FPGA Data Acquisition and Control System

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Thorlabs historically are an optomechanics company and would like to provide more and better electronic, firmware and software building blocks for instruments and instrument systems. Typically, the building blocks for instrument systems include analog input and analog output to and from a digital computing engine. In the 1990's, digital signal processing (DSP) architectures from TI and Analog Devices were in favor as the computing engines. Over the past 20 years, field-programmable gate arrays (FPGA) architectures have displaced DSP, and are at the heart of many data acquisition and closed-loop control systems. The power of these systems is growing in accordance with Moore's law. Another encroachment on the DSP space has come from graphical processing units.

One advantage of FPGA hardware is flexibility, where the fabric can be reconfigured to many purposes. Examples of likely uses for the hardware in this project are lock-in amplifiers, stepper- and brushless-motor controls, interferometer scanning, and high-rate multi-channel data acquisition. The most powerful implementations of motor scanning would use adaptive filters to optimize the parameters over time, to minimize power consumption, reduce electromagnetic interference (EMI) and to reduce vibration. Two of the hottest areas in electronics are FPGA system design and adaptive computing. An excellent example of adaptive systems is deep learning. Adaptive filters open the door to self-optimizing instruments and have been known in the literature for many decades. In a sense, artificial intelligence is an adaptive filtering process.

More recently, FPGA boards have evolved to use an open standard called FPGA mezzanine connector (FMC) which provides a broad data path with high bandwidth. Analog Devices offer an extensive selection of FMC cards with multiple channels of analog-to-digital and/or digital-to-analog converters. The modularity of FMC hardware modules is very attractive for system building blocks. This project seeks to find off-the-shelf hardware and to develop complementary hardware, firmware and software components as needed. It may be beneficial to the scientific community and academic partners to open source these components. The goal of this project is to put together a working FPGA data acquisition and control system, and develop three simple programs.

A prototypical instrument in the portfolio could be a spectrometer that requires at least three channels of ADC. Those channels could be lodged on one or two FMC boards. At least one channel of 16-bit DAC, 200 kHz minimum, 1 MHz preferred and 5 MHz desirable, which could be a separate FMC-compliant board. Other systems might use off-the-shelf camera interfaces to FPGA, and require minimum DAC capability for driving a phase modulation system.

Some systems may require quite fast data acquisition, even up to six or eight channels of 14-bit, 200-megasample per second ADCs. Similar boards are available from Innovative Integration (Simi Valley, CA), but are quite expensive (~$10K). Innovative were purchased by Molex so their product portfolio now is found on the Molex.com website. Their XA-RX is an excellent example of an upper end (from the Thorlabs perspective) FPGA/ADC platform. Typically, a high-data rate system patterned after the XA-RX would provide real-time digital filtering and decimation in a modular FPGA firmware that would allow the user to trade speed for resolution. Every factor of two decrease in data rate is accompanied by an increase of 1 bit in the resolution.

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In addition to the data conversion capability and pipelining/filtering/decimation provided by the FPGA fabric, some systems will require a computing engine of at least modest capability. In some cases, it could be instantiated as a soft processor in FPGA, e.g., LEON3. In others, real-time filtering and decimation of high-volume data will be required, for which fairly deep FPGA fabric will be necessary. The obvious alternative to a soft processor is an ARM like the one on the Zynq boards. The main problem with the Zynq boards is that they have only one high pin count-FMC slot.

A small FPGA board that we used in a previous interferometer control project was about $38 in quantity. It was a joint effort by Arrow, Altera and Terasic to produce an entry level FPGA board. And turned out to be a beautiful compact computing engine for an OEM FT-IR instrument module. A piggybacked analog interface board was mounted on an expansion port. The FPGA was quite modest by the standards of five years ago, clocked at 100 MHz. It had sufficient fabric to instantiate a microprocessor for operating a servoloop and the glue logic for analog I/O similar to what is described above. There was plenty of horsepower left over for real-time digital filtering of the detector signals for transfer function compensation. The FPGA chip at the time cost more than $5 each and less than $20 each. The board may have been sold at a loss. By 2015, Arrow et al. had moved onto the MAX10 platform. Which is another acceptable starting point for us, but I don't recall that it has an FMC interface and more unlikely to have two. Other interesting offerings in this space are the Red Pitaya boards, which are surprisingly powerful and inexpensive.

Project requirements

-Literature search to understand intellectual property and technology landscape
-Interview subject matter experts to learn more about FPGA and toolchains
-Use VHDL/Verilog simulators to model example systems
-Construct a proof of concept system using off-the-shelf FPGA and FMC boards
-Implement lock-in amplifier, filtering and decimation, and closed-loop control
-Benchmark performance with representative data sets
-Keep sponsor updated with weekly progress reports, and biweekly or monthly video sessions.
-Write a comprehensive final report, outline due at end of first semester

Student requirements: EE, CompE
Budget: $2000
Faculty liaison: Dr. Feng Li