Real-Time Machine Learning in Scanning Probe Microscopy

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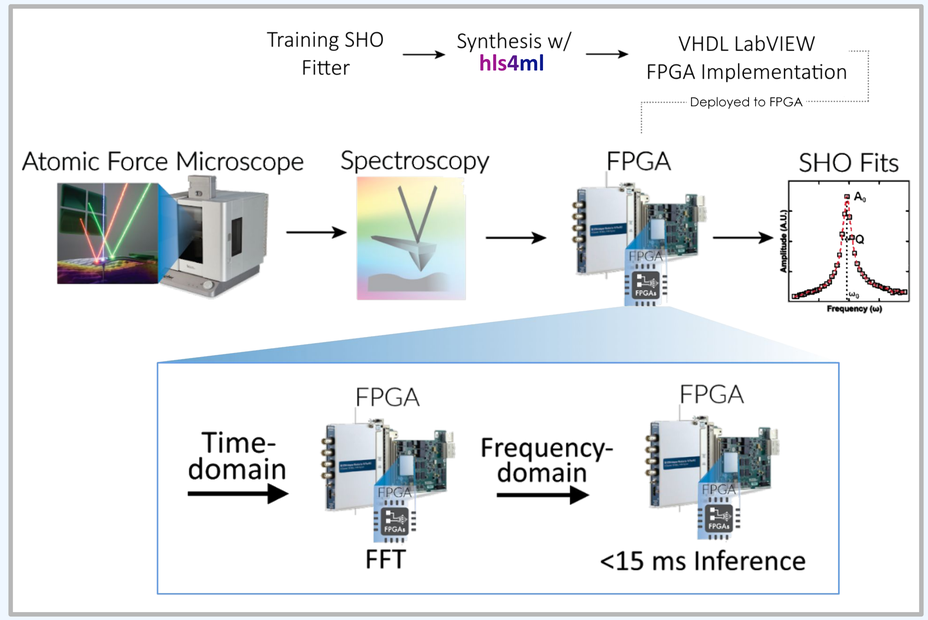
Abstract

Increased development and utilization of multimodal scanning probe microscopy (SPM) and spectroscopy techniques have led to an orders-of-magnitude increase in the volume, velocity, and variety of collected data. Scientists traditionally rely on empirical models to make predictions on complex datasets; however, this is not possible in SPM due to the low-veracity and high-velocity of the data collected. Recently, there has been an increase in the application of machine and deep learning techniques that use batching and stochastic methods to regularize statistical models in order to execute functions or aid scientific discovery and interpretation of this data. While this powerful method has been applied in a variety of imaging systems (e.g., SPM, electron microscopy, etc.), simplistic analysis alone takes on the order of weeks to months. Here, we will develop an implementation that uses cantilever resonances acquired in BEPS to conduct real-time prediction of the simple harmonic oscillator (SHO) fit.

Methods

- Computational resources are brought as close as possible to data acquisition source to conduct SHO fits in real-time with negligible overhead
- Fast fourier transform performed on second FPGA
- HLS4ML tool utilized to prune and build an IP Block in a Hardware Description Language for FPGA deployment
- National Instruments PXI-platform is leveraged, equipped with two Xilinx FPGAs to deploy pruned and quantized SHO fitter neural network
- System is benchmarked for real-time analysis of band excitation piezoresponse spectroscopy methods



Field-Programmable Gate Arrays

- Composed of a series of reconfigurable logic blocks enabling greater flexibility than NPUs, GPUs, and CPUs
- Hardware description language used to describe digital logic circuit to implement
- Entirely independent from CPU management
- Parallel processing capabilities allow for near real-time inference
- Non-volatility allows for lower power consumption
- High level synthesis allows for use of a high-level language (C/C++) for hardware logic design

Progress/Results

- Test pipeline fully operational with arbitrary waveform generator and oscilloscope
- SHO fitter NN and FFT use <30% of FPGA resources
- Tests on sample data with current pipeline indicate latencies on the order of microseconds

Conclusion

- Proof of concept for use of FPGAs for real-time machine learning in scanning probe microscopy
- Foundation has been provided for deploying on-sensor neural networks using reconfiguring hardware for real-time analysis and control of materials imaging systems

Future Work

- Create pipeline interface with atomic force microscope rather than signal generator
- Streamline this pipeline further by keeping all functions on single FPGA
- Build streamlined LabVIEW interface for pipeline control
- Apply this method to additional scanning probe microscopy and spectroscopy techniques

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Acknowledgement(s):
David and Lorraine Freed Undergraduate Research Symposium, Lehigh University
Alibek Kaliyev, Andrew F. Zheng, FJ. Olugbodi, Nhan V. Tran, Rama K. Vasudevan, Stephen Jesse, Philip Harris