Products Used: PXI, NI LabVIEW™ 7 Express, LabVIEW 7 Real-Time Module, LabVIEW 7 FPGA Module, and PXI-7831R

Building High-Precision Control Systems with LabVIEW 7 Express

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The Challenge: Developing a high-performance, compact, and modern control system for a scanning probe microscope.

The Solution: Using National Instruments PXI platform, LabVIEW 7 Express, LabVIEW 7 Real-Time Module, LabVIEW 7 FPGA Module, and PXI-7831R reconfigurable I/O boards to implement a fully digital, modular control system that is easy to use.

Improving Control Systems for Scanning Probe Microscopes

At Nanonis, we have developed a control system for scanning probe microscopes (SPM) with a new approach. Based on our experience in constructing and using SPMs at The University of Basel and The Swiss Federal Institute of Technology in Zurich, we believe that the software provided with scanning probe systems is usually difficult to use and lacks the flexibility that an industry-standard system requires. Hardware for SPM control systems typically uses several components with mixed analog and digital circuitry and takes up an entire rack, which is several feet tall. We wanted an easier, more flexible way to build a control system and provide an intuitive user interface. To achieve this, we moved to a fully digital system and implemented all the system functionality in software.

We reduced our cost of the PLL by $20,000, and our LabVIEW 7 FPGA system achieved higher performance than any traditional setup with external components.

Principle of High-Precision Scanning Probe Microscopy

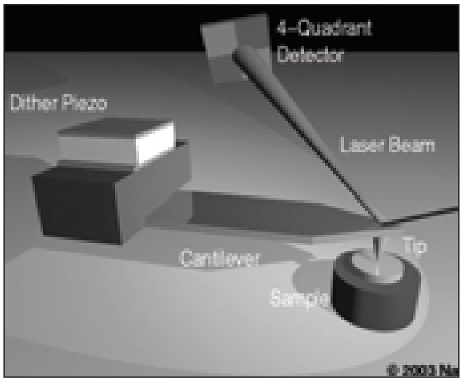
Atomic force microscopes are custom tools used in fields with an interest in surface properties at nanoscopic scales. By scanning a sharp tip over the sample, users can record the topography of the surface. These microscopes provide such precision that users can see individual atoms. SPM is a broader term describing other, more sophisticated methods, including the registration of magnetic signals and electric or mechanical properties such as friction.

Users commonly perform these methods in the dynamic mode – the tip oscillates above the surface, and any force between tip and surface influences the oscillation parameters, such as frequency and Q-factor. Upon detection of such a change, a feedback loop adjusts the tip-sample distance to maintain a certain tip-sample interaction, also known as noncontact mode. This feedback must be very agile. The distance and speed at which a tip scans over the surface in an experiment that resolves individual atoms is comparable to a jumbo jet flying at full speed at a height of 1 mm over the Earth's surface.

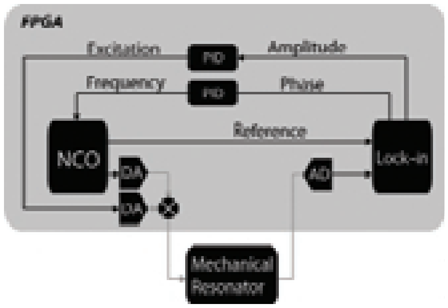
Optimizing Control System Speed

With the recent advances in microelectronics technology, we now can implement fully digital systems. For our hardware platform, we chose PXI, an open standard of industrial PCs for measurement and control applications. We implemented the time-critical control algorithms with the LabVIEW 7 Real-Time Module running on a 1.26 GHz CPU in the PXI chassis. These algorithms include the raster scan generators, the tip-sample distance controller, the data acquisition tasks, and some further auxiliary feedback controllers that must adhere to tight timing requirements and run under a real-time operating system. The user interface for the SPM controller, which we also programmed in LabVIEW 7 Express, runs on a remote machine connected using an Ethernet cable.

In addition to configuring the I/O operations, we also used the LabVIEW 7 FPGA Module to configure algorithms that needed to operate in the megahertz range. Using the LabVIEW 7 FPGA Module, we developed algorithms for implementation in hardware simply by writing LabVIEW code.



We measured the deflection of the cantilever with a laser beam and a four quadrant photo detector.



The block diagram of the PLL implemented on the FPGA illustrates the Numerical Controlled Oscillator that generates the reference and the excitation signal for the high-Q mechanical resonator. A lock-in detects phase and amplitude of the resonantor's response signal. Two PID controllers track the resonance frequency and maintain the oscillation at a constant amplitude.

Programmable hardware delivers high speed, determinism, and true parallelism. LabVIEW code looks very similar to signal flow in hardware, so it is logical to use it to describe programmable hardware and download it to the chip.

Because we programmed the controllers in LabVIEW, we could easily shift them from the real-time engine to the FPGA. This helps us optimize the speed of our controllers by using an FPGA for the fastest and most time-critical demands.

Building and Testing a Digital Phase-Locked Loop on the FPGA

With our LabVIEW-based system, we built and tested a phase-locked loop (PLL) on the PXI-7831R reconfigurable I/O board. In our first implementation, we ran the proportional integral derivative (PID) controllers for phase and amplitude on the real-time engine. As a result, we reached a demodulation bandwidth of up to 3 kHz. Encouraged by this result, we decided to implement the complete PLL on the FPGA.

With the onboard 16-bit analog-to-digital and digital-to-analog (A/D and D/A) converters running at 200 kS/s and a 32-bit accumulation phase register, we now can reach a demodulation bandwidth of more than 10 kHz. Though the oscillation frequency is limited to approximately 100 kHz, we are currently evaluating the use of external look-up tables and faster 14-bit A/D and D/A converters to improve this frequency. We wrote our LabVIEW code to configure the digital lines of the PXI-7831R to interface directly to the external components.

The intrinsic parallelism of LabVIEW was key to writing efficient, structured, and modular code without any knowledge of FPGA programming languages.

With the digital interfaces of the PXI-7831R, we can effortlessly extend our system capabilities. After initial tests, we are confident that we can achieve 24 MS/s with a frequency resolution of 0.1 uHz. The fully digital implementation has two main advantages. First, the high-phase accuracy is impossible with analog electronics. Second, we can adjust the demodulation bandwidth from more than 10 kHz down to the millihertz range for highest resolution.

Reducing Costs and Improving Efficiency

With the LabVIEW 7 FPGA Module, we implemented a high-performance, fully-digital PLL. The intrinsic parallelism of LabVIEW was key to writing efficient, structured, and modular code without any knowledge of FPGA programming languages, such as VHDL. By seamlessly integrating our existing real-time controller with FPGAs, we can improve our application's performance even further.

We reduced our cost of the PLL by $20,000, and our LabVIEW 7 FPGA system achieved higher performance than any traditional setup with external components. With LabVIEW, we have a unique development environment for programming the FPGA, the PXI real-time controller, and the graphical user interface.

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