Control Design Guide for Next-Generation Machines

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I. Smart Machine Industry

Like generations of technologies before, smart machines will impact almost every domain of life. They will alter how we produce goods, perform surgery, organize inventory, and even how we educate future generations. These systems not only perform repetitive tasks at soaring speeds and high accuracy, but they can adapt to changing conditions and operate more autonomously than ever before.

Characteristics of Smart Machines

Engineers and scientists are tasked with designing machines that are dramatically more flexible and versatile. There are two needs that are driving innovation in smart machines: one is the individuality and complexity of produced goods and the other is the ever-increasing demand for productivity and quality. Machine builders no longer design single-purpose machines -- they create flexible, multipurpose machines that address today's manufacturing needs such as smaller lot sizes, customer-specific variations of products, and the trend toward highly integrated products that combine different functionality in one device.

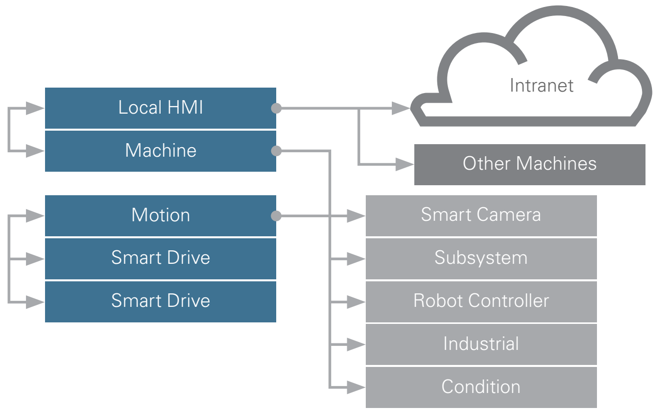
Modern machines can operate more autonomously than ever before. They can also prevent -- as well as correct -- processing errors caused by disturbances like changing conditions in the raw material, the drift of the thermal working point, or the wear and tear of mechanical components. With an extensive network of embedded sensors, smart machines hold information about the process, the machine condition, and their environment. This improves uptime and increases the level of quality. In addition, these systems can improve their performance over time and learn through analytics by leveraging simulation models or applying application-specific learning algorithms.

These machines also exchange information with other automation systems and provide status information to a higher level control system. This allows for intelligent factories and automation lines that can adjust to changing conditions, balance the workload between machines, and inform service personal before a machine fails.

II. Key Technologies

Decentralized Cooperative Control

Modern machines follow a modular approach. They contain a network of intelligent subsystems that jointly perform all the automation tasks within the machine and communicate with higher level control systems at the enterprise level, making intelligent factories possible. To enable systems that are adaptable and extendable, the control system architecture needs to reflect this modularity as well. Protocols for industrial communication are required to interconnect subsystems and maintain timing and synchronization. A shift toward a software-centric design approach and programming tools that provide the ability to use one design tool to implement different automation tasks allows customers to reflect the modularity of the mechanical system in their control software.



Decentralized Cooperative Machine Control System

While simple systems might get away with the classical concept of having one central controller connected to decentralized I/O, modern machines implement a hierarchical control architecture where higher level control systems are connected to slave controllers that perform clearly defined and self-contained operations.

Traditional programmable logic controllers (PLCs) still play an important role in this setup, especially for the implementation of Logic or Safety functions, but modern machine control systems incorporate more advanced embedded control and monitoring systems to implement closed-loop control, machine vision and image processing, and advanced analog I/O for tasks like machine condition monitoring. In addition to connecting to the main controller, intelligent subsystems also interact within the same level of the hierarchy to trigger and synchronize tasks that enable applications like high-performance vision-guided motion or position-based triggering and data acquisition.

Embedded Sensing and Processing

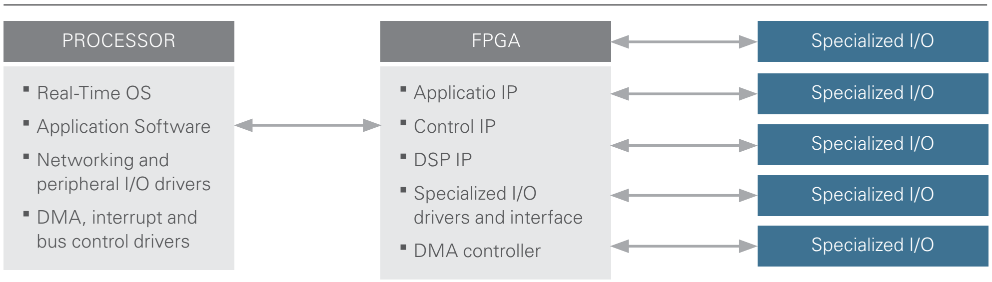
Sensors and measurement technology play an increasingly important role because they give machine builders the ability to create systems that are able to sense their environment, perform real-time process monitoring, ensure the health of critical mechanical components, and use this information for adaptive control. This requires control systems that can integrate sensor data, gather information in real time, and use information from multiple sensors in parallel while running high-speed control loops. High-performance embedded controllers with industrial-grade ruggedness offer direct sensor connectivity through modular I/O devices, and the ability to process and react to data in real-time. Leading machine builders adopt heterogeneous computing architectures that combine a real-time processor and programmable hardware to solve the most demanding applications.

Heterogeneous Computing Architectures

As machine control applications grow in complexity, hardware architectures and embedded system design tools must evolve to address increasingly demanding requirements as well as minimize design time. Historically, many embedded systems have featured a single CPU, so system designers have relied on CPU clock speed improvements, the shift to multicore computing, and other innovations to achieve the processing throughput required by complex applications. However, more and more system designers are migrating to computing architectures that feature multiple distinct processing elements, to provide a more optimal balance between throughput, latency, flexibility, cost, and other factors. Heterogeneous computing architectures provide all of these advantages and enable the implementation of high-performance embedded systems for advanced machine applications.

To illustrate some of the benefits that heterogeneous computing architectures can provide, consider an architecture composed of a CPU, an FPGA, and I/O. FPGAs are ideally suited to handle parallel computations such as parallel control loops, signal processing operations on a large number of data channels, and the execution of independent automation tasks within one system. Additionally, because FPGAs implement computations directly in hardware, they provide a low-latency path for tasks like custom triggering and high-speed, closed-loop control. And, incorporating FPGAs into computing architectures also improves the flexibility of embedded systems, making them easier to upgrade than systems with fixed logic and enabling them to adapt to changing I/O requirements. Coupling a CPU and an FPGA in the same heterogeneous architecture means that system designers do not need to choose between these FPGA advantages and the corresponding strengths of a CPU. Additionally, a heterogeneous architecture can be more optimal than attempting to adapt a single-element solution to a problem that the element is not well suited for. For example, a single FPGA might handle a parallel task requiring low latency equally as well as a large number of CPUs.

HETEROGENEOUS COMPUTING ARCHITECTURE



Embedded system designers can combine a microprocessor and an FPGA in a heterogeneous computing architecture to use the strengths of each processing element and more optimally meet complex application requirements.

Although embedded system designs that feature multiple processing elements have many advantages, they raise some challenges when it comes to software development. Thespecialized architectures of individual processing elements and the fragmented set of tools and expertise required to program them means they often require large design teams. For example, FPGA programming commonly requires knowledge of VHDL programming–a skill that can require a significant training investment, larger staff, or costly outsourcing. Additionally, developing the software stack to support a heterogeneous architecture is a considerable undertaking that involves driver integration, board support, middleware for inter-element communication, I/O interface logic, and more. System designers can address these challenges with an integrated hardware and software platform composed of a standard heterogeneous architecture, interchangeable I/O, and high-level system design software.

Building on knowledge of the underlying hardware, high-level design tools abstract both the system architecture and I/O during the development process, improving productivity and reducing the need for system designers to manage low-level implementation details. When developing embedded systems based on heterogeneous architectures, system designers can use high-level system design tools that can abstract the architectures of individual computing elements, such as FPGAs, and provide a unified programming model that can help designers take advantage of the capabilities of different elements. Furthermore, abstraction in high-level design software aids in the concise description of functional behavior and facilitates code reuse despite changes in hardware or communication interfaces.

III. Design Approaches

To address growing complexity and requirements, machine builders must design highly modular systems that satisfy customer-specific needs and adapt on-site for different manufacturing processes and product variations—sometimes even without operator interaction. Although a modular approach allows OEMs to develop reusable components that can be leveraged across machines, it significantly changes the way systems are designed. The mechanical system's modularity needs to be reflected in the control system architecture. Rather than use a traditional monolithic system, modern machines are based on a network of control systems. Modern machines require a seamless communication infrastructure that can handle the time-critical data, lower priority data, as well as status information and communication with a supervisory system.

One of the biggest challenges for machine builders today is incorporating advanced features with a traditional custom design approach. In the face of tight time-to-market requirements and fierce competition, machine builders don't have the time and resources to justify the development of custom embedded hardware.

Furthermore, hardware selection for machine control systems can be a daunting task. Machine builders often find themselves in a situation where they need to consider the ease of use and low risk of "black box" solutions versus the performance and price benefits of a custom embedded system that allows them to design-in differentiated features that can ultimately determine their machine's success or failure in the marketplace. Because custom solutions can push design teams out of their comfort zone, they often tend toward traditional black box solutions, despite knowing that this might limit their capability to add differentiating features to their machines.

To address these challenges, National Instruments offers a platform-based approach that gives domain experts the ability to configure a modular embedded system and program different automation tasks with one graphical design tool. This approach, known as graphical system design, is adopted by leading machine builders and uses NI LabVIEW graphical programming and the LabVIEW reconfigurable I/O (RIO) architecture.

The LabVIEW RIO architecture offers a hybrid approach: a fully customizable off-the-shelf platform, with real-time processors and user-programmable FPGAs, that provides access to a wide range of existing I/O modules from NI and third-party vendors. The LabVIEW RIO architecture is available in a variety of form factors and performance levels - Whether you need the small size of Single-Board RIO, the ruggedness of CompactRIO, or the extremely high performance of FlexRIO, the system design software remains consistent and code can port seamlessly across each family of deployment targets.

LabVIEW makes it possible to program CPUs and FPGAs on heterogeneous hardware using a consistent graphical programming approach, with support for common programming languages such as C/C++ and IEC 61131-3. In addition, LabVIEW abstracts system timing, I/O access, and inter-element communication allowing you to focus on innovation, not implementation.

With add-on modules for motion control, machine vision, and control design and simulation; features for machine prognostics and condition monitoring; and extensive support for I/O hardware and communication protocols, LabVIEW gives machine builders the ability to consolidate their development toolchain and further streamline the design process. In addition, using the features and IP provided through the LabVIEW FPGA Module, machine builders can focus on the design and optimization of their custom algorithms rather than spend weeks or months on hardware design or use a third-party company to design yet another application-specific black box embedded solution. Custom I/O front ends and board-only versions based on the same architecture provide an additional level of flexibility.

Learn more about the LabVIEW RIO architecture and NI's offering of heterogeneous computing platforms at ni.com/embedded-systems.

The Changing Landscape for Machine Designers

The landscape for machine designers has evolved. Demands to reduce design cycles and incorporate advanced functionality have profoundly changed design approaches. Design tools can now offer an unprecedented level of flexibility and speed. Algorithms and tools that were once available only for high-end research are now breaking into the industrial market.

National Instruments provides an embedded hardware and software platform that seamlessly integrates with other design tools and can be used to deploy heterogeneous architectures to advanced machines.

If you are pushing the envelope with a high-performance machine that needs to be better, faster, and smarter than previous designs, you will likely need advanced I/O, custom motion control, machine vision, accurate timing and synchronization, and specialized control algorithms. You are stepping outside the boundaries defined by traditional devices. When you do so, a platform-based approach based on a reconfigurable architecture becomes the most effective way to implement these systems.

IV. Application Examples

Leading machine builders deliver innovation and differentiation in the market by leveraging the following types of technology:

- Heterogeneous computing architectures that combine real-time processors and reconfigurable hardware for a variety of control and processing tasks
- Modular I/O that can connect to any sensor, signal, bus, or device
- A hardware and software platform that provides
  - Built-in signal processing libraries, control algorithms, complex mathematics, and I/O interfaces
  - Simulation, modeling, and design verification and debugging tools
  - APIs for networking, communication, and data transfer and logging
  - Customizability and extensibility through software to meet evolving needs and customer requirements, even after deployment

Learn more about NI tools and technologies for machine control applications at ni.com/machinedesign.

Wafer Processing

In semiconductor manufacturing, there is a never-ending push for greater efficiency and semiconductor material yield. As circuit features shrink in size and global price competition intensifies, wafer processes push the physical and operational limits of equipment manufacturers. One result is the increasingly narrow tolerances for the physical and electrical parameters of incoming wafers used in delicate process steps, such as mask and etch. Automation Works uses integrated National Instruments motion and vision tools to help develop cutting-edge semiconductor manufacturing equipment.

Electronics Manufacturing

While many fiber-optic parts are still hand assembled, the Albuquerque division of LightPath Technologies designed an integrated, automated approach to produce collimators, which are gradium lenses fused to fiber-optic cables that help direct light. The performance and reliability of these intricate parts are integral to the overall performance of the telecom systems.

Automated Welding

Tasked to develop a rugged, cutting-edge, automated pipeline welding system, Serimax decided to use NI CompactRIO. With the help of an NI Alliance Partner, they created a powerful system that adapts to address various customer requirements, provides maximum uptime, meets the highest reliability and quality standards, offers worldwide support, and has flexible hardware and software that can address control and monitoring needs throughout existing machine types in the future.

Metal Forming Machine

Bevel and cylindrical gears can be found everywhere—from automobiles and airplanes to trucks and tractors to wind turbines powering a thousand homes to the lawn mowers and power tools found at these homes. Gear tooth surfaces and spacing are critical parameters to improve operational characteristics. Using the LabVIEW RIO architecture, Viewpoint Systems and Gleason Corporation added exciting new capabilities to their gear finishing machines, allowing them to produce higher quality gears in 30 percent less time.

Medical Devices

The field of protein crystallization is an important component of the drug-discovery process. Proteins under investigation are mixed with various combinations of reagents in an attempt to discover a recipe that will create conditions suitable for the formation of protein crystals, which can then be examined via X-ray diffraction. The number of possible permutations of mixtures can reach the millions, making the search for the optimum recipe tedious. Coleman Technologies uses NI embedded control and monitoring tools to build a medical device that fully automates the process of identifying protein crystals.

Learn more about these applications and find examples for a specific industry at ni.com/solutions.