Optimizing control and design for industrial robotics

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Introduction

With the rise of factory automation, robotics has become increasingly important in the production of goods. Robotics can increase manufacturing efficiency, reduce cost and increase quality. Globally, manufacturers are relying increasingly on robotics to churn out products with increased speed and consistency.

This white paper serves as an introduction to industrial robots in general and more specifically about robot control units. It covers some important applications and system technologies that would help understand how industrial robots control units are architected, as illustrated in **Figure 1**.

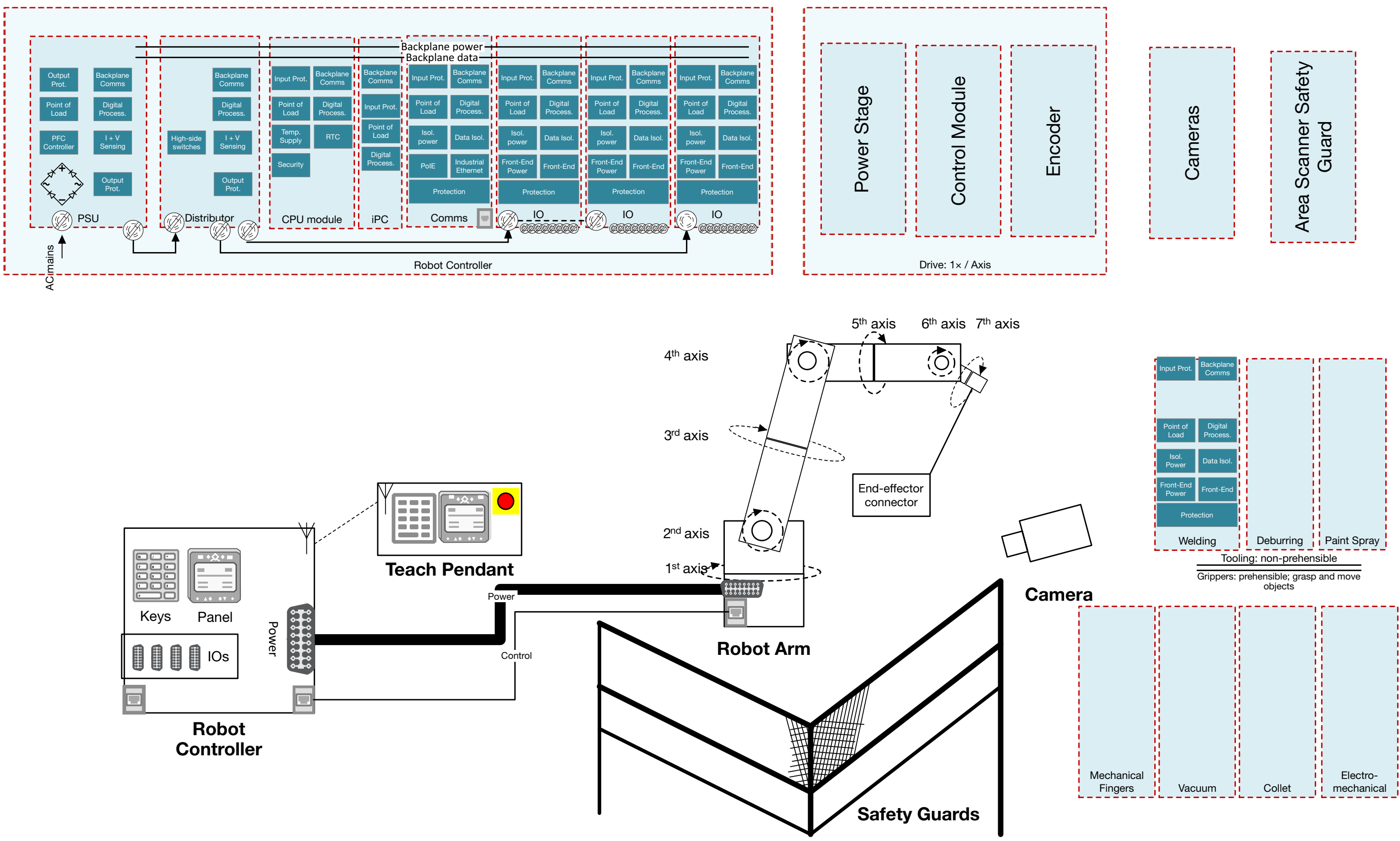

Figure 1: *Typical system components in an industrial robot system.*

For more information on this topic, [read our how sensor data is powering artificial intelligence (AI) in robotics] white paper.

Applications

Applications that benefit from industrial robots are product assembly, material handling, machine tool management, packaging, welding and logistics.

Logistics robots especially have become increasingly important in online retail. These are autonomous robots that assist in gathering items for shipment from warehouse inventory, and efficiently enable shipment. **Figure 2** shows an example reference diagram for an autonomous guided vehicle (AGV). Online retailers are starting to utilize autonomous logistics robots for order fulfillment. For large retailers, it would be nearly impossible to run their business without robotics or some form of automation. Some example applications for robotics are shown in **Figure 3** on the following page.

The advantages robotics provide are achieved by advances in functional safety and reliability of systems designed by robot vendors. Texas Instruments (TI) has a wide range of processors that fit perfectly for these applications, including **Sitara™ processors** for the robot central processing unit (CPU) and **Hercules™ Arm® Cortex®-R4 and -R5 based microcontrollers** for functional safety applications. Customers looking to achieve safety integrity levels (SIL) in their robot products can do

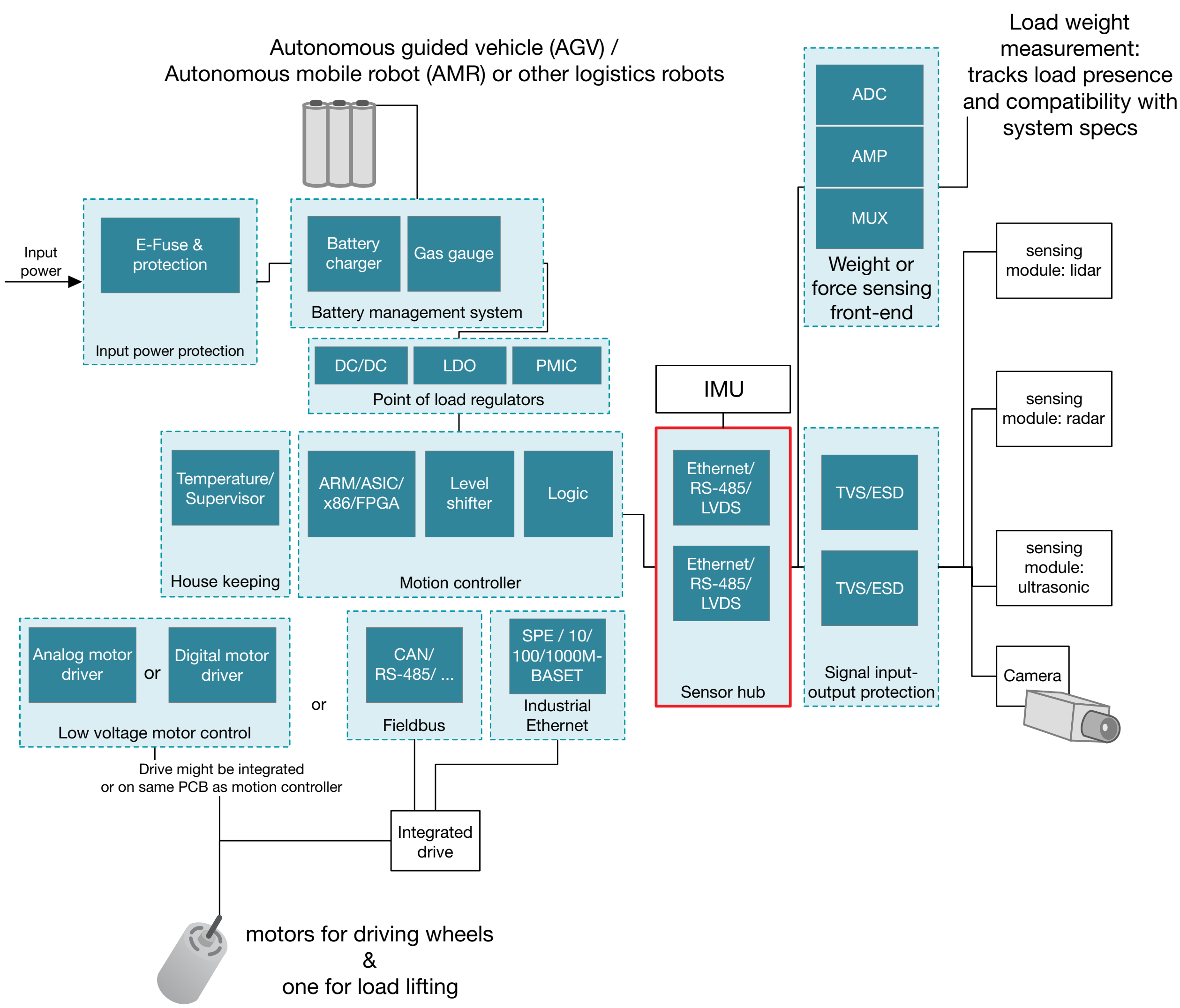

Figure 2: *High level block diagram for an autonomous guided vehicle or robot.*

so by designing their systems leveraging [Hercules devices](), followed by system certification from an independent assessor.

Another growing application for robotics is unmanned aerial vehicles (UAV) also known as drones. With advancements in sensor and battery technologies, drones have become common place in agriculture applications such as crop monitoring and soil and field analysis. Drones are also used in some countries for vaccine and donor blood delivery services to rural regions. As technology evolves, more applications in robotics will emerge.

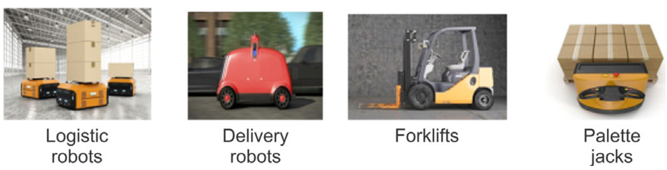

Figure 3: *Examples of robot applications.*

Industrial robot controller systems

High-end industrial robot controller

High-performance industrial robot systems in factories utilize robot arms, controllers and teach pendants. Various types of robot arms are available depending on the application. Each robot arm has their own number of controlled axes and payload capacity. The controller within the system is designed to manage many types of robot arms through a configurable and flexible system based on modular system architecture. See **Figure 4** for a typical system block diagram for a high-end industrial robot. As far as scalability, the controller system supports functional modules and the capability to scale the performance and functionality based on the system configuration. The basic robot controller system includes individual modules supporting the main CPU, motion control, input / output (I/O) control, sensor(s), functional safety and industrial communication. The backplane system bus to connect multiple functional modules is critical for high-performance robot operation and therefore requires high data throughput and low latency. The typical robot controller system uses an application-specific integrated circuit (ASIC), PCIe or Ethernet base for the backplane system bus. In addition to these common modules of the robot controller system, an additional functional module can be added to extend the capability of the robot arm based on the requirements from various applications.

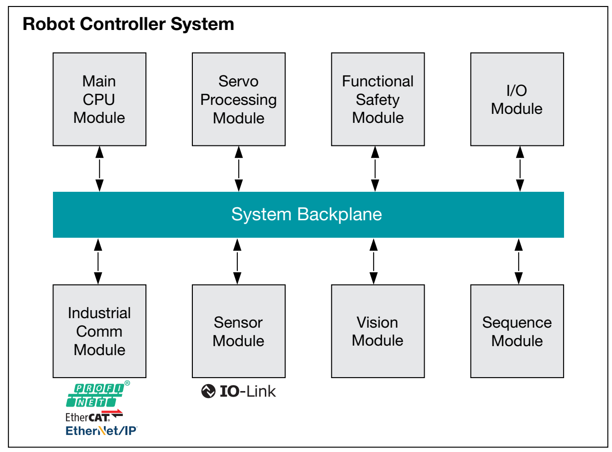

Figure 4: *Robot controller system example for high-end industrial robots.*

[Sitara processors]() can cover the functionality and performance needs required by most functional modules in the high-end robot controller system category. Sitara AM57x processors can provide high processing performance required by the main CPU module and servo processing module. [Digital signal processors (DSPs)]() provide additional signal processing performance required for servo and motion signal processing in lower power consumption. [Sitara AMIC processors]() are optimized for industrial communication and can be used as the interface to the system backplane bus when an industrial communication protocol is needed. Sitara processors can support multiple industrial communication protocols with programmable real-time unit industrial communications subsystem (PRU-ICSS). They can also reduce development cost and time required for developing separate modules for supporting various industrial communication protocols.

Integrated robot controller for cobot and SCARA robot

The control system for a collaborative, or selective compliance assembly robot arm (SCARA), robot is simpler than a high-end robot controller, as it typically controls less axes and has a slower speed than high-end robots. **Figure 5** shows an example system block diagram for a single-board robot controller system for collaborative or SCARA robots. The control system can also be much simpler and can consist of a single board or a few boards. At the same time, smaller size and lower system cost becomes more important to save factory space and integrate the controller as a part of an industrial robot arm system. Because a SCARA robot can be placed much closer to humans, functional safety becomes more important to use a robot without other safety system such as safety fences.

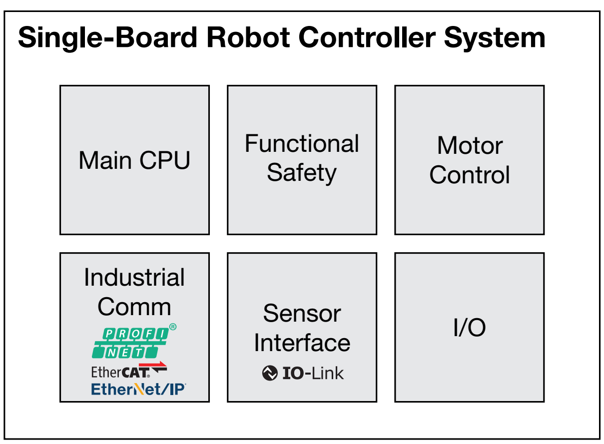

Figure 5: *Single-board robot controller system for collaborative or SCARA robots.*

Sitara AM57x and AM65x processors can support most of the required features and functionalities with integrated industrial communication, motor control and functional safety and realize robot controller system with fewer system components.

Controller for Cartesian robots

The robot controller solution for Cartesian, or single-axis, robot is much simpler and only requires basic functionality for controlling one or two axes motors. However, current controller systems are based on a few MCU and ASIC devices given that robot control and motor control are separated and additional industrial communication IC is required. Sitara AM437x and AMIC120 devices feature multi-protocol industrial communication, robot/motion control and motor control including encoder interface with a single device and can support Cartesian robot controllers with one or two axes as shown in **Figure 6**.

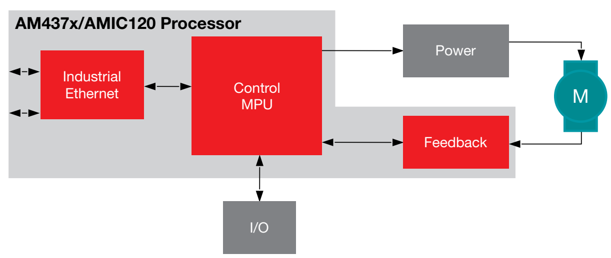

Figure 6: *Single-chip robot controller system based on AM437x or AMIC120 processors.*

Industrial communication

There are over a dozen different communication protocols on the market for industrial Ethernet, field-bus and position encoders, each with its own pros and cons. EtherCAT®, PROFINET® and EtherNet/Industrial Protocol are some of the most popular Ethernet-based protocols in the servo drives market. Hiperface® Digital Servo Link, EnDat 2.2 and Bidirectional Interface for Serial/Synchronous C are among the more popular position-encoder protocols for other types of industrial robots.

Many of these protocols have ASICs that allow users to attach to host processors to support specific communication protocols. In some cases, with a multi-chip solution, the protocol's stack runs on the host processor and the ASIC performs the media access control layer. Manufacturers who only plan to support a single protocol prefer this distributed architecture, since ASICs are typically optimized for specific communication standards. Once the need to support multiple protocols arises, a multi-chip solution loses its attractiveness because of the new development effort and costs and the maintenance of multiple versions of their boards for each protocol.

By leveraging integrated multiprotocol support onto the host processor, designers can save costs, board space and development effort, while also minimizing the latency associated with communication between external components and the host. A single platform supporting multiple standards enables you to maintain a single board for the different versions of your end product. Another consideration is the need to support Time Sensitive Networking (TSN) and then desigining a solution that's flexible enough to adapt to evolving TSN standards. The Sitara AM6x processor family provides a solution through its flexible PRU-ICSS, which enables gigabit TSN as well as traditional 100-Mb protocols like EtherCAT.

Functional safety considerations

Industrial robots have been used for over five decades in widely varying applications, ranging from spot welding in manufacturing to the pick-and-place operations in the packaging industry. The emergence of more complex robotic applications and systems in recent years has led to advances in functional safety capability of MCUs. This enables use of robots in new application environments and enables robotic automation that can operate in closer quarters with humans in the production environment. While the use of collaborative robots in industrial production is only now beginning, there has been a lot of work already in the development of the required safety capabilities residing in sensors and processors and in the standardization of industrial robot requirements.

Highly integrated MCUs and processors can also help streamline functional safety development. Developed according to the IEC-61508 safety standards, TI Hercules MCUs include features enabling functional safety in hardware and detect potential failure modes with quick response time. Hercules MCUs are also used in applications requiring a dedicated processor to perform a specialized function. In these systems, the Hercules MCUs function as the "safety checker" that ensures that the system is always maintained in a safe state of operation. Sitara AM65x Arm-based processors feature two or four Arm Cortex-A53 cores and include a dual-Arm Cortex-R5F MCU subsystem to make it easier for customers to develop functional safety applications. To learn more about functional safety, read our white paper titled, "**The state of functional safety in Industry 4.0**."

Enabling machine learning

As robotic technologies advance, so do complementary sensor technologies. Much like the five senses of a human being, combining different sensing technologies offers the best results when deploying robotic systems into changing and uncontrolled environments. Even the simplest tasks that a robot performs will depend on machine vision to feed data into machine learning technology. Grasping an object, for example, without pre-determined locations and motions would be impossible without leveraging machine vision to reconstruct a 3D image and utilizing machine learning algorithms to translate this visual information into a successful action on the part of the robot.

Machine learning, and its branch named deep learning, has recently become a popular approach to processing all the data collected from sensors to enable the system to make intelligent decisions. Sitara AM5749 processors enable designers to run **machine learning** inference at the edge. Machine learning technology helps simplify programming and enables new ways to operate robots.

Software is also increasingly important in the development and deployment of robots and designers need an easy-to-use, flexible software platform to add features to their products as needed. Solutions like the **Processor SDK** (software development kit) allows designers to maximize their software reuse and migrate software across the TI processor portfolio. The Processor SDK is a unified software platform for TI processors that enables quick setup and out-of-the-box access to benchmarks and demos. Additionally, specialized versions of the Processor SDK Linux include support for the ROS (Robot Operating System) framework utilized by developers of robot controllers.

Conclusion

There are a variety of system considerations a robotics designer has to make when designing a robot. Determining the central processor, system safety levels, sensors and software are all important when considering the application the robot is trying to address. When developing any robotics application, it's important to have options when evaluating system components. Scalable hardware and software solutions like Sitara processors or Hercules MCUs give designers the flexibility to create a variety of capable solutions for robotics.

Additional resources:

- Learn more about TSN in our white paper titled, "**Time-sensitive networking for industrial automation**."
- For more information about how sensors are being used in robotics, download our white paper titled, "**How sensor data is powering AI in robotics**."
- Read our white paper titled, "**Bringing machine learning to embedded systems**" to learn more about machine learning with Sitara processors.
- Download our **reference design** for Processor SDK Linux in robotics applications.