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Using Xilinx Devices to Solve Challenges in Industrial Applications

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The automation of factory floors is driven by the insatiable demand for higher productivity, lower total cost of ownership, and improved safety in industrial systems. To meet this demand, industrial applications require faster computing performance, reconfigurability, higher data bandwidth, and higher system level integration. Industrial applications are now pushing the limits of what traditional logic devices are able to deliver. This white paper describes the trends and challenges seen by designers and how Xilinx devices enable solutions to meet their stringent design goals.

Leading Solutions for Industrial Automation

Across the broad spectrum of industrial applications, ranging from video surveillance to manufacturing automation, there are a few common trends that drive the need for industrial-optimized semiconductor devices. First, there is a shift from point- to-point data transfer to network-based communication. In video surveillance, this allows integrators to build larger, scalable, upgradeable, and more cost-effective systems for end customers. It also opens up video-stream accessibility to any device that can connect to the network, such as smartphones and tablets, for remote monitoring and control. Factory automation and control systems benefit from the expandability that networked communication and control offer, such as easily adding and upgrading equipment that is connected using standardized protocols.

The second major trend is towards miniaturization of application processing systems. Industrial surveillance cameras are beginning to incorporate sophisticated analytics and video processing in the camera itself, as opposed to sending video streams to a central server to be processed. Many factory equipment suppliers have learned that by incorporating sophisticated motor-control algorithms, they can use low-cost motors to do the job of large, expensive motors while reducing power consumption and improving reliability and safety. However, these control systems can take up much more space than is available at the motor, so the need for miniaturization is critical.

The third major trend across industrial applications is an increased focus on lower power consuming electronics. This is mostly a result of the need for miniaturization, because when high-performance electronics are squeezed into a tight, sealed box, there is no way to quickly remove heat. As the heat inside the box increases, performance of the system is reduced, and excessive heat can eventually cause reliability concerns for the components in the system. In some cases, such as in surveillance cameras that use Power over Ethernet (PoE), there is a strict power budget that must be adhered to.

These major trends have led to a demand for high-performance, Ethernet-ready, low-power semiconductor devices to control the next generation of industrial machines. Xilinx has developed a line-up of industrial-optimized logic devices based on cutting-edge 28 nm and 45 nm process technologies to specifically meet the unique needs of industrial systems. Xilinx FPGAs offer standard connectivity options from Ethernet Powerlink to USB while also giving users the ability to achieve hardware-accelerated performance for custom algorithms. Xilinx devices range from low-cost and low-power to high-content and high-performance, facilitating designs in varying ranges of complexity. Table 1 summarizes the selection of Xilinx industrial FPGAs and their corresponding focus applications.

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

Device Family	Process Nodes	Sample Industrial Applications
Spartan®-6	45 nm	Industrial networking, motor control, data acquisition interface
Artix™-7	28 nm	System management, I/O module
Kintex™-7	28 nm	Image and video processing, machine vision, high-bandwidth data transmission
Zynq™-7000	28 nm	Video surveillance, machine vision, motion control, industrial drives platform

Xilinx understands the challenges in the current market, and delivers value to its customers with the following five advantages.

Programmable System Integration

The embedded ARM® Cortex™ A9 processor in the Zynq-7000 All Programmable SoCs (AP SoCs) delivers a completely new level of programmable systems integration—well beyond what Moore's Law alone can provide. The modular cores are reusable across different applications. System designers can implement programmable system integration for applications where the processor needs to control different data streams, such as in motor control, video surveillance, and Ethernet switching. Thus, the reprogrammability feature of the FPGA allows the customer to quickly adapt to changing product specifications and differentiate products with customized features. For instance, in industrial networking, FPGAs support emerging real-time Ethernet as well as traditional fieldbus protocols.

Increased System Performance

FPGAs meet critical timing and performance requirements with parallel processing and real-time application performance. For example, in motor control, FPGAs enable real-time calculation for closing the control loop in less time. They also allow tighter control of torque, speed, and acceleration.

BOM Cost Reduction

Low cost is an important priority for customers. FPGAs and AP SoCs address this need by enabling differentiation via custom algorithms and functions. FPGAs and AP SoCs cut costs by being more efficient. For example, in video surveillance, a single Zynq-7000 AP SoC can reduce BOM cost by replacing ASIC/FPGA, DSP, and processor components. Features and functions supported by an FPGA can be updated long after deployment. In areas such as industrial networking and imaging, where the protocols and standards are shifting and changing, the programmability of FPGAs versus fixed-logic devices (e.g., ASICs and ASSPs) saves migration costs.

Total Power Reduction

Due to integration, low-power process, and power-optimized products, FPGAs consume less power. Process migration from 40 nm to 28 nm lowers both static and dynamic power consumption. 7 series FPGA innovations, such as re-architected transceivers, multi-mode I/O control, intelligent clock gating, power binning and voltage scaling, and the HPL process, lower the FPGA power budget and increase system performance.

Industrial applications such as motor control can reduce total system power by implementing algorithms such as field-oriented control.

Accelerated Design Productivity

Xilinx IP provides easy adaptation to changing interface requirements, rapid design iterations, and new feature additions. Vivado™ Design Suite for high-level synthesis (HLS) improves time to market upward of 2.5 times. The Image Signal Processor (ISP) for machine vision solutions can be implemented in FPGA logic, allowing for customization of algorithms and faster time to market.

Spartan-6 FPGAs (45 nm) are currently powering industrial ecosystems worldwide. Xilinx provides solutions with a scalable architecture in all 28 nm Xilinx devices, including Kintex-7, Artix-7, and Virtex-7 FPGAs as well as Zynq-7000 AP SoCs. These solutions 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.

This white paper addresses how Xilinx 7 series FPGAs and Zynq-7000 AP SoCs offer particularly powerful solutions for meeting industrial application needs. Xilinx value-adds in key segments like industrial networking, motor control, machine vision, video surveillance, and safety are also described.

Xilinx Advantages

Industrial Networking

The factory ecosystem is an increasingly integrated workplace requiring interfaces across 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.

The communications in a factory can be classified into three levels: the Ethernet, Process, and Device levels. See Figure 1.
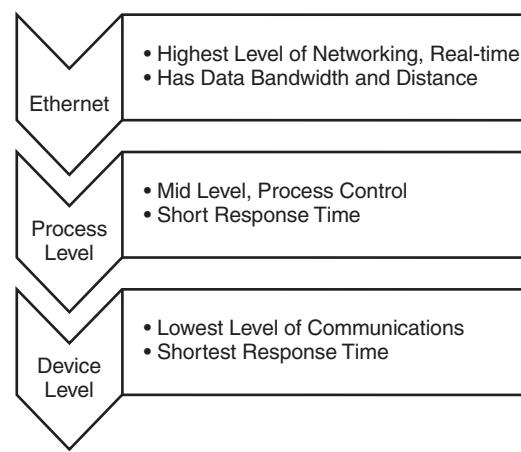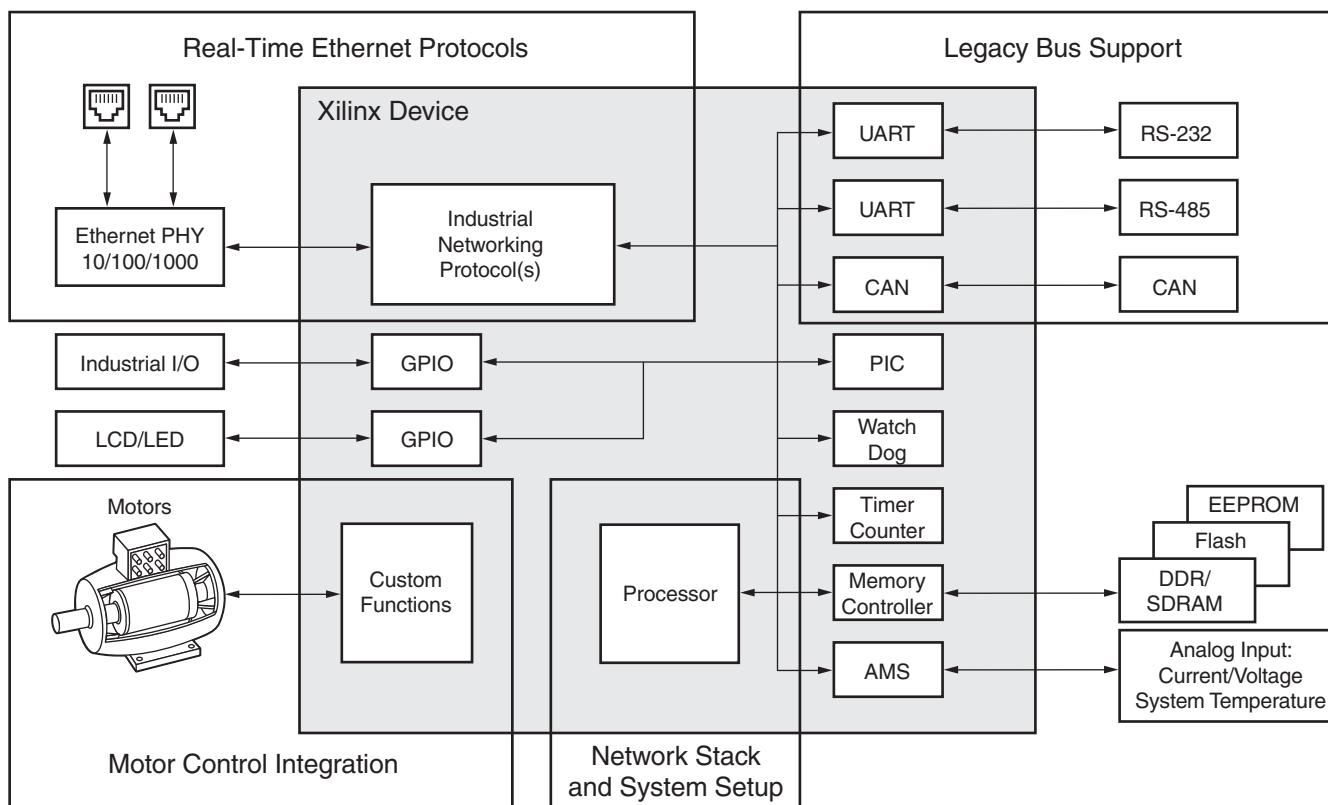
Ethernet
• Highest Level of Networking, Real-time
• Has Data Bandwidth and Distance

Process Level
• Mid Level, Process Control
• Short Response Time

Device Level
• Lowest Level of Communications
• Shortest Response Time

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Figure 1: **Factory Communications 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.

While real-time Ethernet protocols are emerging, there is still a need for Legacy Bus Support for existing factory floor systems. As shown in Figure 2, FPGAs allow easy bridging from Ethernet to RS-232, RS-485, and CAN. FPGAs are used extensively to support multiple protocols in one device because the device can be reprogrammed according to the requirement. Xilinx devices provide flexibility to adapt to system changes and provide access to future protocol evolution. Any communication between devices that is enabled by Industrial Ethernet can be implemented in Xilinx FPGAs.

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Figure 2: **Industrial Networking with Xilinx Devices**

Fieldbus communications employ RS-485, RS-422, and RS-232 as the physical layer interface, with protocols specified by the IEC61158 standard—for example, DeviceNet, CANopen, Profibus, etc. However, as Ethernet matures in the enterprise segment, many fieldbus installations are being replaced or redesigned with real-time Ethernet protocols augmented with deterministic communication profiles and mechanisms. Because of Ethernet's increased bandwidth and performance (compared to a traditional fieldbus), there is a great advantage in adopting Industrial Ethernet based communication standards. Market surveys are estimating that by 2014, the

number of Industrial Ethernet-based nodes can exceed the number of legacy protocol nodes.

Table 2 lists some popular industrial Ethernet protocols, their key industrial automation sponsor, and Xilinx partners.

Table 2: **Popular Industrial Ethernet Protocols**

Ethernet Protocols	EtherCAT	Ethernet Powerlink	Profinet RT	Sercos III	Ethernet/IP	Mechatrolink III
Consortium	EtherCAT Technology Group (ETG)	Ethernet Powerlink Standardization Group (EPSG)	PROFIBUS/PROFINET International	Sercos International	Open Devicenet Vendor Association (ODVA)	Mechatrolink Association
Reference Fieldbus	CANopen	CANopen	Profibus	Sercos I/II	DeviceNet/ ControlNet	Mechatrolink II
What is needed?	Custom MAC + Stack	Custom MAC + Stack	Ethernet MAC + Special Stack	Custom MAC + Stack	Ethernet MAC + Common Industrial Protocol (CIP)	Custom MAC + Stack
Xilinx Partner	Beckhoff	B&R, Avnet	Softing	Automata	PORT	Tokyo Electron Device

To achieve the real time, low latency, and deterministic nature required for industrial applications, 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. Zynq-7000 AP SoCs are strongly positioned for Industrial Ethernet due to competitive features such as integration capability, remote update, analog mixed signal, and multi-protocol support.

Industrial Motor Control

Motors are ubiquitous in industrial applications and account for more than 66% of the electrical power consumed in industrial systems. As the cost of power continues to rise and the automation of factories increases, motor efficiency becomes increasingly important. To achieve optimum efficiency, the motor control electronics read the motor's current and voltage and performs a series of mathematical operations using computed errors and corrections. The calculations result in optimized waveforms to drive the motor. 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, leading to less ripple and less energy dissipated by the motor. This results in a motor drive system with greater precision and efficiency.

MCUs running at low clock frequencies fulfill the needs of simple motor control applications. However, control algorithms are becoming increasingly complex in order to improve motor efficiency and reduce power consumption. Existing solutions run out of processing capabilities. Using an FPGA for hardware acceleration of time-critical tasks can help guarantee determinism. This solution brings performance and flexibility because the motor control algorithm can be developed or improved without changing the hardware.
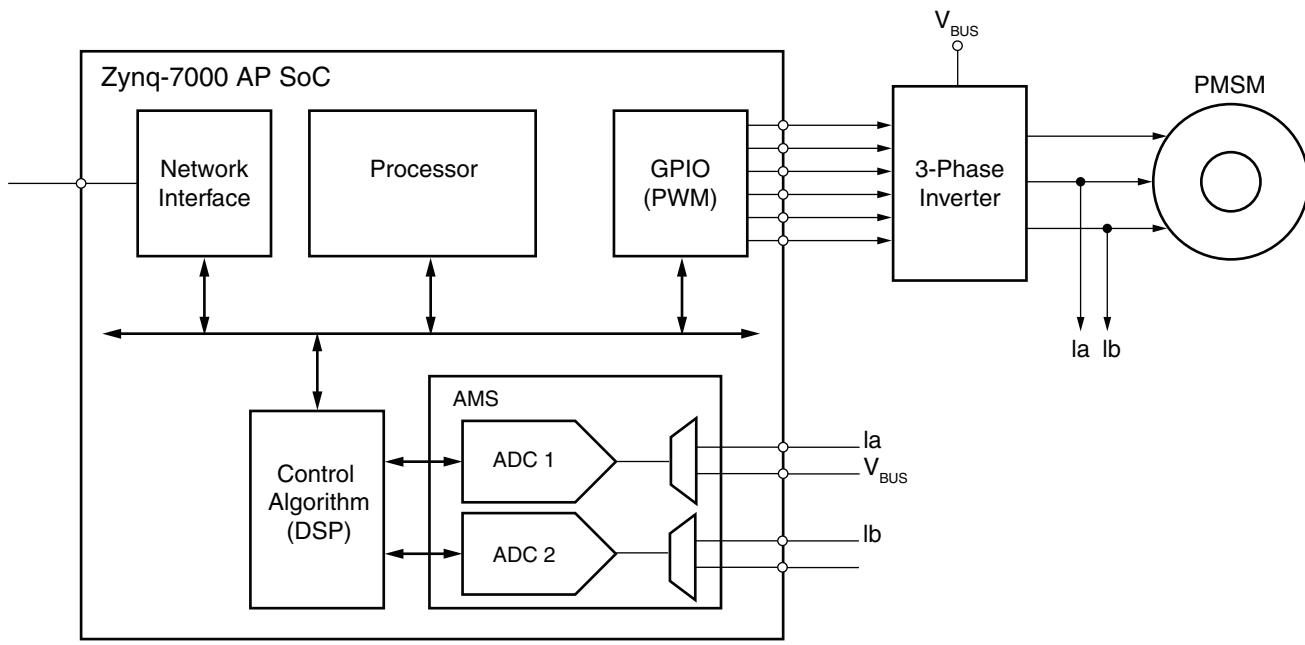
Also, advanced algorithms such as Field Oriented Control (FOC), which delivers great efficiency and performance, typically require fast computational and parallel processing performance that cannot be met using existing solutions. FPGAs can

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 and 7 series FPGAs and Zynq-7000 AP SoCs 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 features the Analog Mixed Signal (AMS) block, which contains two ADCs operating at up to 1 MSPS. The AMS block converts analog readings of bus voltage and currents into digital form to be processed by the FPGA. Since the AMS block is integrated with the FPGA, the need for an external ADC is eliminated, thus reducing another component in the overall bill of materials.

The use of FPGAs in Motor Control enables the designer to construct a processor offloading engine that frees up the main processor to perform system tasks without interruption. This can prove critical for applications that require real-time control, and can also be more cost effective than scaling up to a higher performance system process.

As an example of the benefits of a Zynq-7000 AP Soc -based motor controller, Figure 3 shows that an integrated high-performance motor controller can be designed based on the AMS, an embedded processor, DSP blocks, and support logic functions, including pulse width modulation (PWM), counter-timers, and serial communications channels.

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Figure 3: **Integrated High-Performance Motor Controller**

Xilinx offers 15 high-performance, easy to use, optimized motor control IP blocks in Spartan-6 and 7 series FPGAs and Zynq-7000 AP SoCs that allow the implementation of full vector control and easy integration with industrial networking protocols to realize a full fledged Variable Frequency Drive. The blocks offer fast synchronization, the smallest footprint, high dynamic range, and low microsecond response time. These characteristics are ideal for enabling single and multiple motors. Permanent Magnet Synchronous Motors (PMSM), Brushless DC (BLDCs), and Steppers are fully supported. 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.

A major advantage of using the Xilinx solution is that multiple motors can be controlled at the same time. Also, the user can switch from one modulation scheme to another while the motor is running. For example, the motor can switch back and forth between Pulse Width Modulation (PWM) and Regenerative Pulse Frequency Modulation (RPFM) according to the requirement, without any interruption. 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 detect/inspect manufacturing lines for quality control and for item tracking purposes. Another common use of machine vision is in vision-guided robotics. Machine vision comprises four components: image acquisition, processing, compression (if required), and transmission. All components of the machine vision can be realized using a single FPGA or a Zynq-7000 AP SoC.
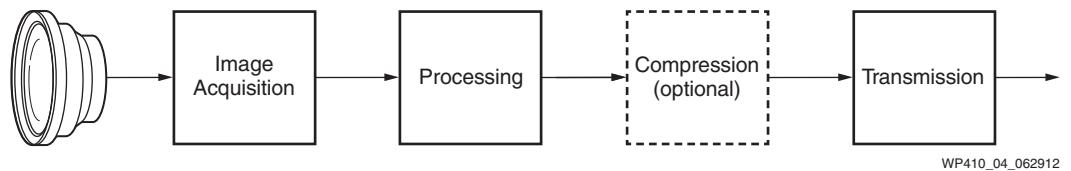

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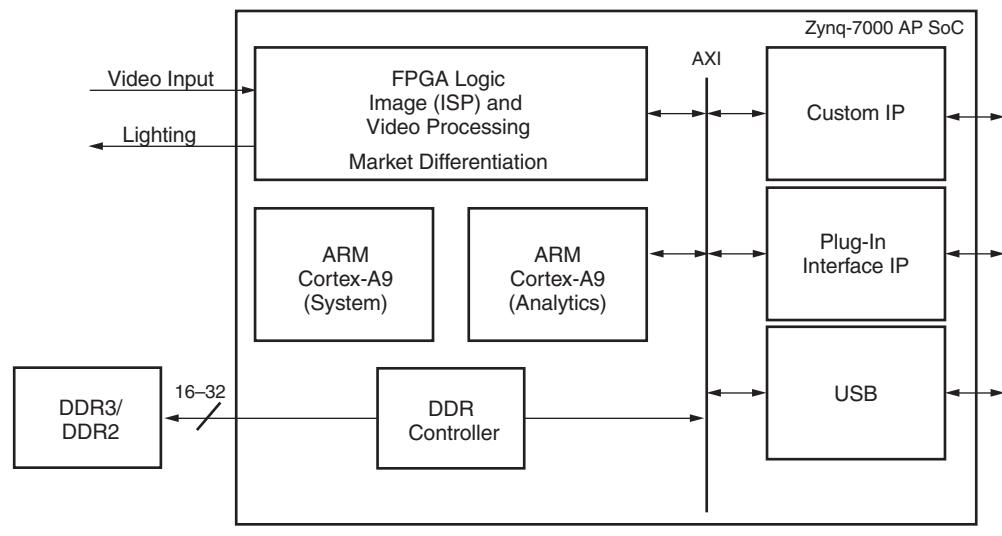*Figure 4:* **Machine Vision Block Diagram**

Because machine vision needs to perform inspection and sorting in the assembly line, it requires sensors that provide a high resolution and a 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% of camera interfaces over the next five years, even though some analog systems continue to exist in 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 using 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 FPGAs feature a camera interface up front that transfers the data into GigE Vision-compliant data packets.

Another advantage of using an FPGA is that the input sensors are very specific and have 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 not only provide the ability to supplement a custom image processing pipeline

unique to each sensor, they 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.

As Figure 5 illustrates, Xilinx devices are the essential components in machine vision for interfacing with sensors and transmission.
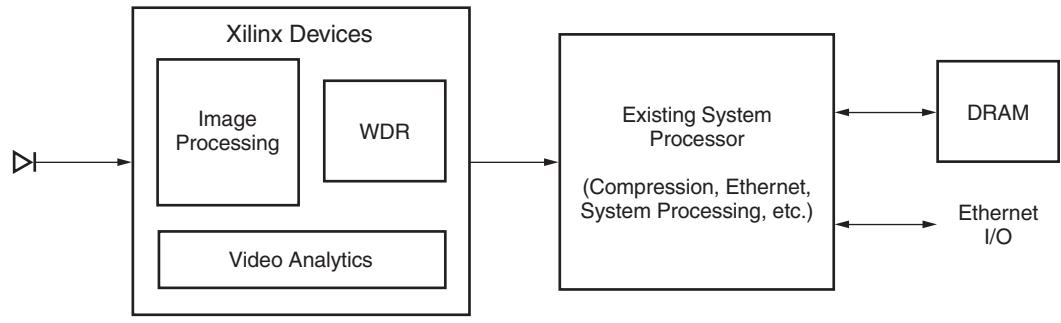

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Figure 5: **Machine Vision Camera Solution**

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. The high processing power requirement makes it important for intelligent cameras to capture and analyze data in real time, compress the data and then transmit. This sequence 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. See Figure 6.

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Figure 6: **Xilinx Video Surveillance Solution**

In this implementation, an FPGA/AP SoC 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.

The Zynq-7000 AP SoC is an excellent fit for video surveillance applications. With a single device, users can implement the image processing pipeline, WDR, and video processing in the FPGA logic. One of the dual embedded ARM A9 processors can be leveraged to run system management functions and an operating system, while the other can be fully dedicated to performing video analytics. By integrating multiple components into a single Zynq-7000 AP SoC, future surveillance cameras can achieve cutting-edge performance at lower cost in a smaller form factor.

Functional 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 maximum 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, as shown in Figure 7.
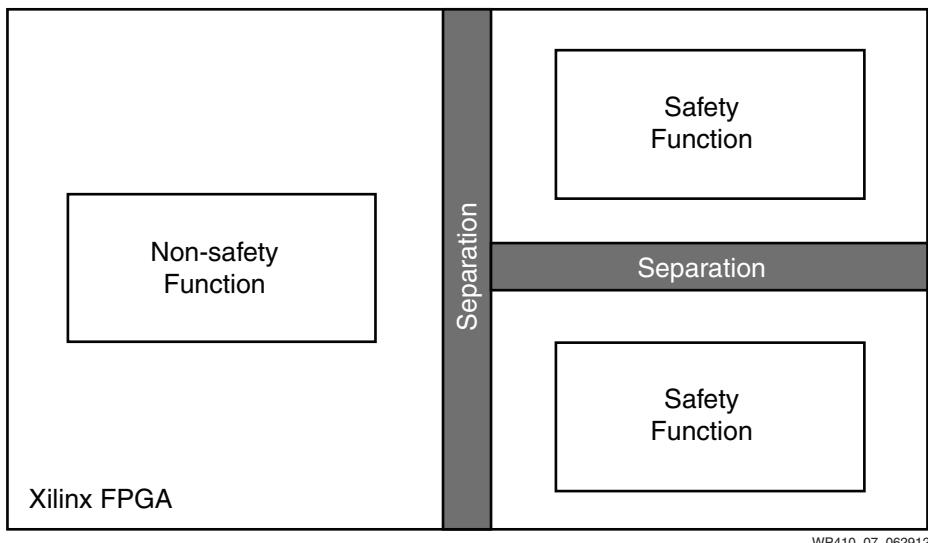
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Figure 7: **Xilinx FPGA Used to Implement Advanced Safety Functions**

Getting Started with Spartan-6 FPGAs

Spartan-6 FPGAs—built and implemented on a 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.

Avnet Spartan-6 FPGA Motor Control Development Kit

The Spartan-6 FPGA Motor Control Development Kit gives designers an ideal starting point for evaluating time-saving, proven, motor-control reference designs. FPGAs provide an integrated approach to achieve high precision, efficiency, and low noise. The kit also shortens the process of developing custom control capabilities, with integrated peripheral functions (Ethernet, Powerlink, and PCI® Express), a motor-control FPGA mezzanine card (FMC) with built-in Texas Instruments motor drivers and high-precision Delta-Sigma modulators, and prototyping support for evaluating alternative front-end circuitry.

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 such as EtherCAT, Ethernet Powerlink, Profinet RT, Sercos III, and Ethernet/IP, as well as 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 and Zynq-7000 AP SoCs 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 architecture that is optimized 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, Zynq-7000 AP SoCs allow for better integration and reduced cost due to lower BOM. The processing capability allows 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 AMS block found in the 7 series FPGAs and in Zynq-7000 AP SoCs 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. PLCs 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.

Zynq-7000 AP SoCs are ideal PLC components. With up to 17 analog inputs, the AMS 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. The on-chip dual-core ARM Cortex A9 processor provides a tightly integrated FPGA logic. It provides a single-chip solution that enables smaller form factors, lowers power consumption, and also reduces BOM costs through system-level integration.

Xilinx Family of FPGA Devices for Industrial Applications

Xilinx offers a wide range of FPGAs and AP SoCs 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.
10/25/12	2.0	Updated the title and the Page 1 abstract, Leading Solutions for Industrial Automation, Industrial Networking, Xilinx Advantages, and Getting Started with Spartan-6 FPGAs.

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