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Implementing a Highly Accurate Trigger System for In-Flight Atmospheric Research with NI CompactRIO and LabVIEW FPGA

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Industry:

Imaging Equipment, Research

Product:

CompactRIO, LabVIEW

The Challenge:

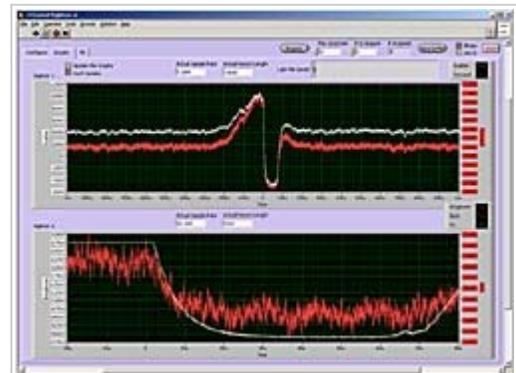
Developing a system for real-time analysis of the optical properties of atmospheric particles.

The Solution:

Using National Instruments CompactRIO and the LabVIEW FPGA Module to design a sophisticated system that helps researchers customize triggers for more accurate measurements.

The National Oceanic and Atmospheric Administration (NOAA) is developing a new instrumentation system to investigate the optical properties of atmospheric particles by measuring the scattering and absorption of particles as they pass through a laser beam. To get the most accurate measurements, the system must be triggered when the particle is in the center of the laser beam.

The laser beam has a Gaussian power distribution, so when a particle of constant velocity crosses the beam, the result is a scattered light signal with a Gaussian shape. Particles scatter different amounts of light based on their sizes and compositions, so the amplitudes and, to some extent, the widths of the Gaussian peaks vary from particle to particle. If a simple threshold is used to trigger the system, small particles cause a trigger to occur near their peaks, whereas large particles trigger early on the rising edge of the peak. Because of these inconsistencies, NOAA required a more sophisticated triggering system.



This Graph Shows the Total Scattered Light Signal Resulting from a Particle Passing Through the Laser Beam. Note the System Triggering at $t=0$.

The Importance of Precise Peak Triggering

By using CompactRIO hardware programmed with LabVIEW FPGA software, we have developed a system that can reliably perform real-time digital signal processing at very high rates to produce a trigger near the peak of the input signal regardless of particle size. The Aerosol Scatter to Extinction Ratio (ASTER) instrument is designed to measure light scatter and absorption from single atmospheric particles. The instrument draws in ambient air, which passes through a laser beam inside a cavity-ring-down system. As particles cross the laser beam, the ASTER instrument measures the resulting scattered light with a photo-multiplier tube detector. When the instrument detects scattering, it must be triggered to obtain a ring-down signal. The scattered light signal and the ring-down signal are then analyzed to determine the total light scattering, absorption, and extinction (scattering + absorption) for that particle.

To optimize this measurement, the ring-down trigger must occur when the particle is in the middle of the laser beam. Because different particles (different compositions and diameters) scatter different amounts of light, the scatter peaks can have different amplitudes and, to some extent, widths. A typical triggering system uses a threshold voltage on a comparator to trigger the system when the scattering signal exceeds a predetermined amount. The problem with this type of system is that small particles trigger the system when they are near the center of the laser, but big particles (or good scatterers) trigger the system just as they enter the edge of the laser beam.

One way to resolve this issue is to monitor the scatter signal in real time, detect the maximum of the peak, and generate a trigger pulse. Because our scatter peaks are on the order of 100 microseconds wide, a system for this type of peak triggering should be able to acquire and analyze data on a microsecond time scale. Few commercial off-the-shelf systems are capable of implementing a custom algorithm in real time at these speeds. Several years ago, we identified one commercial solution, which we used to implement a prototype peak trigger system. However, this product cost \$5,000 for hardware and required additional software tools.

Improved Accuracy with CompactRIO

More recently, National Instruments introduced CompactRIO technology. When the NI cRIO-9201 A/D module with an 800 kS/s sampling rate (for single channel operation) was made available, we realized that CompactRIO could potentially provide us with an effective peak trigger solution. The NI 9401 high-speed digital I/O module provided the second half of our requirements because it can produce digital signals with 100 ns delays. We put these two modules in a 1M gate cRIO-9101 reconfigurable embedded chassis with a cRIO-9002 embedded real-time controller, creating a compact solution for less than \$3,000.

We developed two versions, one simple and one that is more complex. The simple version includes states for detecting the presence of a peak (above a set threshold), finding the top of the peak, sending out the trigger pulse of a specified width, looking for the end of the peak, and waiting a specified delay time before starting over and looking for the next peak. The whole loop runs at a rate of 1.25 microseconds per iteration allowing for the 800 kS/s A/D conversion. Note that the A/D conversion is pipelined – we use a shift register so the main loop can act on the previous measurement while a new measurement is taken. This allows the algorithm logic to act in parallel with the A/D conversion, keeping the overall loop rate to the maximum of 800 kHz.

The algorithm for finding the peak involves storing A/D readings in a circular buffer and comparing the current reading to a previous reading acquired N points earlier. When the current reading is less than the previous reading, the top of the peak has been traversed and the signal is beginning to decline. The N point delay is kept to a minimum to trigger as close to the peak top as possible. However, N must be large enough to provide adequate noise immunity, depending on the signal-to-noise ratio of the signal being analyzed. This algorithm is conceptually similar to looking for the zero point of a numerical first derivative, with crude filtering coming from the N point delay.

Additional Triggering Features

Once we implemented our system in CompactRIO and LabVIEW FPGA, it became much easier to modify the algorithm and add new features. The more complex version includes the ability to generate timed triggers (independent of the input signal), single trigger pulses, and constant low or high outputs of the trigger line. In addition, we increased the system noise immunity by implementing three-point averaging around the current and past data points. Also, we wrote a host computer interface program to change the various parameters from within LabVIEW for Windows. This interface program, which we built in less than half an hour, is another advantage to the LabVIEW solution. With the previous system, we would have experienced great difficulty implementing a host computer interface that allowed real-time algorithm parameter alteration.

CompactRIO and LabVIEW FPGA provide a powerful solution for our custom peak-triggering requirement. The development of this solution was cheaper and faster than with previous hardware and software, and we now can add new features and functionality much more easily. In addition, CompactRIO ruggedness will prove advantageous when this experiment is eventually deployed on a high-altitude research aircraft.

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