Enabling Applications with PI's Breakthrough Cost-Optimized Digital Piezo Controller

Abstract

Until now, high costs have prevented most nanopositioning applications from benefiting from digital controllers-- controllers in which the digital-to-analog converter (DAC) chip is internal to the servo loop rather than external. But digital controller architectures provide many benefits, particularly in accuracy, stability and ease of setup.

PI's novel E-709 controller is the first of a revolutionary new family of cost-optimized compact digital controllers priced at a fraction of their forebears. Its advanced functionality and high performance makes it an enabler for many challenging applications in fields as diverse as microscopy, active optics, photonic alignment and nanoprobing.

Analog vs. Digital Piezo Control

Traditional (analog) nanopositioning controller designs utilize sensitive op-amp circuits (e.g., Figure 1) to implement the familiar and robust Proportional-Integral feedback-driven servo. The job of the servo is to reduce the difference between the command signal (generally a voltage generated by a DAC elsewhere in the controller or on a card in the user's PC) and the feedback signal from the position sensor embedded in the motion device.

The most sophisticated examples of this popular architecture integrate features such as:

- Sensor linearization, which improves the absolute accuracy of the motion system.
- Piezo relaxation compensation, which helps ensure crisp pull-in and stable position-hold in point-to-point operation;
- A notch filter, especially valuable in high-dynamic applications since they desensitize the servo to the mechanism's observable resonances and thereby allow higher-gain operation.

These are standard features of all PI analog servo electronics.

However, in this time-tested architecture, any change in the DAC's output will drive a position change. This is of course very desirable behavior, but if the DAC drifts or noise enters the system through its connection, the result will be position instability.

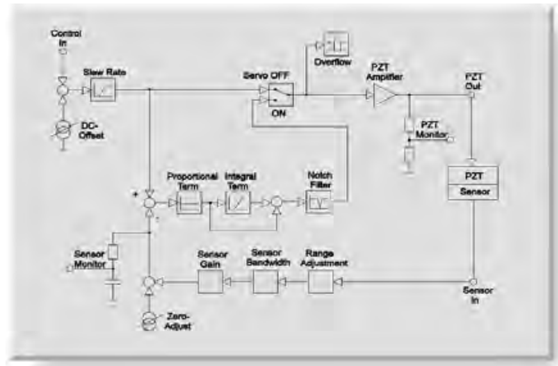

Figure 1. This advanced analog servo design integrates a notch filter for higher dynamic capabilities. The DAC which commands position is external.

By comparison, digital controllers implement their servo functionality in a DSP rather than in analog circuitry (e.g, . Figure 2):

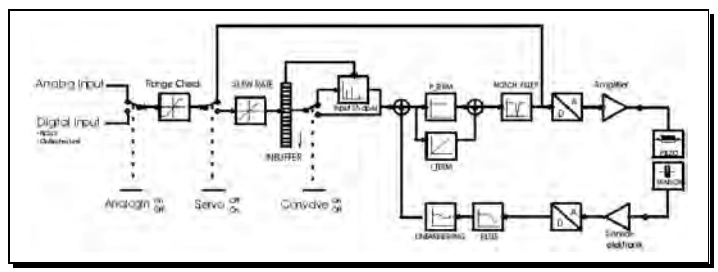

Figure 2. Digital servos place the DAC inside the servo loop and implement the feedback-driven error minimization functionality as an algorithm.

This "true digital controller" architecture allows the DAC to be integrated inside the servo loop. The best implementations provide sensor linearization up to 4th order, versus 2nd order for the finest available analog designs. And DAC drift can be virtually eliminated since the system intelligence can differentiate between desired and undesired motions, as detected by the feedback sensor. This in turn enables integration of high-bitness (but sometimes drifty) DACs for finest resolution.

(Note that many popular piezo controllers add a microprocessor and DAC on top of a conventional analog servo circuit in order to satisfy user demands for computer interfaceability using USB, RS-232 or similar industry-standard interfaces. Some suppliers misleadingly call these "digital" controllers, but their servo functionality remains analog.)

Driving a Savings Cascade

Breakthroughs in digital design have allowed commercialization, for the first time, of a digital piezo nanopositioning controller at the same price as conventional analog controllers. PI's E-709 also is the first digital piezo controller to accommodate cost-effective strain sensors for positional feedback. These sensors are based on the strain of metal foils or semiconductor films (piezoresistive sensors) and are used when space or cost limitations prevent the use of more advanced capacitive sensors, or where the requirements in terms of resolution or thermal sensitivity are not as critical. (E-709 is of course also available for use with capacitive sensors for applications requiring the utmost in resolution, accuracy, EMI resistance, bandwidth and stability.)

The nonlinearity of strain sensors can now be affordably addressed by real-time digital compensation (Figure 3), providing up to a 10X improvement in absolute accuracy.

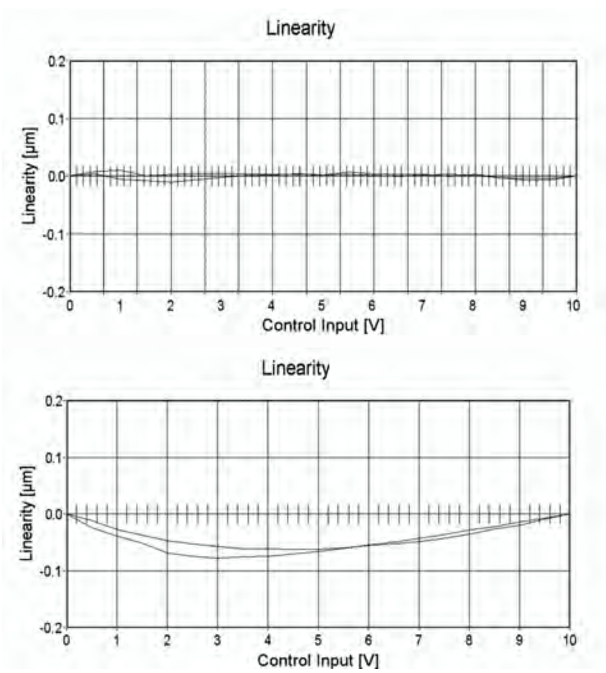

Figure 3. 4th-order sensor linearity compensation--possible with the digital controller architecture of Figure 2--provides significantly better accuracy [Top] than analog compensation can [Bottom]. Yet with E-709, there is now cost parity.

Quicker Set-Up, Greater Flexibility

Changing the gain settings of an analog piezo nanopositioning servo (and the center-frequency of its notch filter, if so equipped) generally requires physical access to trim-pots internal to the controller. These settings should be optimized for the system's load. If the configuration changes significantly, re-adjustment is good practice, but access hassles, time costs and the availability of skilled technicians sometimes prevent this. For example, a sophisticated optical apparatus with a piezo-based focusing mechanism like a PI PIFOC™ or P-601 linear actuator might be used with several microscopy objectives of significantly differing mass. In such situations, a compromise setting is traditionally used to ensure stable operation. This can impose a trade-off in responsiveness.

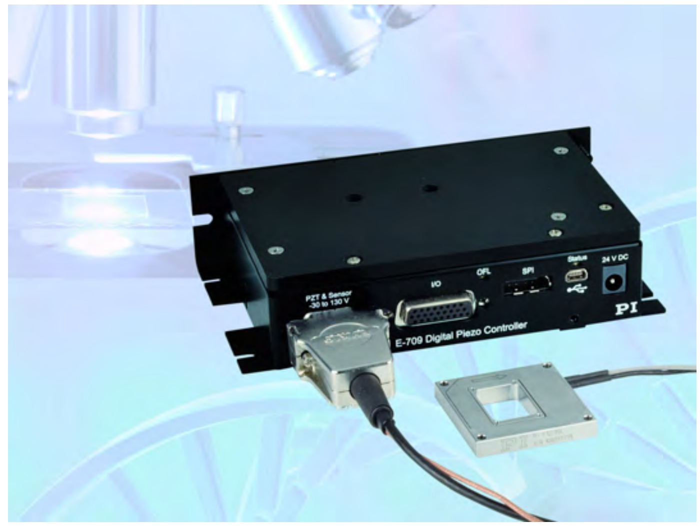

Figure 4. E-709 offers a true digital controller architecture at the price of analog controls.

By comparison, true digital controllers--including E-709--offer dynamic settings which can be easily changed remotely via software and then safely stored to the unit's flash RAM. In the microscopy example just mentioned, highly optimized dynamic parameters can be instantly downloaded to the controller at any time (for example over its USB interface) without requiring physical access to the unit or even a power-cycle.

This capability allows easy optimization for momentary application requirements in addition to configuration changes such as a new load. In OEM applications, the tool's embedded PC can instantly download preconfigured settings to customize the system's dynamical behavior to the requirements at that moment. This can be accomplished on-the-fly without pause. Figure 5, for example, shows two settings for the same load: an extremely fast motion of less than 5msec, and a gentler motion of the same amplitude. The faster, crisper motion might be desirable for time-critical applications like optical sectioning and nano-patterning, whereas the gentler motion might be more suitable for biological samples or surface-following probing applications like AFMs and nanotribology scanners.

And E-709 is unique among popularly-priced nanopositioning controllers in providing *two* notch filters, allowing high-dynamic operation in situations where motion-driven ringing in the motion device and supporting structure would otherwise be problematic.

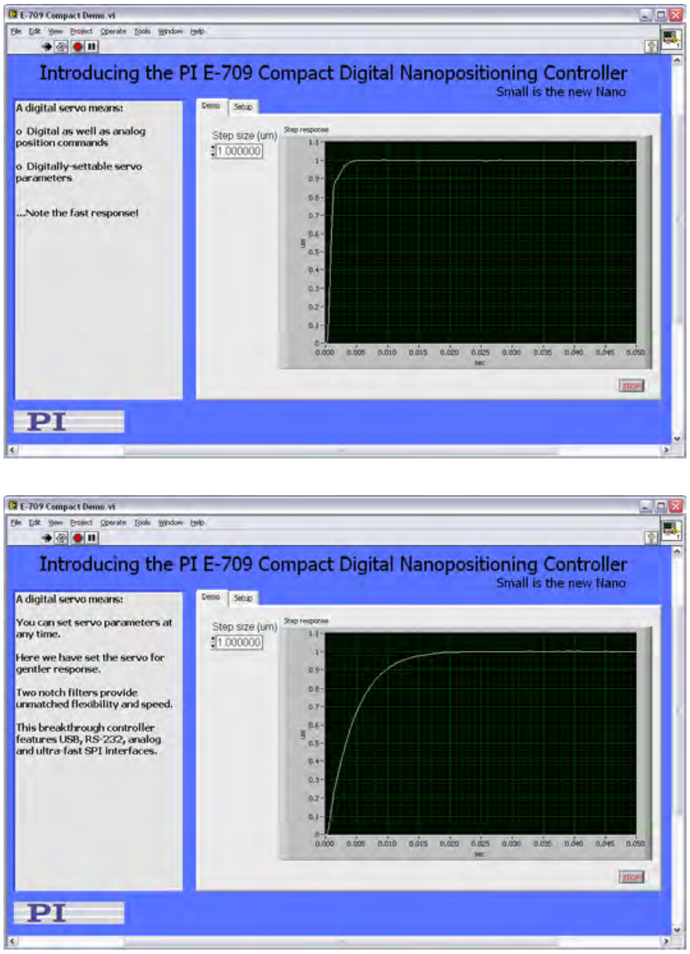

Figure 5. E-709 provides remote settability of dynamic operating parameters like servo gains via software. This allows in-field/on-the-fly optimization to accommodate varying loads and application needs. [Top] This screen-capture from a conference demonstration shows well-controlled, high-dynamic step-and-settle capability which leverages the unit's 10kHz servo rate and powerful integrated amplifier; [Bottom] shows gentler settings suitable for life-science and scanned-probe applications.

When There's A Need For Speed…

E-709 provides a wealth of interfacing capabilities. To begin, there are responsive USB and RS-232 interfaces. Built-in networking capabilities allow multiple E-709s to be daisy-chained together to create multi-axis systems which share a single interface to your computer. Waveform generation and data recording capability are also built-in and facilitate repetitive scanning and similar applications, offloading position generation from the host.

And E-709 comes standard with not one but three real-time interfaces:

- Its analog I/O interfaces, sampled/updated at the full servo cycle rate, provide easy integration with National Instruments' popular multifunction cards among other external command-signal possibilities. LabVIEW® users can even leverage this interface using PI's Analog GCS (General Command Set) library-- the industry's first plug-and-play library for analog nanopositioning.

- A standard high-speed SPI interface offers the ability to communicate with E-709 digitally using industry-standard physical protocols. You can command and interact with the system at its 10kHz servo update rate with no risk of loss or noise pickup in cabling.

- TTL I/O functionality allows triggering and synchronization with other host processes.

E-709 utilizes the same PI GCS command set as all PI controllers. This means you can write consistent code for coarse/fine applications, with the coarse positioner (like our ultra-stable M-686 microscopy stage and C-867 controller) speaking the same commands and adhering to the same protocols as the E-709 regardless of interface. Included with E-709 is a wealth of software tools ranging from an extensive LabVIEW® .llb, to an industrial-class Windows .dll and Linux .so, to PIMikroMove, PI's user-friendly graphical setup and exploration software.

Special OEM Configuratons

E-709 is also available without a case for embedded OEM applications (Figure 6). A version with only an analog interface (E-609) offers special economy for backwards-compatibility applications formerly served by analog controls.

Figure 6. E-709 is available in caseless OEM versions for embedded applications.

Conclusion

E-709 is one of the most significant products ever introduced in field of nanotechnology. By providing features and capabilities formerly reserved for controllers costing many times its price, it enables a host of research and industrial/OEM applications. OEMs will value its quick setup and remote customization capabilities combined with its power, space-saving design and high responsiveness. Even its cabling scheme is targeted to make the OEM’s job easier and more productive. Meanwhile, research users will prize its stability, performance, wealth of supporting software, interfacing flexibility and ease of use.