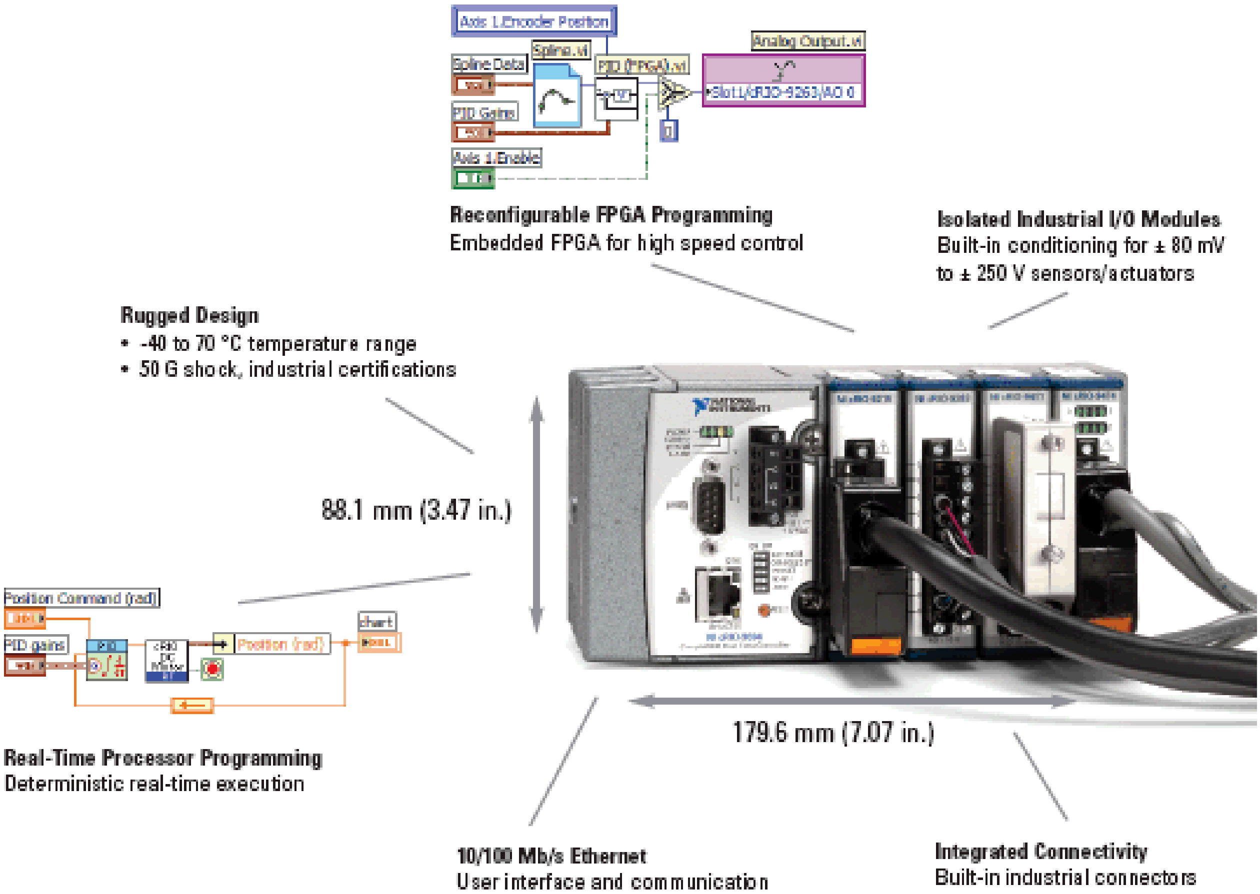
Graphical System Design for Machine Control

Overview

Embedded System Development for Machine Control Using a Single, Automated Graphical Programming Tool Chain and Programmable Automation Controllers (PACs)

by Todd Dobberstein and Brian MacCleery



Learn more about CompactRIO and Graphical System Design by visiting ni.com/compactrio.

Introduction

The traditional process for designing embedded machine control systems typically involves multiple stages of development that each requires specialized electronic design automation (EDA) tools such as state-diagram and flowcharting tools, SPICE circuit simulation, board layout and routing, control design tools, finite element analysis (FEA), C and VHDL languages, multiple target-specific compilers, and human-machine interface (HMI) tools.

New highly automated graphical system design (GSD) tools and PAC hardware systems can help you streamline the machine control development process.These new GSD tools offer complete customization of reconfigurable FPGAs, real-time processors, and industrial I/O modules using the National Instruments LabVIEW graphical programming language. With NI LabVIEW tools, you have open access to low-level resources while taking advantage of easy embedded programming and hundreds of built-in functions for automating common machine control tasks. PAC hardware systems, such as the low-cost CompactRIO embedded system, are designed for seamless integration with the LabVIEW GSD tool chain. With PACs, you can build advanced systems incorporating software capabilities such as advanced control, communication, data logging, and signal processing with a rugged controller performing logic, motion, process control, and vision.

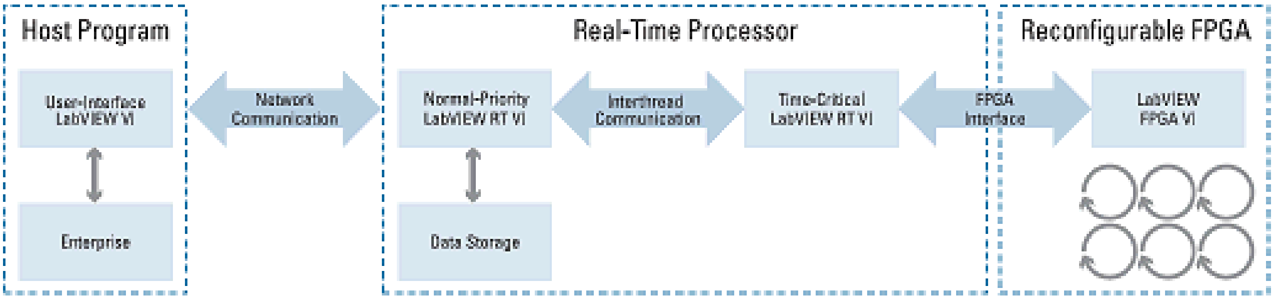


Figure 1. Single Graphical Programming Tool Chain for Embedded System Development

Develop Custom FPGA Logic

You no longer have to be an expert in VHDL programming to take advantage of the reliability and performance of reconfigurable FPGA hardware. The LabVIEW FPGA Module enables you to quickly develop programmable logic applications for CompactRIO by generating VHDL code based on your graphical program, and then automatically performing optimization, synthesis, and downloading. LabVIEW offers a full programming language for RIO hardware that takes advantage of the true parallel processing capabilities of the FPGA and enables code execution within a single FPGA clock cycle (40 MHz). In addition to basic programming structures and digital logic functions, you can drag-and-drop function blocks for motion control, analog PID, analysis, waveform generation, filters, and more.

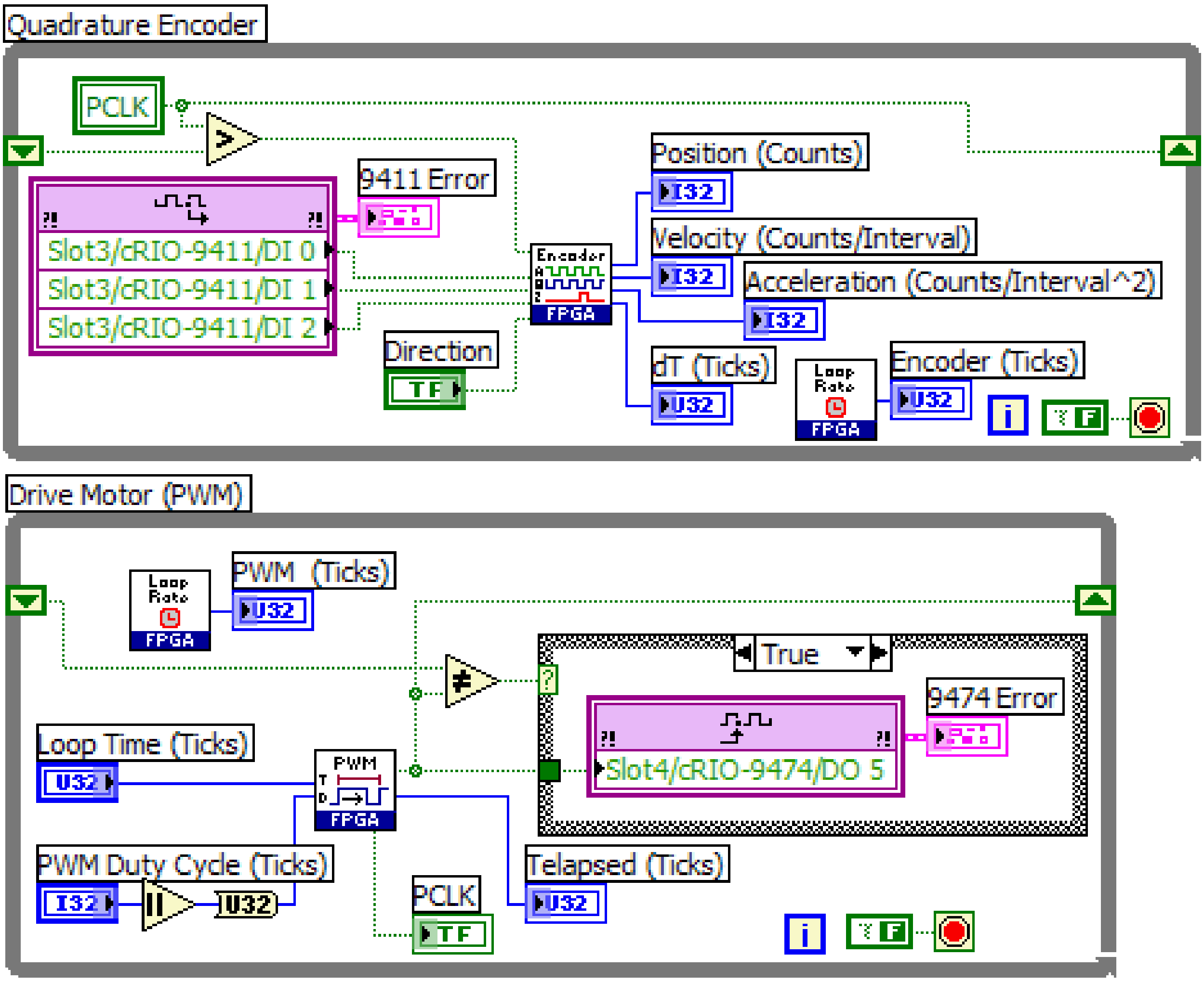


Figure 2. High-Speed, Parallel Loops in LabVIEW FPGA

Hard Real-Time Processing

With the LabVIEW Real-Time module, you can use more than 650 built-in LabVIEW function blocks for motion, PID, analysis, and more for deterministic execution on a floating-point processor. The real-time application typically involves two fundamental loops. The time-critical loop interfaces to the FPGA for deterministic interaction with the FPGA I/O. You can synchronize the execution of your time-critical loop via interrupt requests. The time-critical loop performs control while the normal priority loop within the real-time application performs data storage, analysis, and communication tasks with a networked host computer.

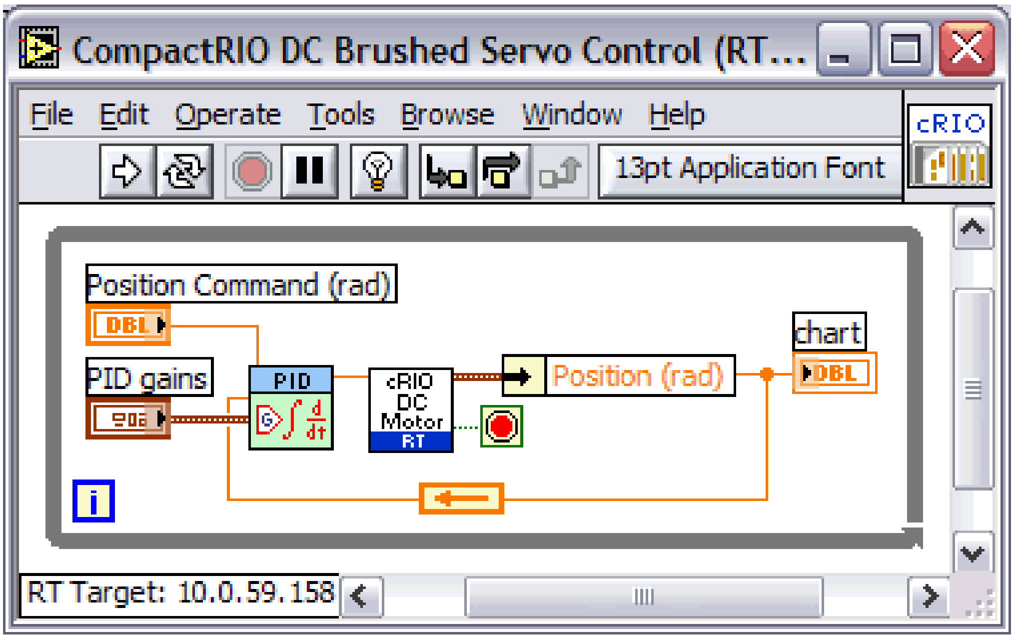
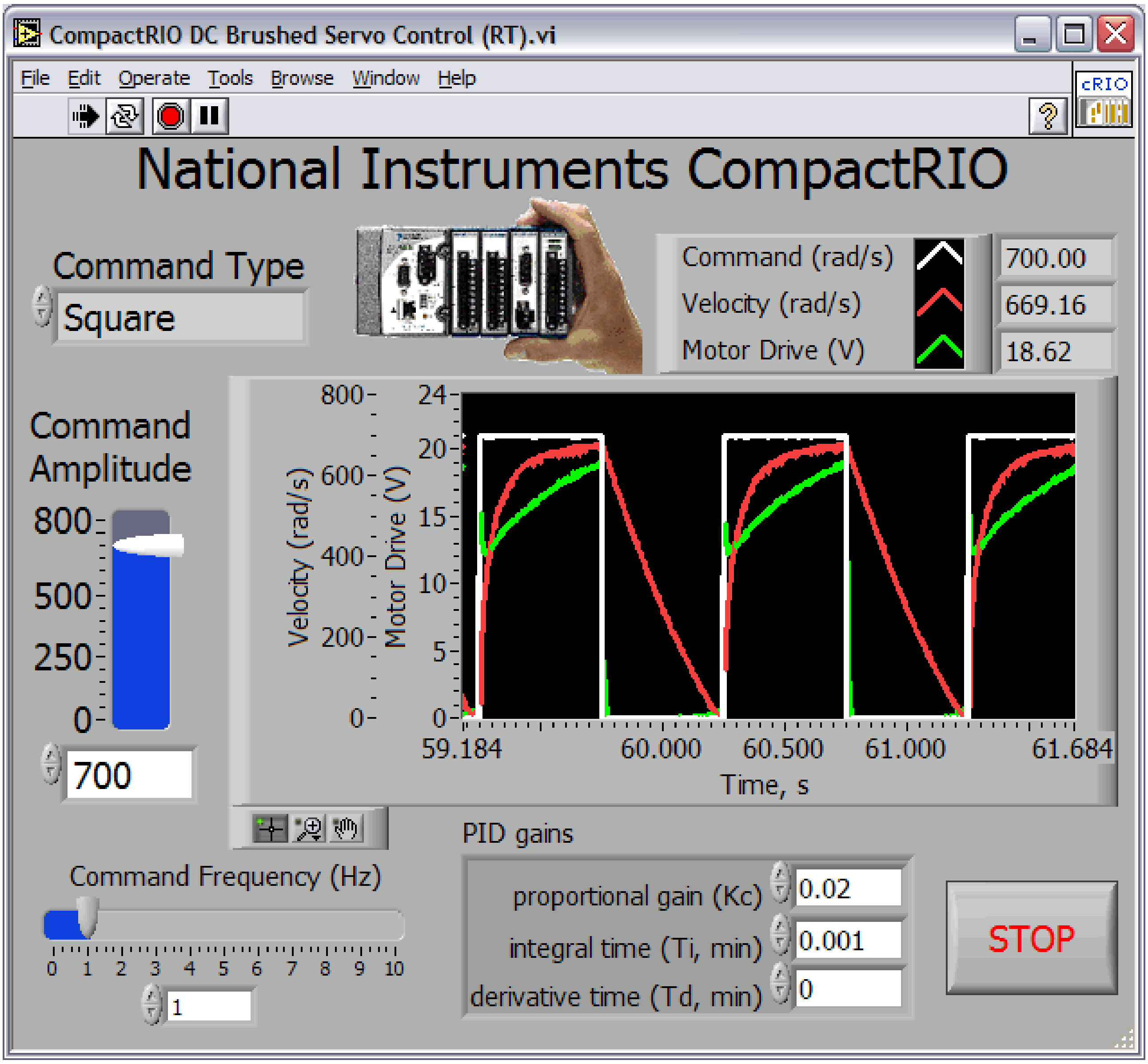


Figure 3. Real-time deterministic processing in LabVIEW Real-Time

Human-Machine Interface (HMI)

With any Windows/Linux/Macintosh computer, you can provide a user interface for your embedded machine control system. LabVIEW real-time controllers have a built-in Web server that automatically publishes the real-time application user interface over the network to a host computer for an HMI with no additional programming.



CompactRIO DC Brushed Servo Control (RT).vi
File Edit Operate Tools Browse Window Help
cRIO
National Instruments CompactRIO
Command Type
Square
Command (rad/s)
Velocity (rad/s)
Motor Drive (V)
700.00
669.16
18.62
Command Amplitude
800
500
250
0
700
Velocity (rad/s)
Motor Drive (V)
800
600
400
200
0
24
20
15
10
5
0
59.184
60.000
60.500
61.000
61.684
Time, s
PID gains
Command Frequency (Hz)
0 1 2 3 4 5 6 7 8 9 10
1
proportional gain (Kc)
integral time (Ti, min)
derivative time (Td, min)
0.02
0.001
0
STOP

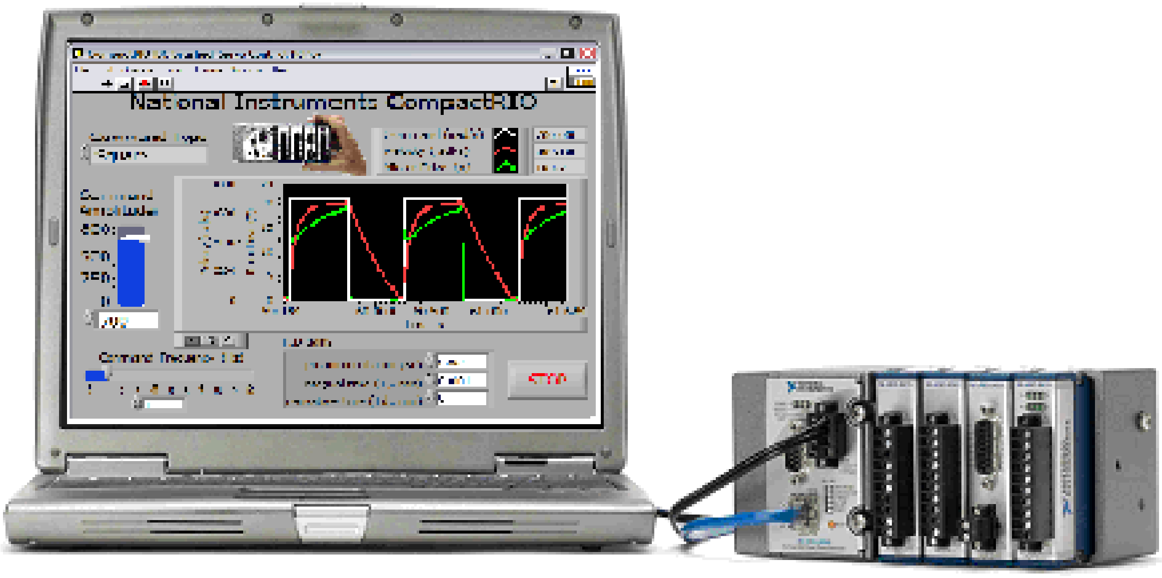


Figure 4. Built-in HMI with No Additional Programming

Hardware Architecture

CompactRIO is a rugged, reconfigurable embedded system containing three components – industrial I/O modules, a reconfigurable FPGA, and a real-time controller.

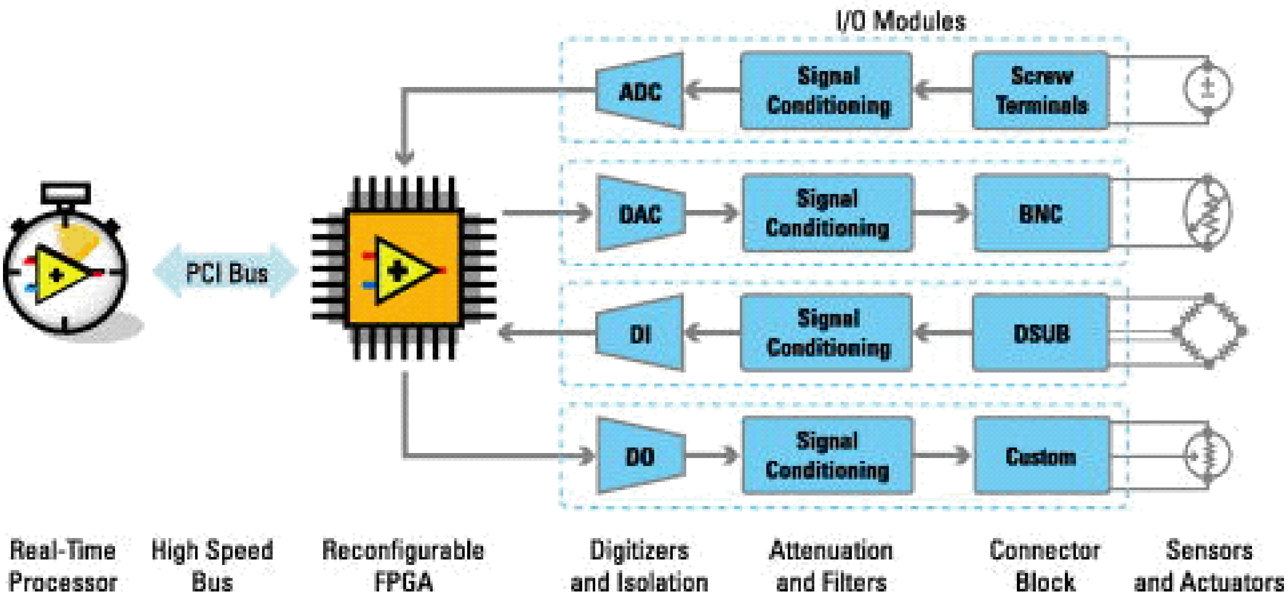


Figure 5. Reconfigurable Embedded System Hardware Architecture

Industrial I/O Modules

The I/O modules contain isolation, conversion circuitry, signal conditioning, and built-in connectivity for direct connection to industrial sensors/actuators. By integrating the connector junction box into the modules, the CompactRIO system significantly reduces space requirements and field wiring costs. Many different types of I/O are available, including ±80 mV thermocouple inputs; ±10 V simultaneous-sampling analog I/O; 24 V industrial digital I/O with up to 1 A current drive; differential/TTL digital inputs; and 24-bit IEPE accelerometer inputs.

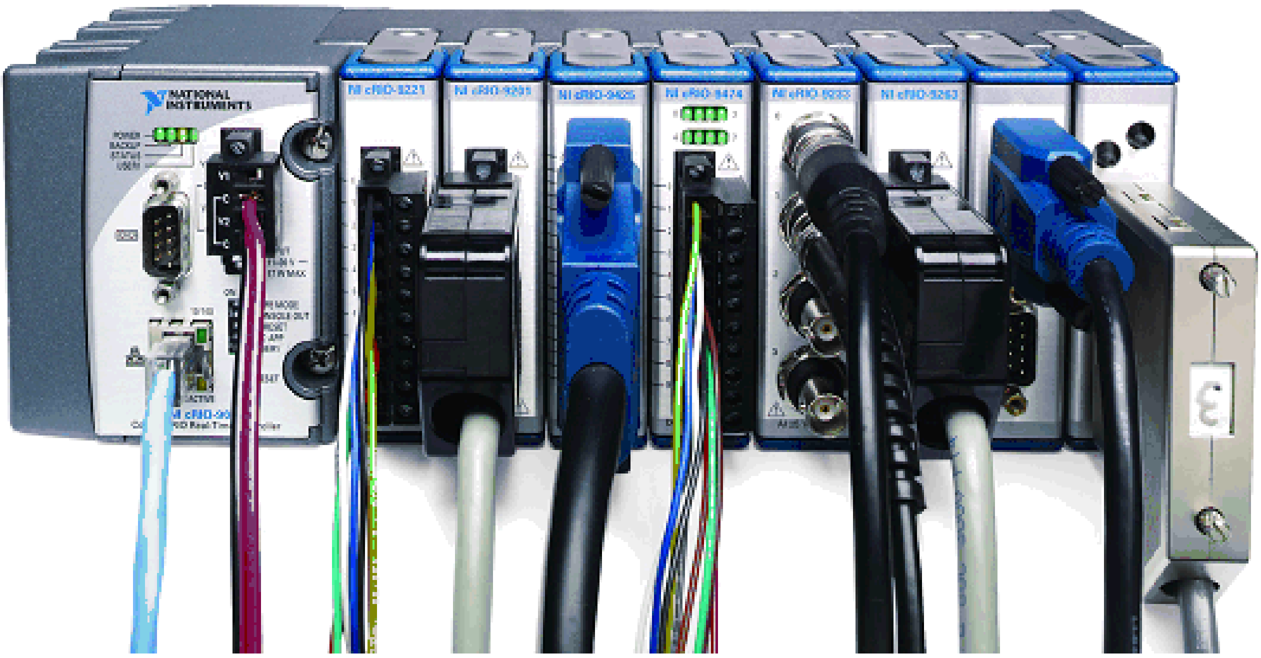


Figure 6. CompactRIO I/O Modules with D-Sub Cable, BNC, and Screw Terminal Options

Reconfigurable FPGA Chassis

The reconfigurable FPGA chassis is the center of embedded system architecture. The RIO FPGA is connected to the I/O modules in a star topology, for direct access to the I/O circuitry of each module and unlimited timing, triggering, and synchronization flexibility. Because each module is connected directly to the FPGA rather than through a bus, there is almost no control latency for system response compared to other industrial controllers. A single chassis can execute more than 20 analog PID control loops simultaneously at a rate of 100 kHz.

Figure 7. CompactRIO Reconfigurable FPGA Chassis

"The reconfigurable nature of CompactRIO and LabVIEW FPGA changes the rules for machine control and vibration monitoring. The end result is a rugged, low-cost, embedded system that can be deployed in a variety of applications and environments where traditional equipment would be unsuitable."

– Darren Lingafeldt, systems engineer for Nexjen Systems, a supplier of heavy-duty electrical test equipment and custom vibration monitoring systems

Real-Time Controller

The real-time controller contains an industrial processor that reliably and deterministically executes LabVIEW Real-Time applications and offers multi-rate control, execution tracing, and communication with peripherals. Additional features include dual 11 to 30 VDC supply inputs, a user DIP switch, LED status indicators, a real-time clock, watchdog timers, and other reliability features.

Figure 8. CompactRIO Real-time Controller

CompactRIO Specifications

Parameter	Specification	Units
Physical/Environmental		
Dimensions	179.5 x 88.1 (7.07 x 3.47)	mm (in)
Temperature range	-40 to 70	ºC
Shock rating	50	g
Industrial I/O Modules		
Channel Density (channels per module)	4,6,8, or 32	channels
Analog Resolution	12,16, or 24	bits
Maximum Analog Input Rate	800	kHz
Analog Input Range	± .08 to ± 60	V
Maximum Analog Output Rate	333	kHz
Analog Output Range	± 10	V
Digital Logic Levels	5 (TTL) or 24	V
Maximum Digital I/O Speed	500	ns
Maximum Digital Current Drive	4	A
Typical Isolation (withstand)	2,300	Vrms
Reconfigurable Chassis		
I/O Module Slots	4 or 8	slots
FPGA System Gates	1 or 3	M
Number of FPGA logic slices	5120 or 14336	slices
FPGA Timebases	40,80,120,160, or 200	MHz
Real-Time Controller		
Real-Time Processor	200	MHz
Dual DC Supply Range	11 to 30	V
Serial Port	RS232	
Ethernet Port	10/100	Mbps

Description	Standard
Electromagnetic Compatibility (EMC)	89/336/EEC EN 55011 Class A at 10 m FCC Part 15A above 1 GHz Industrial levels per EN 61326-1:1997 + A2:2001, Table A.1 CE, C-Tick, and FCC Part 15 (Class A) Compliant
Product Safety	73/23/EEC EN 61010-1, IEC 61010-1 UL 61010-1 CAN/CSA C22.2 No. 61010-1
Hazardous Locations, Class I, Division 2	Class I, Division 2, Groups A, B, C, D, T4; Class I, Zone 2, AEx nC IIC T4, EEx nC IIC T4
Shock and Vibration	IEC 60068-2-64, IEC 60068-2-27, IEC 60068-2-6
Mean Time Before Failure (MTBF)	Bellcore Issue 6, Method 1, Case 3 MIL-HDBK-217F
Marine	Lloyds Register (LR Type Approval System Test Spec No. 1)
Quality/Environmental Management System (QMS/EMS)	ISO 9001/14001

Typical Certifications – Actual specifications vary from product to product. Visit ni.com/certification for details.

See Also:

Click here for CompactRIO product certifications and ratings.

Click here for CompactRIO product manuals with detailed specifications.

Click here for CompactRIO dimensional drawings.

Custom Module Development

With the CompactRIO Module Development Kit, you can develop custom modules to meet application specific needs.

The kit provides access to the low-level electrical CompactRIO embedded system architecture for designing specialized I/O, communication, and control modules. It includes LabVIEW FPGA libraries to interface with your custom module-circuitry for communication at rates exceeding 40 Mb/s.

Figures 9 and 10 illustrate a custom CompactRIO VR module schematics and layouts.

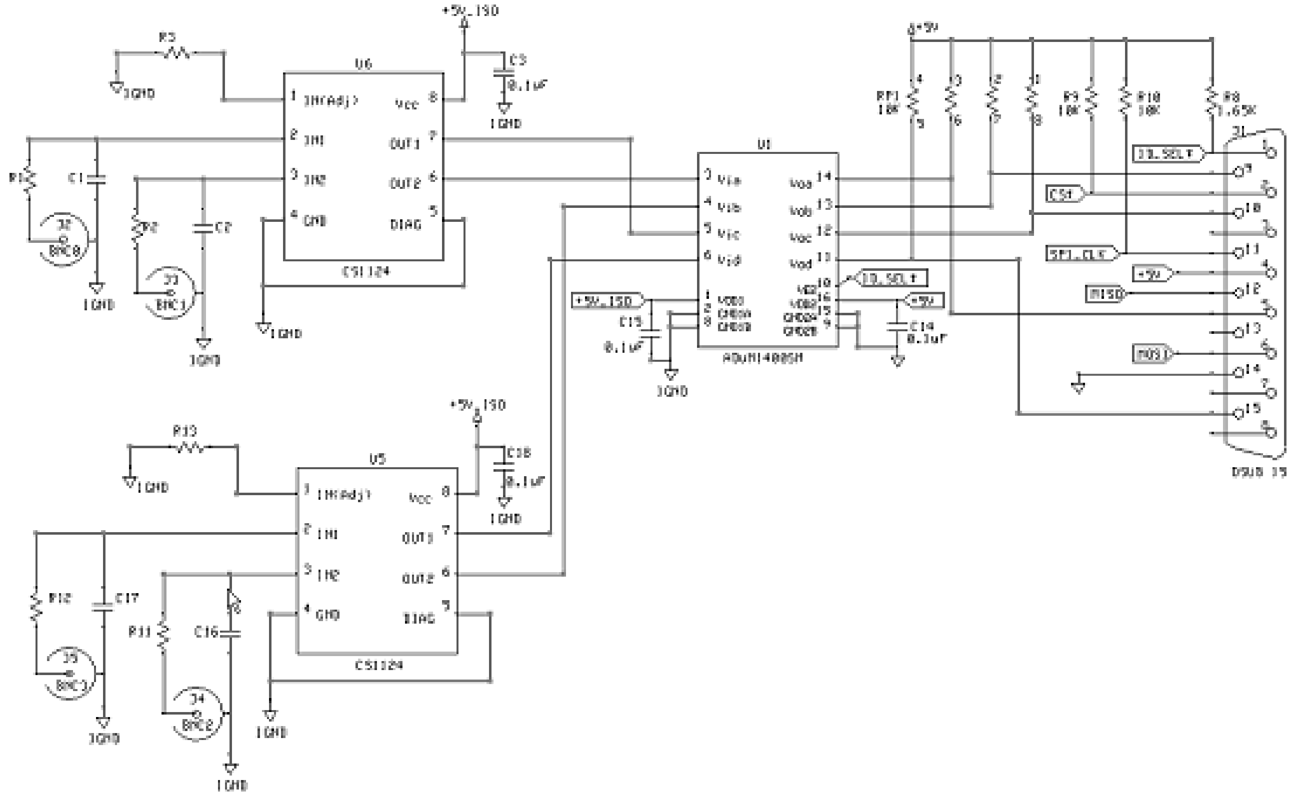


Figure 9. Variable Reluctance (VR) Module Schematic

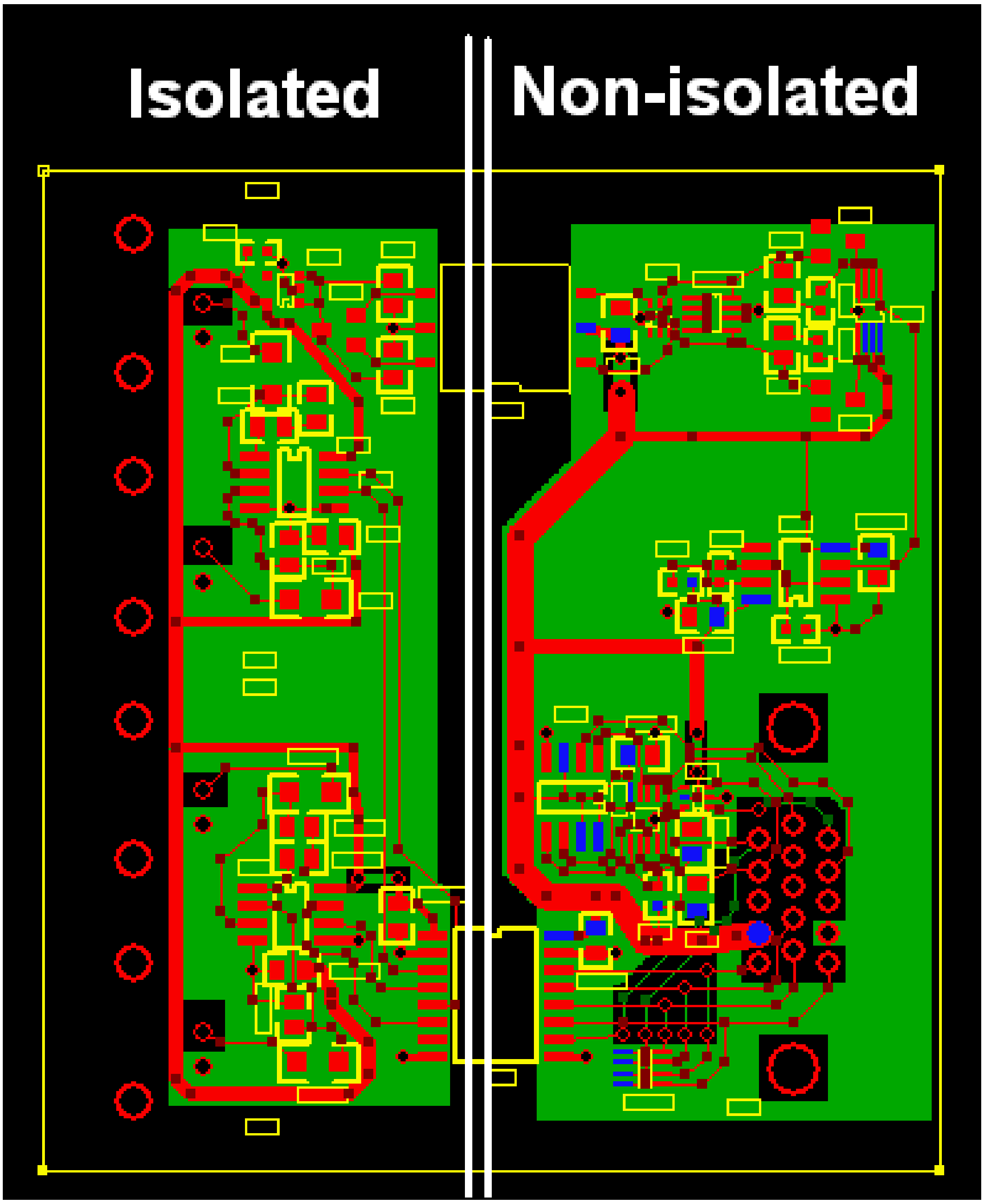


Figure 10. Finished PCB Layout for Custom Module

"CompactRIO and the module development kit deliver a powerful universal prototyping system that control design engineers use to quickly implement highly customized embedded systems using off-the-shelf tools."

– Carroll G. Dase, president of Drivven, Inc., an automotive control and data acquisition solutions provider

Process Automation Corporation (PAC) is using CompactRIO to create a control and acquisition system that acquires high-speed analog data on multiple channels, runs custom processing algorithms, and provides deterministic control to operate a verifiable fastener installation (VFI) tool for metal fastening. This application required a high-performance, reliable system in order to calculate the proper stopping point of the VFI tool in real time, during the acquisition, as torque and displacement values varied when fastening to materials of different density and thickness.

The largest benefit Process Automation Corporation has seen with CompactRIO is its ability to acquire and process data from system sensors at speeds normally reserved for very-high-cost, custom hardware solutions. Because of the small footprint and embedded system operation, Process Automation Corporation could develop stand-alone, embedded applications for hardware control with a much shorter and less-expensive development cycle.

Figure 11. Verifiable Fastener Installation (VFI) Machine

"Coupled with National Instruments reputation for solid performing technology and high value-to-dollar ratio, the CompactRIO platform emerged as the most cost-effective platform for this application. The CompactRIO system provides enough processing horsepower to allow multiple fastener installation tools to operate off of a single CompactRIO chassis. This made CompactRIO over twice as cost effective as the previous system."

– Greg Sussman, Automation Systems Consultant, Process Automation Corporation

Figure 12 shows three custom modules designed by Drivven, Inc. for controlling spark plugs and fuel injectors in a 2004 Yamaha YZF-R6 motorcycle at speeds exceeding 15,500 RPM.

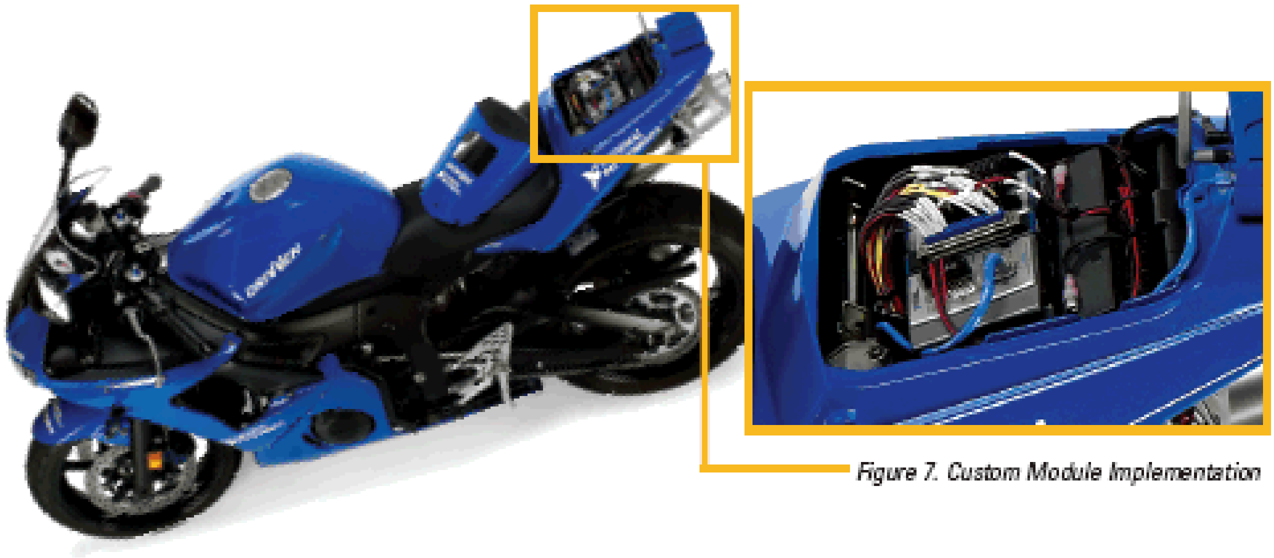


Figure 12. Custom Module Implementation

Typical machine control applications:

- Industrial packaging
- Welding machinery
- High-speed motion control
- Chemical mixing
- Fastening machinery
- Preventative maintenance

Visit ni.com/compactrio for additional graphical system design resources:

- Machine control white paper
- Machine control example programs
- Multimedia Web events
- CompactRIO online training
- CompactRIO customer solutions
- Custom module templates