WP410 (v1.0) November 16, 2011

Using FPGAs to Solve Challenges in Industrial Applications

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The revolution of automation on factory floors is a key driver for the seemingly insatiable demand for higher productivity, lower total cost of ownership, and high safety. As a result, industrial applications drive an insatiable demand of higher data bandwidth and higher system-level performance. This white paper describes the trends and challenges seen by designers and how FPGAs enable solutions to meet their stringent design goals.

Leading Solutions for Industrial Customers

The broad range of Xilinx FPGA devices—ranging from low cost and low power to higher content and higher performance—facilitates designs in varying ranges of complexity, from simple I/O expansion to complex computation and system integration. FPGAs meet critical timing and performance requirements with parallel processing and real-time industrial application performance, permitting greater system integration and lower development cost.

Table 1: **Characteristics of Various Xilinx Products**

Device Family	Process Nodes	Features	Sample Industrial Applications
Spartan-6 FPGAs	45 nm	Low Cost, High I/O	Industrial Networking, Motor Control
Artix-7 FPGAs	28 nm	Low Cost, Unified Architecture, ADC feature	Motor Control, I/O Module
Kintex-7 FPGAs	28 nm	Best Price-Performance Ratio	Computational, DSP, and high-bandwidth applications, such as video, data processing, and transmission
Zynq-7000 EPP	28 nm	Processors and FPGA, ADC Feature	Video Surveillance, Machine Vision, Motion Control Platform

Spartan®-6 FPGAs (45 nm) are currently powering industrial ecosystems worldwide. Xilinx's 28 nm Artix™-7 devices—which share a unified architecture with all 28 nm Xilinx devices, including Kintex™-7 and Virtex®-7 FPGAs and the Zynq™-7000 Extensible Processing Platform (EPP)—allow designers to easily scale up or down to broaden implementation and functionality while maintaining and building upon automation and monitoring IP already developed for designs targeting Spartan-6 FPGAs. In areas such as Industrial Networking and Imaging, where the protocols and standards are shifting and changing, the programmability of FPGAs versus fixed logic chips such as ASICs and ASSPs allows for both faster time-to-market and longer time-in-market.

FPGAs also enable a higher degree of integrated connectivity due to easy integration of third-party IP for industrial networks, legacy bus support, and path to Ethernet-based protocols, along with the ability to support multiple protocols in a single device. In motor control, Total Cost of Ownership savings are achieved by conserving power through tighter control of speed, torque, and acceleration, while improved efficiency allows for smaller, less expensive motors.

FPGAs offer particularly powerful solutions for meeting machine vision, industrial networking, motor control, and video surveillance needs. For example, the flexibility of FPGAs allow designers to quickly adapt to changing image sensor interfaces and image processing requirements, evolve analysis capabilities to keep pace with market requirements, and add features and functions long after deployment.

FPGA Advantages

Industrial Networking

The factory ecosystem is an increasingly integrated workplace requiring interfaces to cross a wide range of applications, such as Programmable Logic Controllers (PLCs), I/O modules, motors, sensors, etc. Industrial networking protocols provide seamless communication between modules, allowing components from different manufacturers to plug-and-play provided they use the same protocols.

In-factory communications can be classified into three levels: the device, process, and Ethernet levels.

1. The device level provides communication between modules such as motor drives and its sensors and needs to have the shortest response time.
2. The process level is the mid-level communication between PLCs, using peer-to-peer formats, requiring a short response time but allowing a higher latency compared to device-level communication.
3. Finally, the highest level of communication is the use of Ethernet, which provides the largest data bandwidth and distance to provide communication between various factory sites.

Traditionally the field bus is communication in RS-232, RS-485 with protocols such as DeviceNet, CANopen, Profibus etc. However, as Ethernet matures in enterprise architecture, many real-time Ethernet protocols are introduced to the industrial market to provide deterministic communication over reliability and safety concerns. Because of its increased performance and great cost saving in cables, many of the field bus communications are becoming Ethernet based. It is estimated that by 2014, there will be more Ethernet-based nodes compared to the number of legacy protocols.

Table 2 shows some popular Industrial Ethernet Protocols, their key Industrial Automation sponsor and geography regions of adoption.

Table 2: **Popular Industrial Ethernet Protocols**

Ethernet Protocols	EtherCAT	Ethernet POWERLINK	Profinet RT	sercos III	Ethernet/IP	MECHATR-OLINK III	CC-Link IE
Key Sponsors	Beckhoff	B&R Automation	Siemens	Bosch	Rockwell Automation	Yaskawa	Mitsubishi
Serial Fieldbus	CANopen	CANopen	Profibus	SERCOS I/II	DeviceNet/ ControlNet	MECHATR-OLINK II	CC-Link
Primary Geography	Europe, Asia	Europe, US	Europe, US	Europe, Asia	North America	Japan	Japan
What is needed?	Custom MAC + Stack	Custom MAC + Stack	Ethernet MAC + Special Stack	Specialized MAC + Stack	Ethernet MAC + TCP/IP Stack	Custom MAC + Stack	Custom MAC + Stack
Partner	Beckhoff	B&R, Avnet	Softing	Automata	PORT	TED	TED

To achieve the real time, low latency and deterministic nature required for Industrial use, many of these Ethernet protocols use specialized Ethernet Media Access Control (Ethernet MAC). This is achieved using hardware acceleration and special data packaging for high-speed encoding and decoding. As a result, users can choose either hardened ASICs or FPGAs for implementation. Some protocols are not offered in ASICs, such as Powerlink and sercos III, making FPGAs the only viable solution.

While real-time Ethernet protocols are emerging, there is still a need for Legacy Bus Support for existing factory floor systems. Spartan-6 devices allow easy bridging from Ethernet to RS-232, RS-485, and CAN. Furthermore, due to the large number of I/Os available compared to ASICs or ASSPs, Spartan-6 FPGAs are used heavily to support multiple protocols in one device, allowing modules to scale from one standard to another. Any communication between devices that is enabled by Industrial Ethernet can be implemented in a Spartan-6 FPGAs or in 28 nm 7 series FPGAs.

Industrial Motor Control

Motors used for industrial applications are ubiquitous and account for more than 66% of the electrical power consumed in industrial markets. As the cost of power continues to rise and the automation of factories increases, motor efficiency is becoming increasingly important. To achieve optimum efficiency, the motor control electronics needs to read current and voltage of the motor and perform a series of mathematical operations using computed errors and corrections. The output results in commands to the inverter. All of these need to be completed in a timely manner, before the motor's feedback readings become obsolete. The shorter the loop time, the faster the motor's response to changes, thus, less ripple and less energy dissipated by the motor—this due to a motor drive system with greater precision and efficiency.

Advanced algorithms such as Field Oriented Control (FOC), which delivers great efficiency and performance, typically require fast computational and parallel processing performance that cannot be met using traditional DSPs or MCUs. FPGAs can provide a number of advantages over traditional processing devices, including: higher performance, lower cost through greater on-chip integration of system components, robustness of solution, DSP capabilities, and solution customization.

Motor control solutions built on Spartan-6 devices can implement algorithms directly in hardware while the soft-core MicroBlaze™ processor manages high-level functions. On-chip DSP and FPGA logic are used to process system-critical information and compute intensive functions such as PID Controller, Clark/Park transforms, and Space Vector PWM. The 28 nm architecture 7 series FPGAs feature the Xilinx Analog-to-Digital Converter (XADC) block, which contains two ADCs operating at up to 1 MSPS. The XADC block converts analog readings of bus voltage and currents into digital form to be processed by the FPGA, thus reducing another component in the overall bill-of-materials. This enables the designer to construct autonomous monitoring solutions that allow for offloading of the main processor. Offloading of a system processor can prove critical for applications that require real-time control—or, they can simply be used to reduce the overall system cost. The combination of an autonomous monitoring solution and a main processor can be more cost effective than scaling up to a higher-performance system process.

As an example of the benefits of an autonomous processing subsystem, an integrated high-performance motor controller can be designed based on the XADC, a soft core MicroBlaze processor, DSP blocks, and support logic functions, including pulse width modulation (PWM), counter-timers, and serial communications channels.

Using a simple application programming interface (API), a central control processor can issue high-level commands to configure and control the autonomous subsystem. The subsystem controls motor functions independent of the central microprocessor, and reports back status or issues interrupts as appropriate.

Separating the motor controller operation through an autonomous solution encapsulates the solution, making the overall system easier to design, test, and maintain. This can also lead to lower cost and overall higher system-level performance.

Machine Vision

Machine Vision is used in factory automation to inspect manufacturing lines for quality control and item tracking purposes. Another common use of machine vision is in vision-guided robotics. Machine vision comprises four components: Image Acquisition, Processing, Compressing, and Transmitting. All components of the machine vision can be realized using a single FPGA or a Zynq EPP.

Because machine vision needs to perform inspection and sorting in the assembly line, it requires sensors that provide high resolution and high frame rate. FPGAs with a high number of I/Os and standards, such as Spartan-6 FPGAs, are often used to interface to the sensor via LVDS signals. Also, high-speed data processing is required to detect defects and abnormalities on high-speed production lines. Depending on the needs of the application, compression might be used to reduce the data bandwidth required when sending raw data. A final component of machine vision is the transmission system.

As with other elements on the evolving factory ecosystem, digital interfaces are rapidly changing and shifting. Camera Link and GigE Vision are expected to provide more than 60 percent of camera interfaces over the next five years, even as IEEE Std1394 and some analog systems continue to occupy the marketplace. Where Camera Link requires 26 pin connectors, GigE Vision can be quickly scaled without apparent limits, and can be easily interfaced to PCs running standard TCP/IP protocols. This allows easier data integration into factory floors networked via low-cost Gigabit Ethernet MAC.

GigE Vision is the emerging *de facto* standard for high-performance machine vision due to its bandwidth of 1,000 Mb/s that allows large uncompressed images to be transferred quickly in real time up to 100 meters with a net speed of 100 MB/s. Spartan-6 and 7 series FPGAs feature a camera interface up front that transfers the data into GigE Vision-compliant data packets. The input sensors are very specific, very high resolution with a high frame rate. Because these sensors are not used in the Consumer video and image capture market, there are very few compatible ASIC or ASSP devices available. FPGAs meet the speed, cost factor, and resolution requirements for effective implementation. This capture is currently available in 1 Gig Ethernet and will seamlessly move up to 10G Ethernet as systems evolve.

FPGAs provide the necessary bridge between vision sensors and power supply, SerDes, and Fieldbus at up to 100 frames per second in HD.

Video Surveillance

Current growth in the use of high-definition, Internet Protocol (IP)-based video cameras is exponential and is expected to hit 40 million cameras per year in 2014. There are currently many ASIC and ASSP video solutions on the market due to rapid development cycles and demand in the broadcast and consumer markets. FPGAs, however, allow for greater product differentiation because their flexibility allows for the implementation of special sensors as well as customer-specific IP and image processing functions. This is not cost-effective with a single ASIC and often not possible with an ASSP-based design. Such applications include multiple sensor dome cameras, HD (High Definition) cameras, night-vision cameras, etc. FPGAs provide the differentiation factor and the processing power to implement such complex solutions.

In early video surveillance systems, very limited processing was performed at the camera node, as the captured image was stored and then processed. However, current data processing is pushed right to the edge of the network, thus requiring electronics in the camera to have high integration and processing power. This is important for intelligent cameras to capture and analyze data in real time, compress the data and then transmit. This is essential for cutting-edge systems being used for facial recognition, license plate tracking, and other currently deployable video surveillance applications. As with industrial networking, video surveillance is moving from traditional standards, in this case coax cables, to Cat-5 Ethernet cables. Coax offers limited bandwidth that cannot support the high level of resolution in newer IP sensors. FPGAs allow IP surveillance cameras to transfer 1080p video at 60 frames per second.

In this implementation, an FPGA is used as a companion device to an existing system. The benefits include adding a high-definition image processing pipeline that enhances and extends the capabilities of existing systems processors, the ability to offload processing from the main system processor, and the ability to adapt to the latest sensors. The ability to add in a customer Wide Dynamic Range (WDR) compression algorithm allows for greater product differentiation.

Getting Started with Spartan-6 FPGAs Today

Spartan-6 FPGAs—built and implemented on proven 45 nm architecture— offer many leading industrial solutions, especially when combined with the Xilinx Industrial Ethernet Kit and Industrial Video Kit as part of the Xilinx Industrial Targeted Design Platform. Because the Spartan-6 device architecture shares common characteristics with Artix-7 FPGAs, IP developed and tested today on Spartan-6 devices can be transitioned and used on future systems built on Artix-7 devices.

Avnet Spartan-6 FPGA Industrial Ethernet Kit

The Spartan-6 FPGA Industrial Ethernet Kit is a comprehensive design environment for rapid prototyping and development of leading-edge industrial applications in connectivity, motor control, and embedded processing. This kit includes a mezzanine card supporting multiple real-time industrial Ethernet protocols and legacy serial connectivity standards. Out of the box, the Spartan-6 FPGA Industrial Ethernet Kit enables OEMs and engineers to produce more reliable designs with shorter cycles and fewer resources.

Avnet Spartan-6 FPGA Industrial Video Processing Kit

The Spartan-6 FPGA Industrial Video Processing Kit offers a comprehensive design environment for the rapid prototyping and streamlined development of high-resolution video conferencing, video surveillance, and machine vision systems. Designed specifically for industrial imaging, this kit enables developers to build camera and imaging applications supporting improved image resolutions, meeting evolving image processing and interface requirements.

Introducing 28 nm Devices for Future Factory Ecosystems

Xilinx 7 series FPGAs leverage the unprecedented low power, performance, and capacity enabled by TSMC's 28 nm high-k metal gate (HKMG) high-performance, low-power (HPL) process technology. Unparalleled scalability is afforded by the FPGA industry's first unified silicon architecture to provide a comprehensive platform base for next-generation systems.

Agile Mixed Signal for Factory Floor

The new Agile Mixed Signal (AMS) general-purpose analog interface introduced with the 28 nm 7 series families provides numerous benefits across a broad range of applications in the industrial ecosystem. The analog subsystem includes dual independent 1 Megasample-per-second (MSPS) 12-bit Analog-to-Digital Converters (ADCs) along with a 17-channel analog multiplexer front end. By closely integrating AMS with FPGA logic, Xilinx has been able to deliver the industry's most flexible analog subsystem.

Replacement of Analog “Housekeeping” Discrete Devices

The AMS feature is optimal for replacing a wide range of discrete analog circuits responsible for system-level “housekeeping” functions, including:

- Power monitoring and management
- Supervisors, voltage monitors, and sequencers
- Thermal management
- System monitor and control
- Single and multichannel ADCs
- Touch sensors

A broad portfolio of the “housekeeping” functions are available from multiple analog mixed-signal vendors in the form of discrete small- to medium-scale integrated devices. These devices come in hundreds of configurations, covering a wide range of possible combinations and needs. To learn more about the benefits of AMS for industrial systems, visit:

http://www.xilinx.com/products/technology/agile-mixed-signal/

Resistive Sensing: Human Interface Devices

Beyond the benefits of system-level integration, the high-performance FPGA logic allows for fine tuning of touch-screen processing algorithms, which can quickly exceed the processing capabilities of most stand-alone touch-screen devices. This expanded processing capability, in turn, can allow for a superior human-machine interface that is optimized to the application needs or the characteristics of the touch-screen materials.

High Availability Systems

Real-time industrial communications systems must also meet high availability standards, working and available 99.999% of the time. To meet these demanding requirements, systems typically employ hardware redundancy and include system monitoring for early indication of potential failures, such as power supply drift or the presence of excessive temperatures. The XADC block found in the 7 series FPGAs and in the Zynq EPP is ideal to address these needs.

Industrial Process Control

Industrial process control is concerned with maintaining the output of a specific process within a desired range. For example, a distillation process can require that the temperature of a liquid be maintained at a specific point within a narrow range. Programmable logic controllers (PLC) are often used in industry for managing these processes by continuously converting analog sensor outputs into digital values, analyzing the data, and then acting on the information based on a user-defined program.

Artix-7 and Kintex-7 FPGAs are ideal PLC components. With up to 17 analog inputs, the XADC block provides the ability to monitor multiple sensors using a single device. FPGA logic provides a powerful compute solution to monitor the data while easily performing filtering, threshold comparison, and control operations. The PLC designer can integrate flexible high-performance DSP functions, microcontrollers, logic functions, and data processing capable of handling millions of data samples per second—far in excess of some of the highest performance microprocessors.

Industrial Safety: IEC 61508

Safety systems have always been a critical component of the manufacturing environment, responsible for monitoring the general health and operation of the manufacturing equipment and shutting down a process when something operates outside its specifications. Smart sensors and actuators with integrated safety features, such as diagnostics and testing, continue to be introduced to market. These smart sensors typically integrate an analog sensor or multiple sensors with digital control logic to ensure that distributed control systems are continuously monitored for maximal safety.

IEC 61508 is the leading Functional Safety Standard for systems containing electrical, electronic, and/or programmable systems. In its basic form, a functional safety system detects a potentially dangerous condition and causes corrective or preventive action to be taken. Detecting dangerous situations is a function of the system under control. It relies upon auditing data from a wide range of sources—including analog sensors—and determines when a particular specification might fall outside a pre-defined tolerance level. These safety functions are typically implemented in a combination of analog and digital components and subsystems.

Xilinx offers FPGAs and the associated IP to address industrial safety. To learn more, visit:

http://www.xilinx.com/applications/industrial/index.htm

Xilinx Family of FPGA Devices for Industrial Applications

Xilinx offers a wide range of FPGAs and EPPs suitable for industrial applications. For more information, visit:

http://www.xilinx.com/products/silicon-devices/fpga/index.htm

http://www.xilinx.com/products/silicon-devices/epp/zynq-7000/index.htm

Summary

FPGAs are an excellent choice for designers building industrial ecosystems to meet the rapidly changing needs of the 21st century factory floor. With Spartan-6 and 7 series FPGAs, flexibility, cost competitiveness, ease of deployment, and integration with legacy systems are all advantages that make FPGAs a leading solution for factory automation and control. To learn more about Xilinx FPGA Industrial Solutions, go to:

http://www.xilinx.com/applications/industrial/index.htm.

Revision History

The following table shows the revision history for this document:

Date	Version	Description of Revisions
11/16/11	1.0	Initial Xilinx release.

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