# Achieving Productivity Gains with National Instruments LabVIEW

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NI LabVIEW is a proven integrated development environment designed for engineers and scientists developing test, control, and measurement applications. Created and optimized more than 20 years ago for engineering applications, this system design platform increases productivity. The graphical nature of LabVIEW creates intuitive, self-documenting code that saves your organization thousands of development hours and yields more results in less time.

LabVIEW can help you accomplish more by streamlining the engineering process from inception to completion. Several LabVIEW characteristics contribute to a significant gain in productivity when compared to other development software:

**Easy to Learn and Use**
- Intuitive graphical programming
- Optimized for engineers and scientists
- Fully integrated with commercial off-the-shelf (COTS) hardware

**Complete Functionality**
- Thousands of built-in functions
- Full programming language
- Completely open environment

**Modular Development**
- Reusability of code modules saves time and effort
- High-level diagram offers clear system functionality
- Easy debugging, testing, and integration with high-level systems

**Supportive Community**
- In-depth education courses available
- Hundreds of textbooks
- Certification opportunities

**EASY TO LEARN AND USE**
Over the past 20 years, NI and LabVIEW users have introduced and improved a tremendous collection of libraries and structures for the graphical language. LabVIEW also offers the following key features that set the language apart.

**Data Flow**
LabVIEW is a development environment based on a graphical programming language. This approach to developing applications significantly reduces the learning curve because graphical representations are more intuitive design notations than text-based code. You can access the tools and functions through interactive palettes, dialogs, menus, and hundreds of function blocks, known as VIs (virtual instruments). You can drag and drop these VIs onto a diagram to define the behavior of your applications. This point-and-click approach shortens the time it takes to get from initial setup to a final solution.
You define the flow of data and the execution of the application through a concept known as dataflow programming. Data is passed from one VI to the next, eventually defining the execution order and functionality of the entire application. Data flow is comparable to reading a flow chart. Block diagrams consist of functions, which are represented by icons, wires that connect these icons, and structures that control execution logic. Data flows from one function to the next, and the functions and VIs do not execute until all terminals or wire connections have data available for processing (see Figure 1).

**COMPLETE FUNCTIONALITY**

**Multithreading and Parallelism**

LabVIEW eliminates much of the tedious low-level coding, such as memory management (variable declarations and so on), required by traditional languages. LabVIEW also has intuitive graphical structures for common programming structures in text-based languages. For example, while loops and for loops are represented as boxes, and the loop iterations execute the code that is represented graphically within the boxes.

LabVIEW is also designed as a parallel language, which means that the graphical language constructs naturally represent the simple concept of parallel execution. This simple concept, however, can be very difficult to implement in text-based languages that traditionally execute sequentially. With LabVIEW, you can develop parallel-executing applications simply by placing multiple loop structures in their code. A graphical representation of two independent loops, as shown in Figure 2, executes independently in parallel as well. This feature is an incredibly simple way to represent a complex coding challenge. Parallel execution can be critical in automated test systems where multiple units under test (UUTs) may be tested; in real-time control systems where time-critical loops are acquiring data and controlling outputs while data is communicated to the host; or in embedded applications where multiple types of inputs must be responded to in a deterministic fashion.

![Figure 1. Sample LabVIEW Block Diagram](image)

When developing parallel-execution applications, you must have tools for setting the priority of different operations. For example, the I/O portion of the program many times is more critical than the user interface. With LabVIEW, you can configure thread priorities at the OS level using intuitive dialogs and settings.

**Interactive Execution and Debugging**

LabVIEW is interactive as well, which means you can easily experiment with different functions in the libraries during development. This is particularly important when programming I/O resources. For example, when configuring a data acquisition operation, you can simply select an acquisition function from the built-in data acquisition library and run it independently. This operation retrieves data from the data acquisition board in the computer, so you can inspect the data to see if the operation is appropriate for the program. If so, simply drop the VI into the program and continue. If not, try another VI in the library until you find the right one.

Debugging in LabVIEW is also interactive, and it features all of the common capabilities of traditional programming tools, such as breakpoints, step over/into/out of, and more. With LabVIEW debugging, you can visualize data anywhere within the
algorithms you develop without degrading the performance of the algorithm or requiring complex programming. For example, if you are developing a complex signal processing algorithm in LabVIEW, you can easily drop graph controls on the front panel and wire them to the data path to view the data at that point. Or, you can connect a control, such as a knob or slide control, to vary the input parameter values of the algorithm. This ability to interactively peek and poke at data and parameter values makes debugging faster and more intuitive.

**High-Level Application-Specific Development Tools**

In addition to being easy to learn and use, LabVIEW delivers the performance needed for advanced applications. The compiled language executes at speeds equal to traditional compiled text languages.

However, for many applications, there may be higher-level ways to represent a solution (or part of a solution) than using low-level code. LabVIEW has a growing collection of higher-level tools targeted at solving particular types of constructs much faster. With most of these tools, you can work at a higher conceptual level to develop a solution, which is then converted into low-level LabVIEW code to deliver all of the openness, flexibility, and performance of the compiled LabVIEW language. These development tools include:

- **Control block diagrams** – for designing linear, nonlinear, discrete, and continuous control systems. You can develop them using traditional control concepts such as transfer function blocks, integrators, differentiators, and feedback loops.

- **State charts** – for defining multiple states and the transition logic between them using a graphical state chart representation.

- **Formula/script nodes** – for implementing complex formulas in text or importing your algorithms defined in traditional math tools such as C code, The MathWorks, Inc. MATLAB® software, or NI MATRIXx design and development tools.

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*Figure 3. LabVIEW Simulation Diagram*

*Figure 4. Statechart Module*

*Figure 5. Formula Node*
• User interface programming – for managing complex user interfaces in graphical code with the event structure in LabVIEW.

By combining these high-level concepts to build specific applications with the flexibility of the LabVIEW language, you get the best of both approaches in one platform.

INTEGRATED I/O CAPABILITIES

LabVIEW is well-known as a data acquisition and instrument control tool. These capabilities built into the language are pervasive throughout the environment. The language itself naturally manages continuous, looping data acquisition operations and delivers significant time savings to developers. The tool provides functionality throughout with an engineering and scientific perspective in the following areas:

I/O Libraries
• Plug-in data acquisition devices
• Modular instruments
• Stand-alone instruments (GPIB, RS232, etc)
• Vision/image acquisition
• Motion control

Analysis
• Signal processing
• Sound and vibration
• Order analysis (rotational machinery analysis)
• Spectral measurements and modulation

Display
• Graphs, strip charts
• Knobs, meters, gauges
• Pumps, valves, pipes
• Thermometers, tanks

The out-of-the-box integration of these different types of engineering-specific controls and libraries cannot be underestimated.
MODULAR DEVELOPMENT
LabVIEW naturally encourages modularity and reuse of code. You can create VIs, or code modules, with a graphical front panel that displays the inputs and outputs of the functional code as graphical controls and indicators. The graphical controls and indicators (knobs, meters, gauges, graph displays, strip charts, and so on) represent data types for the data passing into and out of the functions. You can easily plug these VIs into others to create modular, hierarchical code that you can use to gradually build up complex systems one component at a time and reuse common operations as subVIs along the way. There is no limit to the number of layers or subVIs used in an application, so the language scales with the complexity required for the application.

SUPPORTIVE COMMUNITY
Because the development team can never imagine or keep up with all of the innovative ideas of LabVIEW customers, there is a very strong community surrounding and supporting LabVIEW. Given the number of local user groups, online forums, blogs, and third-party tools, there is probably a LabVIEW solution or tip available to help solve any application challenge.

In addition to community resources, National Instruments and partners provide formal training and certification courses to ensure your success. Formal training, often the fastest, most certain route to productivity with NI tools and successful application development, helps you:
• Save development time and reduce maintenance costs
• Increase performance and reuse of your code
• Shorten your learning curve

Training is available as instructor-led on-site courses, online training, self-paced training, and customer courses.

STRONG CUSTOMER BASE
Every day LabVIEW customers find new and exciting ways to use NI products. At ni.com/solutions, find customer-written case studies demonstrating just some of the examples of how customers are harnessing the power of graphical system design to innovate in virtually every industry and across many applications.

Boeing Tests Noise Reduction Technologies Using LabVIEW and PXI
Boeing is measuring the effectiveness of noise-reducing technologies for its aircraft using LabVIEW and PXI. Its test facility is outfitted with more than 600 ground-based microphones to acquire the noise from a 777 as it flies overhead. The data is then analyzed to get an acoustical image of the airplane so that engineers can see where improvements can be made.
Microsoft Uses LabVIEW and Modular Instruments to Develop Test System for Xbox 360 Controllers
Microsoft developed the test system for the Xbox 360 controllers based on LabVIEW and PXI modular instruments, resulting in a test system that operates twice as fast than the previous-generation system.

Improving Retinal Disease Treatment with LabVIEW FPGA and Intelligent DAQ
OptiMedica Corporation specializes in helping ophthalmologists treat retinal disease and has used the power of graphical system design to develop PASCAL. PASCAL uses LabVIEW FPGA and NI intelligent data acquisition (DAQ) to reduce treatment time as well as patient discomfort.

NI CompactRIO and LabVIEW Help Nexans Spider Level Seabed for Oil and Gas Exploration
Nexans uses LabVIEW and CompactRIO to control hydraulic systems on the Nexans Spider, a remote operated vehicle (ROV) used to level the seabed and clear the way for a 1,200 km undersea pipeline.

CONCLUSION
Combining these elements means that LabVIEW can help you complete more projects. By using an intuitive tool optimized for your specific engineering challenge, you spend less time on the tool and devote more time to innovating.
The Challenge: Developing advanced fault-detection diagnostic and servicing tools to maximize production line performance and reduce equipment downtime.

The Solution: Using LabVIEW® and off-the-shelf hardware components from National Instruments to design a diagnostic tool for packaging machinery.

Machine malfunctions, slowdowns, and other inefficiencies are problems that plague all production lines. The speed of these machines makes it difficult to isolate problems and the origins of machine jams and other unexpected stoppages are often misinterpreted by line operators and can go unrecorded and uncharacterized. One problem or malfunction leads to another in a multi-stage system, creating a domino effect and making the original issue difficult to identify. Additionally, problems may be irregular or develop over a long period of time, making it hard to determine what went wrong.

To solve this problem, researchers at the world’s leading food and beverage company developed the Remote Observer of Manufacturing Equipment (ROME), a solution that actually reconstructs the events that lead to system failure. Similar to the black box flight recorders used on aircraft, ROME is a diagnostic tool designed to support food and beverage machinery. It combines signal-data and video using multiple cameras and provides an integrated time-stamped data bundle.

ROME is the result of our Advanced Manufacturing Systems (AMS) approach developed by researchers to address the problem of reduced equipment efficiency by creating advanced diagnostic and servicing tools to maximize line performance and reduce downtime. ROME provides all the necessary instruments for collecting adequate video, digital, and analog data as well as the tools required for analyzing this data in order to diagnose serious problems such as high-speed equipment stoppages, slowdowns, or production-line inefficiencies.

The ROME system includes at least two high-resolution color video cameras that are scene specific and acquire data at 30 to 60 frames per second. ROME can accept up to 265 digital inputs (optically insulated input voltage from five to 250 VDC/VAC). ROME also accepts 16 analog signals of 4-20mA (12-bit resolution). The system has a real-time clock and is designed with no outputs to eliminate the possibility of influencing the operation of a machine's control system.

High-speed frame grabbers give ROME the power to capture up to 10 seconds of video once a digital trigger, or fault, is detected for post-analysis. ROME can continuously capture data for up to 80 independent 10-second “events” with a 10 second buffer, meaning at any given time the previous 10 seconds of data is preserved. Also, ROME can monitor machinery equipped with any type/brand of programmable logic controller (PLC). The original ROME system has been upgraded to the ROME-2. Both applications were developed by Handeportal Systems.

A prototype of ROME-2 was developed, tested in a laboratory, and installed on
actual production lines. This system continues to provide benefit to the various production lines and is now considered a mainstream fault-detection and fault-diagnostic tool that is increasing overall equipment efficiency.

For this system we chose off-the-shelf hardware components from National Instruments and were able to develop the prototype system for about $20,000. The original development was done by consultants with expertise specifically in real-time programming of data-acquisition and vision-equipped robotics. Since a physical interface can be disruptive to the production line, a custom interface was developed for ROME-2. In order to provide a noninvasive mechanism for ROME, the data-acquisition signals are transmitted in a multiplexed manner to detect high-speed digital triggers from high-resolution LEDs on plant control equipment.

Finally, the addition of a FireWire® hard-drive supports a hot-swappable storage resource that can archive numerous sequences of fault triggers and allows the plant floor staff to hot-swap the drive and perform data-analysis and fault detection. The overall plan for this tool is to provide significant cost-savings by reducing down-time and supporting the concept of predictive maintenance.

The National Instruments LabVIEW graphical system design environment was also a key component to this application because it allowed for rapid development of the real-time detection and analysis platform. Because NI LabVIEW can easily target various operating systems, we were able to prototype within the Microsoft Windows environment and deploy on the real-time OS within NI PXI embedded controllers. COTS hardware from National Instruments offered standards-based hardware that supported deployment in ruggedized manufacturing environments. Moreover, the technical support provided by field engineers and product experts was helpful in resolving problems specific to this application.

Post Processing

Meticulous post-processing of the events captured by ROME is handled by an X86 Microsoft .NET application based program called DataViewer. Its user-friendly GUI permits step-by-step analysis of video frames synchronized with signal data from the event data-buffer.

Multiple resolutions are available and users can define a set of signals of interest to view in the time window. This application is distributed to all analysts at a particular plant. While users can utilize off-line analysis to understand why a machine is not operating at full capability under certain conditions or operates differently at different time periods, they can also use on-line collection to make comparisons between a baseline system running at optimal performance and one that indicates faulty behavior. Such reference-based, or finger-print, comparisons provide an efficient means of predicting faults that could otherwise be quite difficult to determine.

For more information, contact:
Alok Sarwal
Handeportal Systems
12561 Swansea Drive
Parker, Colorado
Tel: 303-683-2509
E-mail: a_sarwal@msn.com

*FireWire* is a trademark of Apple Computer, Inc., registered in the U.S. and other countries.
Korry Electronics is harnessing the power of virtual instrumentation to design control panels for the Boeing 787 Dreamliner.

**The Challenge:** Developing a CAN bus test system to interact with intelligent avionics control panels and communicate switches, control panel lighting functions, and report panel status data such as part number and serial number.

**The Solution:** Using National Instruments LabVIEW for rapid development time, NI PXI-CAN cards with ready-to-run NI LabVIEW driver libraries, and NI TestStand for production test sequencing and reporting.

At Korry Electronics, we needed a solution to test a family of control panels for the new Boeing 787 aircraft flight deck. We are working to meet an aggressive Boeing project schedule that is 16 months shorter than any previous Boeing airplane development project. The 787 systems, which feature an open architecture at the core, will be more simplified compared to existing airplanes and will offer increased functionality. One example is the health monitoring systems the airplane will use to self-monitor and report maintenance requirements to ground-based computer systems.

In the aerospace industry, control panel suppliers are seeking a low-cost replacement to the ARINC-429 bus, and are migrating toward a CAN-based solution due to higher bus speed and data payload requirements. We needed a way to communicate with and monitor multiple CAN buses on each unit under test for correct CAN data, and to transmit control data to adjust lighting and set other panel functions. We chose National Instruments LabVIEW, which features compatibility with NI PXI-CAN cards and ready-to-run NI LabVIEW driver libraries, to achieve the rapid development time the project requires.

The control panels transmit discrete digital switch data, and a unique data word represents each switch position. For control panels that contain rotary potentiometers and encoders, the data values increase and decrease depending on the direction of rotation. CAN data words set all the control panel lighting levels and the control panel indicators with on/off commands. For production testing, we tested one control panel at a time. During qualification testing, we configured the NI PXI test system to allow for simultaneous testing of multiple control panels at the same time via CAN buses.

**Hardware and System Architecture**

The test system hardware consists of two NI PXI-8461/2 CAN interfaces installed in a PXI mainframe along with multiple relay boards, power supplies, and a DMM card. The system can monitor up to four individual CAN buses at once and test 100 percent discrete I/O and DC power functions. Each control panel transmits a unique CAN bus ID that is identified by using LabVIEW routines. The test system can thereby emulate the function of the CAN bus data concentrator used on the aircraft.
The test software, which we wrote entirely in LabVIEW, integrates NI-CAN drivers in custom subroutines to initialize CAN ports for specific CAN addresses and perform CAN data frame read functions. We created additional subroutines to compare the received data to the expected data frames. For each CAN bus session, the CAN and object network interfaces are opened and configured, followed by the CAN read operations and then session closure. For lighting functions, specific CAN data is transmitted to the control panels. We wrote additional programs to monitor switch positions in real time, and others to monitor CAN data from each panel and write time-stamped data to a log file for any changes detected.

During production test, we use NI TestStand to control test sequencing and test results reporting. The first step is to instruct the operator to set each switch, rotary potentiometer, and encoder to a specific position. A test software panel graphically illustrates each switch position of the unit under test. The second step is to create an HTML log file of any data discrepancies noted during test. For switch panel indicators, we use a variety of test scenarios. One scenario illuminates all of the indicators on the control panel and has the operator visually verify that the correct indicators are lit up. We created subroutines to send a CAN message to the control panels for lighting, which can be controlled in real time by transmitting CAN data to control brightness levels from no light to full brightness levels using a LabVIEW dial. In another scenario, the operator clicks on the test software panel, which individually commands each indicator to light up by transmitting a CAN message to the control panel.

**Conclusion and Outlook**

We are successfully developing a family of complex CAN-based control panels for use on the Boeing 787 airplane by utilizing National Instruments software and hardware. We were able to quickly develop new test software using LabVIEW with almost unlimited control of CAN bus data. The PXI-CAN cards have proven easy to configure and highly reliable in operation. We plan on developing test equipment for future programs with short deadlines using National Instruments test hardware and software for many years to come.

For more information, contact:
Allen Cutler
Korry Electronics
Tel: (206) 281-1300
E-mail: allen.cutler@korry.com
Applied Technologies’ wind profiler is designed to give a quick, side-by-side comparison of data compiled from NOAA and ATI source data.

The Challenge: Developing a radar wind-profiler system capable of on-site operational support for aerostat systems.

The Solution: Using National Instruments LabVIEW to design an intuitive graphical interface and a sophisticated software radio acquisition system.

At Applied Technologies, we have designed, tested, and installed a new type of radar wind-profiler system in response to the need for a system capable of on-site operational support for an aerostat system.

An aerostat – a large, tethered airship used for carrying aloft surveillance radars or other electronics – normally flies between 3,500 and 5,000 meters above the ground. Our new wind-profiler system is a modern, pulse Doppler radar system that operates at 449 MHz. It is unique in that the antenna uses a Yagi element array and can point anywhere within a cone above the radar up to 25 degrees off the vertical axis. By continuously and actively steering the antenna beam, we can avoid pointing the main beam at the aerostat, thus preventing any significant illumination of the aerostat payload, greatly reducing interference.

Other important system features include a digital intermediate-frequency (IF) receiver, advanced signal detection (ASD) algorithms, and complete health and status monitoring. With the digital IF, the receiver is greatly simplified and highly reliable. The ASD software utilizes multiple peak-picking and identification routines and time-height continuity analysis to screen out radio-frequency interference (RFI), such as birds and other non-atmospheric backscatter signatures. The ASD routines also allow for shorter averaging times and higher data update rates than traditional processing.

Using National Instruments LabVIEW, we were able to complete the application in only 18 months with only two programmers, and with a significant number of intuitive graphics for both diagnostics and normal data acquisition. We can view all facets of subsystem control, communications, and data flow in real time. We can also set up most displays to accumulate data for 24 hours or more and to play back data, so we can easily see any trends in atmospheric data or system monitoring. With long raw time series, we can achieve fast Fourier transform (FFT) lengths of 64k or more (used to help filter interference such as RFI). The many varied features available in NI LabVIEW – from communications to easy, low-level debugging to comprehensive user interface displays – let us write a very sophisticated control and display program in a relatively short time.

The data system software we developed using LabVIEW is composed of two main programs. The first is the dwell module, which controls the radar hardware and performs initial data processing. The second is the advanced signal detection (ASD) module, which is a new implementation of published techniques developed

“Using LabVIEW, we were able to design the ATI profiler displays for easy “quick looks” by the aerostat flight directors, and build in several new features to aid the operators, such as histogram-like wind plotting.”
by National Oceanic and Atmospheric Administration researchers over the last several years. The dwell module acquires the data and sends clipped spectra to the ASD module for every acquisition cycle. The ASD module then performs multipeak picking using time-height continuity analysis with built-in automatic quality control (QC) to reduce outliers and erroneous data due to birds, radio frequency interference, and other factors.

Data quality is extremely important to aerostat operations, as is minimizing the total averaging time (preferably to under 10 minutes) and maximizing the update rate (every two minutes, at least). Using the ASD module, we can achieve short averaging and continuously acquire rapidly updated data on wind and turbulence, alerting operators of possible meteorological threats.

With the unique full-beam steering feature, the radar uses aerostat position information and correspondingly moves the main beam away. The dwell software accomplishes this automatically and slowly, so that the time-height QC algorithms can continue to track the wind spectra signal. Fortunately, the aerostat also moves slowly, so very little data is lost during normal flight operations. In addition to the aerostat avoidance through the use of beam steering, the system also uses a programmable sensitivity time control (STC) that attenuates the receiver’s front end and tracks the aerostat radial distance to further prevent saturation of the wind profiler receiver, particularly when the aerostat is near the ground. The STC also prevents receiver saturation in the first few gates caused by close-in ground clutter.

The radar hardware monitor (RHM) is composed of a simple and reliable microprocessor and various interface boards for sampling the DC power, RF power, and digital status bits. The RHM fully monitors the radar system to detect equipment failures, and points the antenna via commands received from the dwell software. It runs independently of the dwell computer, but provides status data to the dwell software for review by the operators. The data is displayed in real time in the dwell software and on an LCD on the RHM chassis. Values outside of specification are recorded, and the radar can be shut down if a faulty subsystem is detected.

The system was designed for ease of maintenance, with most maintenance connections (and fuses) on the front of the rack-mounted equipment, allowing for quick value checks with a volt meter or oscilloscope without having to remove equipment from the rack or make connections on the back, where the software cannot be seen or controlled. Surge suppression is also built into virtually all external interfaces.

The new software makes extensive use of graphics displays to show the data in its various states, to help the operators determine the validity of the data and the health of the radar system. Using LabVIEW, we were able to design the ATI profiler displays for easy “quick looks” by the aerostat flight directors, and build in several new features to aid the operators, such as histogram-like wind plotting.

Designed to address the needs of an operational aerostat site, these new design features also facilitate more traditional uses, such as research and weather forecasting. These new capabilities do not significantly affect the relative price of the wind-profiler system – the new system features the same data height capturability – yet they enhance the overall reliability, ease of use, ease of maintenance, and data quality.

For more information, contact:
Scott McLaughlin
Applied Technologies, Inc.
1120 Delaware Ave.
Longmont, CO 80501
Tel: (303) 684-8722
Fax: (303) 684-8773
E-mail: scott@apptech.com

Applied Technologies’ wind profiler is designed to give a quick, side-by-side comparison of data compiled from NOAA and ATI source data.
The cRIO-9102 chassis with fully-loaded cRIO-9002 real-time embedded controller is highly accurate and reliable.

**The Challenge:** Implementing a control and interlock system for a custom electron beam deposition system for use in an advanced semiconductor materials research laboratory.

**The Solution:** Creating a highly reliable control system with an intuitive user interface while minimizing development time using National Instruments LabVIEW and CompactRIO.

As part of the Advanced Materials Research and Development Program at Oregon State University, our group, led by Dr. John Wager, performs cutting-edge research in thin-film semiconductor development. Our recent projects have included the development of transparent thin-film transistors, transparent circuits, and high-performance thin-film based solar cells.

Our semiconductor processing clean room is an integral part of our development program. The room contains tools such as an RF magnetron sputter system, an ion beam deposition system, thermal evaporators, a chemical vapor deposition (CVD) system, and an electron beam deposition system, as well as other processing-related tools. The electron beam deposition system is a useful development tool because it requires a relatively small amount of material (targets) to be deposited and yields high deposition rates.

In late 2004, we needed to replace our aging electron beam deposition system, which had been in use since the early 1980s. We designed a new electron beam deposition system that implements advanced features such as a rasterable electron beam, substrate heating capable of temperatures up to 600°C, and base pressures approaching $1 \times 10^{-7}$ Torr.

**LabVIEW and CompactRIO Reduce Development Time**

Previous deposition system control systems were built around microcontrollers and desktop computers with digital I/O cards and were programmed in Visual Basic. In planning our new electron beam deposition system, we decided to establish hardware and software standards that would make integration into future processing tools possible.

The CompactRIO programmable automation controller (PAC) was an attractive solution for the core control system because of its reconfigurable nature and the ease of programming using LabVIEW. CompactRIO offered the combination of control algorithm hardware implementation in the form of an FPGA and reliable processing with an embedded real-time controller. With the CompactRIO platform, we can accurately interlock and read electron beam conditions in real-time. We also implemented a control program on the host PC so users can access database functionality and real-time system information.

“The result of the project is a control and interlock system that far exceeds what was previously possible. With the system based on CompactRIO, we have a highly reliable, robust, and extremely fast control system.”
Using CompactRIO, we can code completely in LabVIEW, which is much easier than any other platforms we have used. The real-time controller in CompactRIO lets us run our applications in a time-critical manner and provides a high degree of reliability and protection, which is important when monitoring and controlling expensive processing equipment.

We developed our control logic entirely in LabVIEW using the LabVIEW FPGA Module. Since LabVIEW was already the standard for our test and measurement applications, coding with the FPGA module in LabVIEW was very straightforward. We wrote, tested, and debugged the FPGA and host code in about one working month – much less time than previous systems that were coded in assembly language or Visual Basic.

The result of the project is a control and interlock system that far exceeds what was previously possible. With the system based on CompactRIO, we have a highly reliable, robust, and extremely fast control system. One of the most appealing features of the LabVIEW approach is that we can decide to add functionality, such as PID substrate heat control, with the addition of a parallel while loop and a small amount of code. The new user interface provides information and controls that were not available with the previous system, and we were able to incorporate advanced features such as e-mail notification and database logging to Microsoft Access into the host program.

For more information, contact:
Chris Tasker
Oregon State University, Dept of Electrical and Computer Engineering
3031 Kelley Engineering Center
Corvallis, OR 97331
Tel: (541) 737-2976
Fax: (541) 737-1300
E-mail: chris@eecs.oregonstate.edu

The cRIO-9102 chassis with fully-loaded cRIO-9002 real-time embedded controller is highly accurate and reliable.
PCI-Based Control System for Laser Etching an Intraocular Lens

The Challenge: Developing a high-resolution, deep ultraviolet (UV) laser etching system to produce highly complex, custom acrylic or silicone intraocular lenses for implantation in the human eye after cataract removal or for refractive correction, allowing the physician to better fit patients.

The Solution: Creating a high-speed, mixed-signal PCI data acquisition and control system that interfaces to an ophthalmology-based topographic wavefront measurement system, a UV-enabled digital micromirror device, and a deep UV laser system, all through National Instruments LabVIEW software and PCI hardware.

The human visual system is complex, consisting of the cornea, the lens, and the retina. Over time, the lens can form cataracts, preventing it from focusing light on the retina, resulting in vision loss. Surgeons correct cataracts by removing the lens and inserting an artificial lens (IOL). Current methods for manufacturing IOLs are limited to producing simple refractions – spherical and cylindrical. Physicians can now measure higher-order aberrations of the eye, but cannot correct them with currently available manufactured products. It would be advantageous to produce IOLs to correct these aberrations to provide patients with superior vision. No systems previously existed to accomplish this.

A well-known cataract surgeon commissioned FEO Solutions to develop a prototype of such a system, providing mass manufacturing capability, interfacing to commercial eye measurement systems, data import from remote locations, and scalable, maintainable, user-friendly software. The customer required delivery of the prototype in nine months. We could only spare one physicist and one electro-optical engineer for the project. It took a commercial refractive surgery company nearly two years, with multiple engineers, to interface one wavefront measurement system to their refractive laser surgery system. Based on our previous work with National Instruments hardware and NI LabVIEW software for a laser refractive surgery system eye tracker, we felt confident that we could meet the challenge.

Each part of the system had a unique requirement met by NI hardware and LabVIEW software. In the eye measurement interface section, the software had to interface with many systems using different communication protocols and data sets. In the profile generation section, the software had to calculate several equations and merge the results to construct a 3D model of the etch pattern. The IOL is etched using the laser control section, where the software had to precisely control the UV laser fire and laser energy, and to monitor the beam uniformity; and the laser beam shaping section, where the software had to control 786,432 micromirrors on the UV-enabled DLP device (UV-DLP).

In treating a patient, the first task is to measure the patient’s visual system, which is performed with systems in clinics located remotely from the IOL etching system. Systems for measuring corneal topography, or wavefront components, output their data in a proprietary format, which is available from the manufacturer. The remote clinics upload the patient’s measurement data to a common FTP-based database. The IOL etching system, which is based on LabVIEW, accesses the FTP database (which was written using the LabVIEW Database Connectivity Toolkit) via the Internet to get the patient’s data (using LabVIEW Internet Toolkit).
The data is then parsed based on the manufacturer’s format. This format is contained in a LabVIEW configuration file, allowing for easy addition of other measurement systems’ files as they become available. The parsed information is saved to the hard disk and then passed to the profile generation code.

Next, the system must generate a 3D volumetric profile based on the measurement data. Profile generation begins with a basic IOL formula to calculate the IOL power. The IOL equations are implemented using LabVIEW math functions. Once the IOL power is determined, the code converts the power to a radius-of-curvature (ROC) based on an index of refraction. From the ROC, a 3D shape defining the basic IOL shape is generated. This profile is then altered by adding the higher-order aberrations captured by the wavefront system (for example, spherical aberration and coma). This 3D profile is displayed at every step, using LabVIEW 3D surface graph functions so the surgeon can review the profile. The resulting 3D profile is then sent to the laser beam shaping code.

Based on the etch depth per laser pulse for each IOL material, the code “slices” the 3D profile into a number of individual 2D layers. (For example, for a spherical shape, each layer is represented by a “circle” with a different diameter.) Each individual 2D slice is presented as an “image” to the UV-DLP device via a high-speed USB port. Each mirror is then set to reflect or not reflect the laser energy, based on the “image.” The 2D mirror configuration is read back to confirm correct positioning. Each mirror in the device’s 1024 x 768 array is 13 µm², and thus, when the laser is fired, nearly 768,000 individual 13 µm² laser beams are directed to the IOL surface.

With the mirror configuration set, the excimer UV laser is ready to fire. The LabVIEW code first sends the desired energy setting to the laser via the RS232 link. When the laser is ready, it enables a digital “ready” signal. The code reads the “ready” signal and sends a digital “fire” signal to the laser. Once the laser fires, it enables a “fired” signal. Upon receiving the “fired” signal, the code reads the laser energy output via the RS232 link, and a second energy reading from the deep UV imager via the National Instruments PCI-6036E data acquisition device. The code continually monitors these two energy readings and adjusts the laser accordingly to maintain the required energy (via a PID loop).

When the laser pulse is fired and reflected from the UV-DLP device mirrors to the IOL blank, the surface is etched as described by each 2D slice “image.” For the example above, the result is an IOL with a spherical shape. Note that this laser uses digital I/O and RS232 for monitoring and control. Future lasers may use Ethernet or USB. With LabVIEW, we can easily modify the system to use these new laser interfaces.

Laser beam uniformity is checked before each procedure begins. It may also be checked during the procedure to ensure optimum results. The system checks beam uniformity using the deep UV imager. Here, a National Instruments PCI-1409 captures a single laser shot from a custom-designed UV camera. Using the NI Vision Development Module for LabVIEW, the system calculates laser beam intensity at every point (via an individual camera sensor). The system then uses this intensity information in the laser beam shaping section to decide which micromirrors to turn off and how long they will be turned off to compensate for any beam non-uniformities. With this method, the system achieves the smoothest etch of the IOL surface.

We successfully constructed the system and etched an IOL blank in August of 2005, thus meeting the customer’s deadline. We continue to refine the system while preparing it for manufacture. We are also implementing an automated laser alignment and calibration tool for the system, which is also simplified by due to the scalability of LabVIEW.
The Challenge: Developing a test system for accurate IC engine clearance measurement from tappet top to cam lobe that can replace our existing PLC-based test system.

The Solution: Developing a flexible, rugged, and cost-effective test system using the National Instruments PCI-6220 and PCI-6527 data acquisition devices with National Instruments LabVIEW.

Using a shim – a thin piece of metal or composite – to level a machine tool or to make components fit together is often quicker and less expensive than grinding and machining to make the same mechanical adjustments. Shims act like folded pieces of paper people place under table legs to prevent the table from wobbling.

Properly adjusted valve clearances are necessary in IC engines so that the valves will open and close as they should, because clearance distance directly affects engine performance. Because it is not cost-effective to achieve the required clearance by machining the mechanical parts, these clearances are adjusted by inserting appropriately sized shims. It is now an industrial practice to use feeler gauges to measure clearance manually.

At Captronic Systems, we have automated this procedure using National Instruments data acquisition (DAQ) devices along with NI LabVIEW, 10 LVDT probes for clearance measurement, and four pneumatic systems for mechanical alignment of the cam shaft and cam cylinder with the tappet top.

System Configuration
The test system, which we created for four-cylinder engines, consists of two fixture stations, one to measure the cam shaft lobe profile and the other to measure tappet top positions – both with respect to a master, which has the desired cam shaft lobe and cylinder tappet top dimensions. The system contains 10 LVDT probes, four for tappet top measurements, another four for cam profile measurements, and two for cam base measurements. Four pneumatic systems bring the LVDT probes onto the components whose dimensions are to be measured, and light indicators designate machine statuses like “no air” and “error” and indicate initial conditions. Twenty-four digital input feedback signals confirm each action and read the machine status.

The system uses the NI PCI-6220 for LVDT probe measurement and the NI PCI-6527 isolated DIO device to monitor machine status and to control the mechanical sequence required to bring the LVDT probe over the cam shaft and cylinder tappet top.

System Implementation
We implemented the entire system within 23 man-days. The power of LabVIEW helped us complete the system in such a short time span. An experienced employee takes approximately one minute to measure and select the appropriate
shims manually. Error in manual measurements depends on the employee and his fatigue level. With our new test system, the entire measurement and shim selection process takes less than three seconds.

The system software is divided into manual and auto mode of operation. In manual mode, the system carries out all the mechanical actions guided by the user. Every action has its own interlock with past actions as well as with some proximity and read switch status. In manual mode, all the LVDT probe measurements are referenced against the master, and LVDT probes are adjusted to read within some predefined value in one direction to avoid polarity mismatch.

In auto mode, all operations are carried out automatically after the “cycle start” user acknowledgment. Shim sizes are calculated automatically after LVDT probe measurement and processing. The auto mode includes a provision to stop the cycle at any time using an emergency stop button and reset the current cycle to restart. In auto mode, both the fixtures are operated in parallel. The system guides the user through the message display in the panels, and self-diagnostic features indicate failure of any read or proximity switches to the user. The system generates reports for employee productivity monitoring as well as selected shim values at designated times.

The existing PLC-based shim-selection machine did not provide the signal processing capabilities and user interface requirements required by the application. Our new test system based on NI data acquisition hardware and LabVIEW software is highly flexible, rugged, and cost-effective, increasing assembly line productivity by 20X and guaranteeing measurement accuracy within ±10 microns.

For more information, contact:
Vijay Jayabalan
Captronic Systems Pvt., Ltd.
Alif Arcade, # 19
Bangalore, Karnataka, India
(91) 80 25535046
E-mail: vijay@captronicsystems.com
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.

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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For more information, contact:
David Thomson
NOAA Earth System Research Laboratory
Boulder, CO
Tel: (303) 497-3470
Fax: (303) 497-5373
E-mail: david.s.thomson@noaa.gov
The Challenge: Creating a scalable, low-cost system to test the effectiveness of designs in reducing commercial jetliner noise during takeoff, landing, and sustained flight.

The Solution: Using National Instruments PXI controllers and chassis, dynamic signal analyzers, and LabVIEW software to design a scalable, distributed test system with tight timing and synchronization to perform phased array data acquisition for flyover tests.

As part of the Quiet Technology Demonstrator 2 (QTD2) project, Boeing flight tested new technologies intended to reduce noise generated by its aircraft. Measuring the improvement these technologies provide required a flexible, accurate, and scalable test system to perform phased array acoustic imaging during the tests. We needed a distributed system architecture with the ability to expand to up to 1,000 channels or more while still maintaining tight timing and synchronization between channels.

Phased Array Data Acquisition and Analysis
To flight test new technologies for quieter operation, we conducted research at a facility in Glasgow, Montana. We used an array of microphones to acquire noise data, which we then processed into noise-level maps showing from where and at what frequencies the noise was generated and how loud it was.

By overlaying the noise-level maps with a visual image, we could assess the effectiveness of noise reduction technologies, identify opportunities for additional noise-source reductions, and distinguish between engine and airframe sources. Using NI tools, we could then validate several advanced noise-reduction concepts, including chevrons on the engine exhaust ducts, new acoustic treatment for the engine inlet, and aerodynamic fairings for the main landing gear.

Previous System Limitations
During the first stage of the QTD project in 2001, we deployed a VXI test system that was limited in both channel count and channel bandwidth. The system required a centralized data architecture that required us to co-locate all the VXI chassis for synchronization, necessitating long cable runs from the microphones to the data acquisition system – about 10 miles of cable per 100 channels of data acquisition. In addition to the channel and architecture limitations, we faced challenges including time delays when synchronizing instruments across multiple VXI chassis, significant cost per channel, and significant time required for data retrieval. We wanted to deploy a new system in the second stage of the project (QTD2) that would address these issues.

NI System Solution
Using the flexibility and modularity of PXI, we were able to create a scalable system with virtually unlimited channel-count capability. In addition, by taking advantage of NI timing and synchronization cards, we could distribute the data acquisition hardware into the microphone array, decreasing cabling by nearly 80 percent while maintaining within one degree of phase match between channels.
To collect the data, we used the National Instruments PXI-4462 dynamic signal acquisition module, which provided acquisition rates up to 204.8 kS/s. We used eight PXI chassis, each containing the NI PXI-4462, PXI timing and synchronization cards, and PXI MXI-4 fiber-optic connections. With the timing and synchronization cards, we distributed the acquisition clock and start trigger to every data acquisition channel in the system.

Each PXI MXI-4 fiber-optic card linked a PXI chassis with a National Instruments PXI-8350 server-class machine running Windows XP and NI LabVIEW. We were able to separate the chassis from the controlling computer by up to 200 meters with the fiber-optic link. We connected each NI PXI-8350 controller through Gigabit Ethernet to one central host computer for faster post-acquisition data recovery to the host computer and other systems used for data processing and analysis. With increased performance and an unlimited, distributed architecture, we reduced the cost per channel by more than 50 percent compared to our previous system.

The Phased Array Flyover Test
We outfitted the test facility with more than 600 ground-based microphones arranged in a custom spiral pattern spread over the end of the runway in a 250-foot-wide by 300-foot-long area. We acquired the noise of a 777-300ER as it flew overhead and immediately retrieved and processed the data to get an acoustical image of the airplane. A data processing computer cluster connected to a host computer via Gigabit Ethernet analyzed the data in real time.

During a typical test cycle, the aircraft flew over the microphone array approximately every six minutes. The system was able to upload the previously acquired data and be ready to acquire more data within that window. During the test sequence, we conducted more than 300 acquisition events, yielding 78 minutes of flyover results – more than 1 TB of data.

Hardware System Architecture
To create a system that is scalable to 1,000 channels, the NI system architecture uses multiple PC-based controllers and PXI chassis. In this architecture, a master chassis controls timing and triggering while slave chassis distribute clocks, control local acquisition, and store data to disk. A host computer controls the configuration of all the PXI systems, provides the user interface for software setup and control, and receives all the data from each PXI system. A master PXI chassis controls timing and triggering while slave chassis receive the timing and triggering signals, acquire data locally, and store it to disk. We could transparently and remotely control the PXI systems with the PXI-8350 1U rack-mount, server-class controllers bundled with a fiber-optic MXI link, giving us the flexibility to distribute the dynamic signal acquisition devices in several clusters around the microphone array with the device controllers located in a trailer up to 200 meters away.

Based on commercial off-the-shelf hardware, Serial ATA drives configured in RAID 0 installed in the PXI-8350 let us stream all channels directly to disk at full sampling rate. This modular system gives us the framework to easily scale channels as needed.
to reach a higher channel count, or to divide up the system for lower-channel-count applications.

**Software System Architecture**

We developed the system completely in LabVIEW. We were able to directly reuse or easily adapt code and designs from other Boeing developers and from the NI Web site. Even with the LabVIEW learning curve, one person developed the entire application in less than six months.

By taking advantage of a carefully chosen software architecture and the modular nature of PXI systems, we simplified the process of scaling the system. We clearly demonstrated this when, midway through development, we needed to add 128 channels to our system. It only took about two hours to scale the system from 320 to 448 channels – from unpacking and plugging in the input modules to making a two-minute update to a configuration file.

**Timing and Synchronization**

We used National Instruments PXI-665x timing and synchronization control modules to provide tight synchronization among modules in a single chassis and to extend timing and synchronization to multiple chassis. Using a combination of NI PXI-6653 master modules with NI PXI-6651 slave modules allowed all the PXI chassis to operate using the same clock. Cables distributed the timing signal throughout the system, allowing up to 200 meters of chassis separation while still maintaining tight synchronization among the dynamic signal acquisition devices. With this architecture, we could match all 448 channels spread over eight chassis within one degree at 93 kHz.

**Dynamic Signal Acquisition**

Looking ahead during our data system selection process, we knew that we needed a system we could use for a broad range of applications, from full-scale tests to scale-model tests in a wind tunnel. We also needed a system that had higher sampling rates and a larger dynamic range than our existing system. To meet these needs, we selected the PXI-4462 dynamic signal acquisition module with four simultaneously sampled input channels and 93 kHz bandwidth.

For full-scale tests, the frequency of interest is typically no higher than 11.2 kHz; however, higher sampling rates are required for wind-tunnel tests with scale models as small as 1:20. With 24-bit, sigma-delta analog-to-digital converters, we could measure signals as low as 1.25 microvolts. With the integrated electronic piezoelectric (IEPE) integrated current source for sensors provided by the PXI-4462, we achieved a 30X cost reduction and greatly reduced the complexity of the transducers for certain applications.

Using NI software and hardware, we were able to create a high-end, low-cost system that could distribute the acquisition system across multiple chassis, tightly synchronize all channels, provide high channel count with full bandwidth on all channels simultaneously, and allow virtually unlimited channel-count expansion. With this new system, not only were we able to improve capabilities of the individual acquisition channels, but we also achieved a 5:1 reduction in the amount of cable required and cut the cost of microphone systems by 30:1 for flyover test applications.

For more information, contact:
James R. Underbrink
Boeing Technical Fellow, Data Systems and Processing Technology
at the Boeing Aero/Noise/Propulsion Laboratory, The Boeing Company
Tel: (206) 655-1476
E-mail: james.r.underbrink@boeing.com
For additional information on LabVIEW visit ni.com/labview