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TEXAS INSTRUMENTS

Design considerations when selecting a TI ARM®-based processor for industrial applications

Introduction

The technical sophistication of industrial applications is creating difficult challenges for the 8- and 16-bit microcontrollers (MCUs) that have traditionally dominated the sector.

Sensor-to-boardroom networks, distributed factory automation architectures, high-performance graphics and the widespread use of multimedia data types in high-end displays have all combined to put most aspects of industrial control and automation solidly within the performance spectrum of 32-bit processors.

For design engineers, the 32-bit trend offers a golden opportunity to swap the proprietary 8-/16-bit architectures for a standard 32-bit architecture readily supported by a robust software development ecosystem, which offers superior performance and has a sufficient number of chip vendors to assure competitive pricing.

ARM® Ltd.'s 32-bit processor cores have proven value in competitive markets, such as mobile phones, consumer electronics and enterprise systems. Its ARM9™, Cortex™-M3 and Cortex-A8 cores all feature capabilities making them strong contenders for integration into embedded processors targeted at the industrial control and computing market. Other applications these ARM cores can serve
equally efficient include point-of-service (POS), test-and-measurement, medical instrumentation, HVAC, remote monitoring and motion control.

Texas Instruments Incorporated (TI) offers designers a wide range of differentiated products including embedded processors in the Stellaris® MCUs, based on the ARM Cortex-M3 core, and the Sitara™ microprocessors (MPUs), based on the ARM9 and Cortex-A8 cores.

Scalability is the key to TI's ARM strategy. Given that software development drives over 50 percent of a product's total development costs, designers find it beneficial to develop multiple products on a single development platform. TI offers an extensive portfolio of embedded ARM devices that can span several generations of code-compatible ARM architectures.

In addition, TI's extensive customer support allows customers to scale performance, utilize a wide selection of peripherals and drive down system cost with enough headroom for differentiated features and future flexibility.

Processor selection

Knowing processor performance requirements is useful when choosing a TI embedded processor for industrial applications. Particular care should be taken, however, to include a realistic estimate of the performance required by the human-machine interface (HMI), particularly involving video, 2-D and 3-D graphics.

Other considerations, such as peripheral mix, are also highly relevant. Once a performance requirement is determined, applications roughly break down into three categories for applications requiring:

- Less than 150 Dhrystone MIPS: MCUs based on the ARM Cortex-M3 core provide the best price and performance

- From 150 to 500 MIPS: MPUs based on the ARM9 core are likely to be the best choice
- From 500 to 1,500 MIPS: MPUs based on the Cortex-A8 core are best for higher computing requirements

Human-machine interface

The widespread use of 3-D graphics, audio, video and other media types in industrial applications has made it a critical factor in processor selection.

Basic user interfaces characterized by touch-screen actuated buttons, slide bars and basic graphics can be handled by an MCU, such as one based on ARM®'s Cortex™-M3 core. Beyond that, a high-level operating system is required and the processor type shifts from an MCU to an MPU.

In automated facilities, operators working from remote-control stations often require monitoring and observing as much of the factory floor as possible and enabling this requires a new level of graphics capability. For example, most industrial systems are distributed, and operators typically access to each segment by clicking on tabs on the screen to view graphical displays of particular zones.

Advanced HMIs can display visualized data, 2-D and 3-D graphics, and video transmitted from inspection cameras on the factory floor. They can display critical process or production metrics in overlay windows. Scaling, rendering and windowing are common capabilities for HMIs. Touch-screen, keypad and voice are optional input types, all requiring an interface or peripheral.

A high level of interactivity, including switching views of inspection cameras, and issuing commands to alter the process or assembly line is often essential to factory floor operations. The control console could easily be kept busy receiving and processing data from hundreds of devices in the underlying architectural layers.

From a processor perspective, this level of interactivity can add up to an MPU with built-in video graphics capability, rich I/O options and lots of processing power. Among the few processors that meet all these qualifications are those in TI's Sitara™ family, based on Cortex-A8 and ARM9™ cores.

Not all industrial designs require the level of performance available in Cortex-A8 or ARM9-based processor. Controlling a limited number of PLCs is better suited to a Cortex M3-based processor in TI's Stellaris® family.

These kinds of limited applications typically do not require advanced graphics capability. Relatively basic HMIs consist of a touch-screen LCD display using representations of buttons slide bars and dials to construct the interface. Stellaris approaches its graphics interface from a software perspective since hardware assist is not necessary.

Its software development libraries include 130 fonts and several graphics primitives such as a line, rectangle and circle. Function calls can be developed to display widgets including checkbox, container, push button, radio button, slider and list box.

In addition, peripherals and software libraries play a significant role in selecting the right processor. TI has differentiated its embedded processors in several ways, including custom hardware blocks and other types of architectural enhancements.

Sitara™ MPUs: Programmable Real-Time Unit

Processors based on the ARM9™ core can realize significant performance and cost benefits by taking advantage of the Programmable Real-Time Unit (PRU) and the Universal Parallel Port (uPP).

PRU is a small, 32-bit processing engine with its own GPIOs, 4 KBytes of instruction memory and 512 Bytes of data memory. Designed to provide additional resources for real-time processing on chip, it can be programmed with simple assembly code to implement custom logic. In industrial applications, the PRU is usually configured into an I/O block, but it can be programmed to execute a variety of control, monitoring or other functions not available on chip.

TI provides a debugger and extensive support for the PRU helping ease the use. Customers have configured UARTs, timers, PWM controllers, EtherCAT slave functionality and smartcard interfaces with PRU. It is particularly valuable in industrial automation applications because many industrial automation interfaces are not common enough to justify being included in the list of interfaces, such as Ethernet, Controller Area Network (CAN) and USB that are most frequently integrated on chip.

The PROFIBUS interface, which is typically implemented in a 32-pin ASIC in a DIP package, is a good example of the value of integrating this functionality on chip. Both master and slave PROFIBUS functionality can be implemented using the PRU. Eliminating the ASIC from the design saves about U.S. $6 to system cost, and the PRU solution also saves board space and design time.

The **uPP – Universal Parallel Port** is available exclusively on ARM9™-based TI embedded processors. In industrial applications, the uPP is most often used to enable a fast interface between the processor and a FPGA or CPLD. The uPP has two independent channels that can operate in the same or opposing directions simultaneously and attain I/O speeds of more 1 Gb/s. Internal DMA allows it to offload the processor of DMA processing overhead.

The system-level cost savings by using the uPP can be significant. The most popular way to implement an FPGA interface without uPP, for example, is to use a memory card to make the FPGA look like memory to the processor. This solution can add U.S. $1 to U.S. $2 to total system cost. The cost can be avoided by utilizing Sitara family members based on the ARM9 core.

Sophisticated HMIs are becoming more common in factory-control applications. The processing demands these interfaces place on the processor can reach over 80 percent of the processor core's total available MIPS.

To avoid this performance penalty, TI has integrated a graphics accelerator into its Cortex™-A8-based processors to offload the core of standard graphics functions including scaling, windows overlay and basic display functionality.

Stellaris® MCUs: Determinisitic behavior

One of the differentiating characteristics of ARM's Cortex-M3 core is its hardware support for deterministic behavior. Instead of fetching data from caches, the Cortex-M3 fetches instructions and data directly from on-chip flash memory. It also includes hardware that saves the CPU state during an exception. It takes 12 cycles after receiving an external interrupt for the processor to pass control to the interrupt handler. Six cycles are required to service a higher priority interrupt.

From a design perspective, the Cortex-M3's built-in determinism enables it to replace a two-chip solution for motor control with a single MCU. In the past, a digital signal processor (DSP) would be required to control the motor associated with the node. Meanwhile, the MCU would be handling connectivity with the rest of the system. Cortex™-M3-based MCUs can handle both.

Hardware support of deterministic performance works best with a deterministic network protocol. The CAN protocol offers this feature and is capable of multicasting. TI provides six Stellaris® evaluation, development and reference design kits to support CAN.

Deterministic behavior improves the quality of the raw MIPS generated by the MCU. The Cortex-M3 delivers performance that customers have not been able to access in the MCU space previously. Designers find that they can do more with a Cortex-M3 processor running at 50 MHz than they could with other MCUs running at 100 MHz.

In addition to generating efficient use of available raw MIPS, Stellaris MCUs also maximize the utilization of Flash memory. The amount of on-chip Flash is a major contributor to MCU cost. By storing the RTOS in ROM, more Flash is created available to the system designer to service the application. Other information stored in Stellaris ROM include: peripheral setup and configuration code, Advanced Encryption Standard (AES) tables for cryptography and Cyclic Redundancy Check (CRC) functionality for error detection.

Peripheral integration

The industrial market is very broad, and its individual applications have a very wide range of required functionalities. Design requirements for specific applications are addressed by integrating peripheral blocks on the processor. For the majority, similar lists of generic peripherals are available from leading IC embedded processor vendors. Still at this level of integration, TI offers product differentiation.

Its Stellaris and Sitara™ families of embedded processors offer the advantage of integrating both the Ethernet PHY and MAC on chip, which reduces costs compared to a two-chip solution and saves board space. In addition to Ethernet, TI also provides a variety of chips with integrated CAN interfaces.

Below are additional I/O options in demand due to offering a wide range of data transfer applications:

- I^2C – a multi-master serial computer bus used to attach low-speed peripherals.
- UART/USART – an advanced high-speed, general-purpose communications peripheral
- SPI – a widely used synchronous serial data link that operates in full-duplex mode
- Inter Integrated Sound (I^2S) – drives a low distortion signal to an external IC for audio applications
- External Peripheral Interface (EPI) – a configurable memory interface with modes to support SDRAM, SRAM/Flash, legacy Host-Bus ×8 and ×16 peripherals, and a fast Machine-to-Machine (M2M) 150-MB/sec parallel transfer interface
- Universal Serial Bus (USB) – USB interface for point-to-point or multipoint applications often including USB host support for external storage of machine configuration or USB-on-the-Go

- MultiMediaCard/Secure Digital (MMC/SD) – the MMC and its successor, the SD format, are both Flash memory card standards
- Serial ATA (SATA) – the SATA computer bus standard is used for connecting host bus adapters to mass storage devices such as hard disk drives and optical drives

In industrial applications, functionality such as very fast general purpose I/Os (GPIOs), pulse width modulation (PWM), quadrature encoder inputs and ADC channels are important for motor control and other machinery and process equipment. These peripherals are available in different combination on Sitara™ and Stellaris® processors.

Software development

Design teams developing applications on top of high-level operating systems (OSs) often discover that they must fill in gaps between an embedded processor's custom capabilities and the generic OS's inability to take advantage of them. By having to develop codes for OS enhancements, it takes time away from application development.

To ease the development process, TI provides Linux and Windows® Embedded CE board support packages (BSPs) that are optimized to run on TI's Sitara MPUs.

In addition, TI has developed frameworks for the routine activities that occur when interacting with media. The frameworks – which are similar to middleware – allow design teams programming in C to focus on programming applications. Similarly, PLC programming is made easier by a framework allowing the designer to work in C and not have to concern himself with the intricacies of distributed processing.

For customers, who design with real-time operating systems (RTOSs), TI has developed relationships with leading RTOS vendors such as Green Hills Software (Integrity OS), and QNX (Neutrino OS), to name a few. Just as with Linux and Windows Embedded CE, optimized versions of these RTOSs free designers time so they can spend more time on their application.

Power consumption

Power has become an important characteristic for all applications, even those that draw power from the power mains. But whereas portable designs are largely concerned with the power consumption of the processor, industrial systems designers also have an eye on electric bills and keeping utility costs as low as possible over time. Reduced power consumption also has positive environmental effects.

Electric motors are ubiquitous in factories and processing plants and in general consume large percentages of the plant's power. However, deterministic performance in the MCU core has a significant role to play in power efficiency. As in the Cortex™-M3 when the efficiency of the MCU's interrupt service increases by 60 percent, less system level power is consumed. A 60 percent better interrupt service means the MCU can stop and start motors 60 percent faster – and this power saving adds up throughout the year.

Another power issue is the trend toward designing fully enclosed factory automation systems to guard against dust and other contaminants normally found in factory environments. If cooling the processor and associated electronics requires more than a heat sink, the designer is forced to consider vents and fans, which defeats the original goal of an enclosed system.

Conclusion

The design environment for industrial control and similar applications is evolving for the better. More vendors are offering processors based on ARM®'s field-proven embedded processors cores and there is a robust ARM software development ecosystem to support the migration to 32-bit ARM architectures.

That does not mean, however, that all ARM-based products are equal. A large and growing inventory of MCUs is not sufficient. Product differentiation is important. To a large extent, this will be determined by the industry leading software development tools, libraries and configurations that TI makes available to its customers.

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