


Figure 2: Large area scan of the crest from the NPL logo

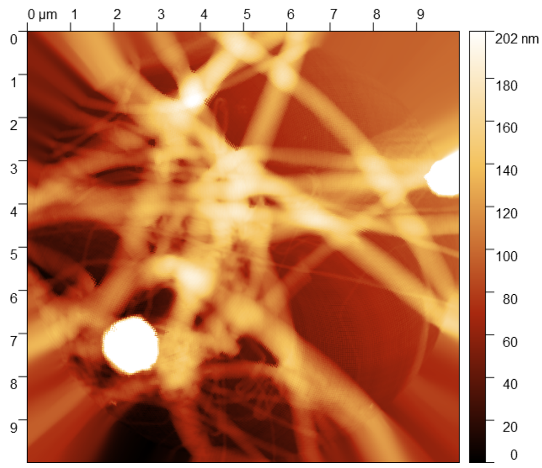


Figure 3: Scan of collagen sample demonstrating ability to resolve small features.

Conclusions

Using a longer-range stage with PVT control allows the HS-AFM to scan larger areas than previously possible. 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 is quicker than a similar area with stitching because time is saved by not moving the coarse stage between frames and because there is no need to image any overlap between small frames. Error is reduced as data stitching always introduces some errors around the frame edges (Klapetek 2024).

The ability to move in arbitrary scan paths has come about as a result of moving from the two axes being individually controlled to a PVT motion path playback approach.

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 of the feature itself. An example of this could be the imaging of a wafer containing an array of quantum devices for quality control purposes.

Finally, there is the potential for similar scan methodology in applications other than AFM. These applications could include other imaging applications as well as non-imaging applications such as lithography.

Author contributions

• Edward Heaps: Technical work at NPL

• Graham Bartlett and Jayesh Patel: Technical work at Queensgate

• Craig Goodman and Alison Raby: Project management at Queensgate

• Andrew Yacoot: Project management at NPL and technical advice

• Petr Klapetek: Data stitching

All authors contributed to writing and editing of this text.

Acknowledgements

We thank Innovate UK for funding from the Analysis for Innovators (A4I) Programme. This work was additionally partly funded by the UK Government's Department for Science, Innovation & Technology through the UK's National Measurement System programmes.

Loren Picco (Bristol Nanodynamics) is thanked for the collagen sample. Robert Ferguson (NPL) is thanked for aligning and assembling the mirrors on the HS-AFM.

Disclaimer

The naming of any manufacturer or supplier by NPL, Queensgate or CMI in this scientific journal shall not be taken to be either NPL's, Queensgate's or CMI's endorsement of specific samples of products of the said manufacturer, or recommendation of the said supplier.

Furthermore, NPL, Queensgate and CMI cannot be held responsible for the use of, or inability to use, any products mentioned herein that have been used by them.

References

Yang *et al* 2023 *Surface Science and Technology* 1 7 ISSN 2731-7838

Marchesi *et al* 2021 *Scientific Reports* 11 13003 ISSN 2045-232

Fukuda S and Ando T 2023 *Biophysical Reviews* 15 2045–2058 ISSN 1867-2469

Payton *et al* 2016 *International Materials Reviews* 61 473–494

Heaps *et al* 2020 *Measurement Science and Technology* 31 074005

Bartlett *et al* 2021 E*uspen's 21st International Conference & Exhibition* (Copenhagen, Denmark)

Klapetek *et al* 2017 *Measurement Science and Technology* 28 034015

Klapetek et al 2024 to be published in *Measurement Science and Technology*