Case Study

Intel® FPGA
Functional Safety Data Package

Using Intel® FPGAs for Servo Control and Functional Safety in High-Performance Robot Controllers

Yaskawa Electric selected multiple Intel® FPGAs for use in its YRC1000 robot controller. The company also reduced the amount of work needed for functional safety certification by adopting Intel's IEC 61508-certified Functional Safety Data Package.

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Shrinking workforce among factors behind greater use of industrial robots

The robotics industry has strong market growth in the industrial machinery sector. Process efficiency improvement and automation are more urgent than ever given the short supply and rising cost of labor brought about by a shrinking workforce and aging demographics in several countries. As a result, use of multiaxial robots capable of diverse operational and transportation tasks is expanding rapidly in manufacturing and other workplaces. Along with conventional robots that operate behind a safety enclosure, use of collaborative robots and automatically guided vehicles (AGVs) capable of sharing space with humans is also on the rise.

While past practice has been to use custom Large Scale Integrations (LSIs) for robot control, development costs have risen in tandem with semiconductor process miniaturization, with development times being measured in years.

Safety measures are also an essential requirement for robots. One example is the need for light curtains or other such sensors to halt robot operation immediately on detection of any human intrusion into the safety enclosure. This places an obligation on robot manufacturers to obtain certification that their products comply with the relevant standards in some regions*[1].

This issue is one of the reasons why Intel FPGAs capable of logic replication are increasingly being used in robots as an alternative to ASICs. Intel FPGAs feature high device reliability and are already widely used in a variety of industrial machinery. Intel was also among the first in the FPGA industry to act on compliance with functional safety standards and the associated certification. This case study describes the use of Intel FPGAs in robot controllers by Yaskawa Electric.

Yaskawa Electric's YRC1000 robot controller combines small footprint with fast and precise control

Yaskawa Electric is a major manufacturer of industrial robots. The company's 6-axis vertical articulated robots, are marketed worldwide under the Motoman brand for a wide range of uses. These include arc welding, spot welding, painting, handling and assembly, biomedical applications, palletizing, press part handling, shearing, cutting, laser cutting, deburring, polishing, coating, and the transportation of semiconductor wafers and glass panels for LCDs or photovoltaic cells. In recent years, the company also focused on collaborative robots (cobots) that are able to work alongside people on production lines.

Along with the manipulator, an arm with multiple axes of movement, industrial robots also require a device called a programming pendant that is used to teach the robot its movements and a controller that replicates the movements in each axis as instructed by the pendant.

The YRC1000 high-performance robot controller made improvements in acceleration control that replaced the speed control mechanism used in the past, which means that the controller can operate the manipulator at maximum speed. Likewise, a new technique for arm tip trajectory control ensures that the same trajectory is closely replicated regardless of speed, including during test operation and playback mode. The YRC1000 is also the smallest-in-class among Yaskawa Electric robot controllers, being 50% smaller by volume than the previous DX200 model. Other features include compatibility with different power supply standards in different countries (Figure 1).

Multiple Intel FPGAs are selected for implementation of robot control, servo control, and functional safety

Seeking greater performance and precision, Yaskawa Electric chose to adopt a number of Intel FPGAs for applications that include robot control, servo control, and functional safety (Figure 2).

For Yaskawa Electric, the main benefits of using Intel FPGAs are as follows (Figure 3):

(1) Higher servo control performance and lower power consumption: Moving the multi-axis manipulator involves calculating the control values needed to achieve the desired movements and then outputting these to the various motors. This includes complex trigonometric functions and other calculations based on the current positions and angles determined by the encoders for each axis.

Rather than software running on a microprocessor, accuracy and speed are more easily achieved by executing this kinematic calculation on hardware. In other words, it is an ideal application for Intel FPGAs, which are equipped with an onboard digital signal processing for executing high-speed 32-bit double-precision floating-point arithmetic on hardware and offer deterministic performance.

Intel FPGAs also offer an extensive range of hardware IP, including PCI Express, thereby facilitating circuit miniaturization and lower power consumption by enabling the integration of peripheral logic while ensuring reliable bus connectivity.

This lower power consumption allows for fan-less housings, eliminating the need for mechanical parts that are subject to wear and avoiding the intake of dust.

(2) Most of the safety-related systems required by IEC 61508 and other functional safety standards can be consolidated in Intel FPGAs. Moreover, the use of multiple devices means they can monitor one another. Meanwhile, the deterministic performance made possible by hardware implementation, as noted above, is ideal for safety-monitoring applications where delays are not acceptable.

Intel also supplied its IEC 61508-certified Functional Safety Data Package (TÜV Rheinland certified), to help Yaskawa Electric reduce the amount of work required for functional safety certification of the controller.

(3) Cost reduction: Semiconductor process miniaturization and rationalization reduces the total system cost, not only by making the FPGAs themselves more cost competitive, but also through other considerations such as the integration of peripheral logic, reduction in circuit size, and shorter development times made possible by the flexibility of logic configuration on FPGAs.

(4) Long product availability: Maintenance considerations call for an extended device supply period because industrial equipment typically remains in use for 10 years or more. The extended product lifecycle of Intel FPGAs meets the needs of industrial-sector customers.

(5) Development timeline: Along with shortening the development and verification cycle compared to ASIC development, the use of FPGAs means that changes to logic can be made rapidly in the event of a problem, or if necessary, for modifications or enhancements to functional requirements.

As shown in Figure 2, the controller uses an Intel processor and an Intel network controller as well as Intel FPGAs.

Figure 1. Features of Yaskawa Electric YRC1000 robot controller

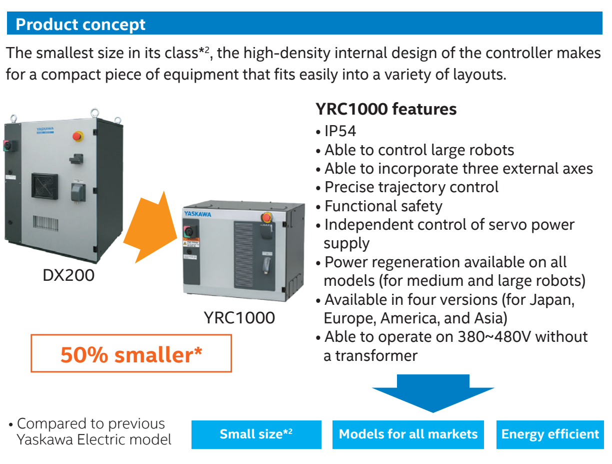
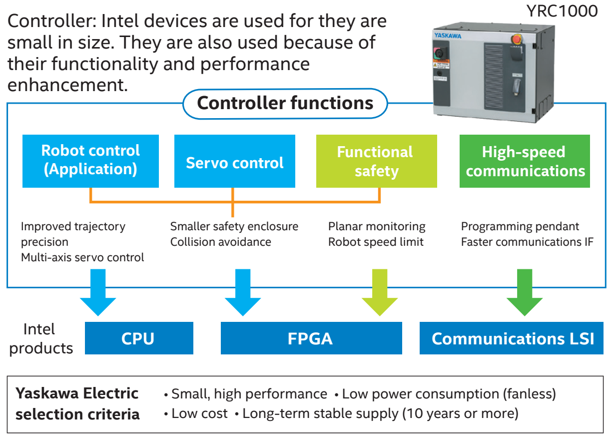


Figure 2. Multiple FPGAs used in Yaskawa Electric YRC1000 robot controller



Cross-monitoring of encoders by multiple Intel FPGAs safety functions implemented in accordance with functional safety standards

Stringent safety measures are essential when using robots or other industrial machinery to help ensure that harm does not come to nearby people or property in the event of an operational error or malfunction, and to keep consequences of any such incident to a minimum. While there are many ways of providing these safety features, such as the use of safety notices or the physical barrier provided by a safety enclosure, the term "functional safety" refers to risk mitigation by means of electric circuits, electronic circuits, or software.

To comply with the functional safety standards, it is typically necessary to augment the control system with additional safety functions. On the YRC1000, these safety-related systems are implemented on a separate circuit board (the "safety circuit board") (Figure 4).

The task of Intel FPGAs on the safety circuit board is to continuously monitor the position and speed of the robot arm based on data from the encoders for each axis. One example of a safety function would be a mechanism for immediately halting the axis motors if for some reason the arm moves outside a predefined region or exceeds a predefined speed.

The YRC1000 also incorporates various other enhancements to reliability and safety, including having the different Intel FPGAs cross-monitor each other's encoder data.

Use of Intel's IEC 61508-certified package helps reduce the time and effort for controller certification

Compliance with functional safety standards is a mandatory requirement of various countries and regions. The 2006/42/EC machinery directive of the EU, for example, mandates compliance with IEC 61508. This obliges equipment vendors to update their internal quality management systems to encompass the relevant standards and to incorporate this into their development and verification processes.

Furthermore, it is also common practice to use a third-party agency to certify that a company's equipment complies with functional safety standards.

Recognizing the importance of the standard, Intel launched its industry-first IEC 61508-certified Functional Safety Data Package for reducing the amount of time required to certify the functional safety compliance of systems that include Intel FPGAs in 2010, the same year as the second edition of IEC 61508 was published.

The Functional Safety Data Package is intended for designs up to IEC 61508 safety integrity level three (SIL3), with certification of the FSDP being handled by TÜV Rheinland, a German third-party certification agency. The package includes the following items:

(1) Guidelines for using Intel FPGA development methodologies and tools to design systems that satisfy the IEC 61508 certification requirements

(2) A tool for FMEDA which calculates failure rates and safe failure fractions (SFFs) for systems that use Intel FPGAs

(3) Safety manuals specifying how to use the Intel® Quartus® Prime design software and Intel FPGA systems in a way that complies with IEC 61508

(4) Certified IP for hardware such as the Nios® II processor, and IEC-61508-compliant diagnostic IP (including source code) for monitoring the integrity of FPGAs, memory, and clock signals

(5) Latest reliability reports on Intel FPGAs

(6) Compliance certificate issued by TÜV Rheinland

* Refer to the list at the end of this article for details of the Functional Safety Data Package contents*3.

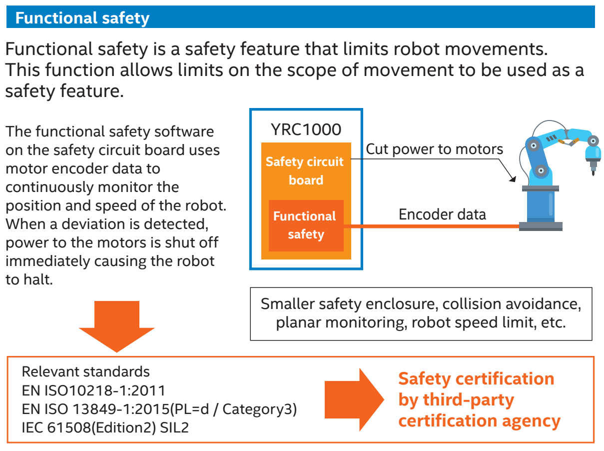
Along with the robot controller described in this article, the Functional Safety Data Package has helped shorten the time and reduce the costs involved in implementing functional safety and acquiring certification for safety-critical industrial machinery such as industrial servo drives, inverters, safety devices, and automation controllers (Figure 5). Depending on the circumstances, Intel estimates that the product development time can be greatly shortened.

At Yaskawa Electric, the Intel Functional Safety Data Package was successfully utilized in the development of the YRC1000 safety-related systems shown in Figure 5, shortening the time taken for certification under the IEC 61508 SIL2, EN ISO 10218-1:2011, and EN ISO 13849-1:2015 safety standards.

Figure 3. Benefits of using Intel FPGAs

	Item	Benefits
Q	Servo control	• Use of FPGA to achieve single-chip implementation including peripheral control logic and utilizing the onboard Arm Cortex-A9 processor to perform double-precision floating-point arithmetic • Use of PCI Express hardware IP to provide reliable high-speed bus connections to external devices • Use of low-power FPGA to achieve fanless implementation
Q	Functional safety	• Use of FPGA for single-chip monitoring of encoder position information, with cross-monitoring between different chips • Users can shorten the time taken to acquire certification by using devices (FPGAs) and a development environment that satisfy IEC 61508 functional safety requirements.
C	Cost reduction	• While industrial products tend to be produced in smaller quantities than consumer products, the reasonable pricing of FPGAs makes them a realistic option.
D	Long Product Availability	• Devices can be used for 10 years or more (typically 15 years or more), with a product life of 10 years or more being required when intended for industrial applications.
D	Development time	• Use of FPGA enables rapid product development compared to a custom ASIC (SoC), with development benefiting from the ability to make frequent modifications to internal logic

Figure 4. Overview of YRC1000 functional safety



Intel FPGAs and Functional Safety Data Package meet the changing needs of industrial robots

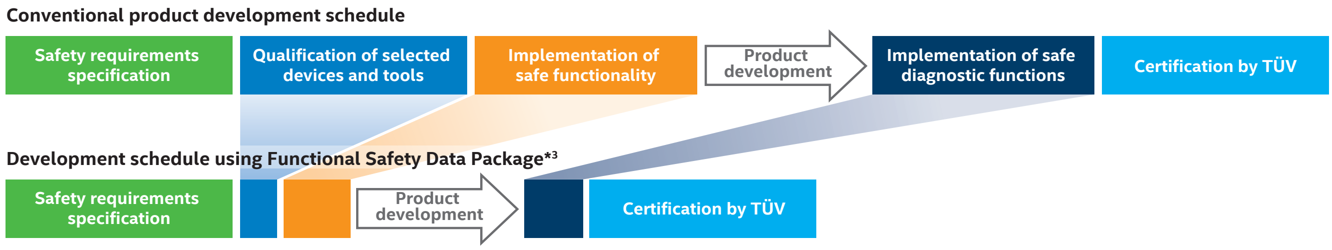
The concept of smart factories or smart plants that feature more intelligent operation is attracting attention against a background that includes the never-ending pursuit of productivity and efficiency, advances in IT, and a shrinking workforce in several countries.

The wider adoption of these smart practices will likely be accompanied by greater use of such technologies as collaborative robots, autonomous robots, and autonomous AGVs, especially the industrial robots described in this article. Trials have already commenced on remote control applications that incorporate fifth-generation (5G) telecommunications and private 5G systems. Along with higher performance and precision, there is also a need for further enhancements to safety and reliability.

Intel FPGAs and the flexibility they offer for modifying logic will likely prove to be valuable assets for dealing with safety requirements as well as with these new smart practices and other rapid market changes. As one of the world leaders in industrial robots, Yaskawa Electric, has already put Intel FPGAs to work improving the performance and precision of its robot controllers and facilitating functional safety implementation. By adopting the Intel Functional Safety Data Package, they have also reduced the amount of work required to obtain functional safety certification.

As the environment for robots and other industrial machinery continues to evolve, Intel FPGAs and the Functional Safety Data Package are ready for use.

Figure 5. Intel FPGA Functional Safety Data Package for industrial applications



Functional Safety Data Package for Intel FPGAs*4

Tools		IP and documentation		Devices	
Intel® Quartus® Prime Standard Edition Software version 17.0.2 • Platform Designer • Simulation library • Synthesis • Layout/wiring • Timing Analyzer • Signal Tap II Logic Analyzer • Nios II debugger • In-system memory editor • Power consumption analyzer • Safety design partitioning flow	**A tool for FMEDA calculation** • Intel® Cyclone® 10 LP FPGA • Intel® MAX®10 FPGA • Cyclone® V FPGA • Cyclone® V SoC	**Nios II embedded processor** **DDRx memory controller** **Platform Designer IP suite** **Diagnostic IP** • CRC calculation • SEU checker • Clock checker **Nios II lockstep solution**	**Safety manuals** • Intel® Quartus® Prime Design Software • Intel Cyclone 10 LP FPGA • Cyclone V SoC • Cyclone V FPGA • Intel MAX 10 FPGA **Reliability report** **TÜV Rheinland compliance certificate**	**Intel® Cyclone® FPGA** • Intel Cyclone 10 LP • Cyclone V SoC • Cyclone V • Cyclone IV **Intel® Arria® FPGA** • Arria V SoC • Arria V • Arria V GZ • Arria II GX/GZ	**Intel® Stratix® FPGA** • Stratix V • Stratix IV • Stratix IV GX **Intel® MAX® FPGA** • Intel MAX 10 • MAX V • MAX II • MAX II Z

*1: The EU Machinery Directive 2006/42/EC https://ec.europa.eu/growth/sectors/mechanical-engineering/machinery_en
*2: Yaskawa official website https://www.e-mechatronics.com/product/robot/controller/yrc1000/feature.html
*3: The extent to which actual development schedules can be shortened depends on the particular circumstances.
*4: As of October 2020

For more information about industrial functional safety, please visit the following website.
https://www.intel.co.jp/content/www/jp/ja/industrial-automation/programmable/applications/automation/functional-safety.html

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