Case Study

Industrial Robotics
Veo FreeMove

# Using Intel® FPGAs in Veo FreeMove* System to Enable Safe, Dynamic, and Flexible Human-Robot Collaboration

**Veo Robotics selected Intel® FPGAs for its FreeMove* 3D safeguarding system for factory and warehouse workcells that allow humans and robots to work together seamlessly. The FreeMove system implements sensor data collection and functional safety. Cyclone® V FPGA and tools for functional safety certification enable Veo Robotics to achieve safety certification of the FreeMove safeguarding system in less time and with reduced effort.**

**The manufacturing and logistics industries are increasingly relying on a greater level of human-robot collaboration, which in turn, places greater emphasis on safety and safeguarding.**

Standard industrial robots, which carry payloads up to two tons, have strict safeguarding requirements. To ensure safe operation, they're most often caged off and require tag-out/lock-out entry, significantly slowing interaction with the production line and reducing productivity.

To keep pace with market needs, manufacturing and logistics must become flexible enough to continuously adapt to change. Greater flexibility in manufacturing and logistics is achieved by allowing robots and humans to work safely alongside each other. Combining the brute strength, power, and predictability of a standard industrial robot with the dexterity and judgment of a human worker in the same workcell enables a more dynamic, flexible, and efficient manufacturing than previously done before. This is made possible by Veo Robotics FreeMove*.

**Figure 1.** Human Robot Collaboration

This case study also provides two example scenarios where the use of FreeMove system would deliver benefits and a return on investment to end users.

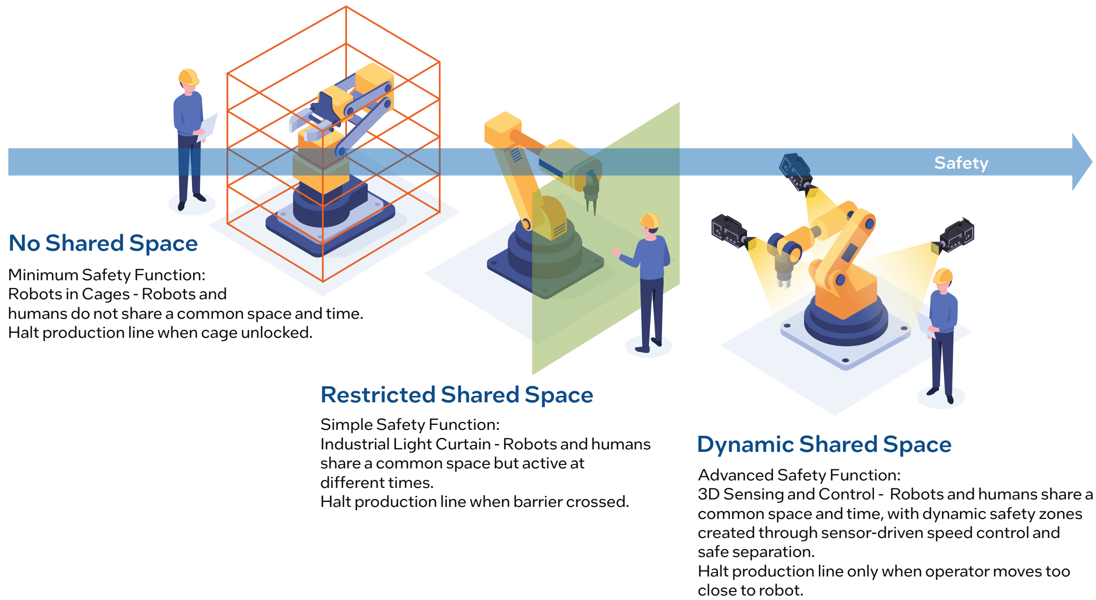


**Figure 2.** Shows the Evolution of Functional Safety in Robotics Operations

## Veo Robotics makes robotic arms safer for collaboration with humans

Veo Robotics is a pioneer in industrial automation, enabling a new wave of flexibility in manufacturing and logistics that hasn't been possible before. Veo enables safe interaction between humans and robots by building sensing systems that maintain safe speeds between robot arms and workpieces and human counterparts.

Industrial robots and supporting systems that deliver safer operations have long been enabled by Intel FPGAs such as the Cyclone V FPGA. The hard real-time deterministic compute of Intel FPGAs combined with functional safety certified devices, intellectual property (IP) and tools make them suitable for various tasks such as data collection, processing, and monitoring in robotics applications.

This combination of low latency and device reliability made Cyclone V FPGAs the first choice for Veo when implementing their industry-leading FreeMove safety system.

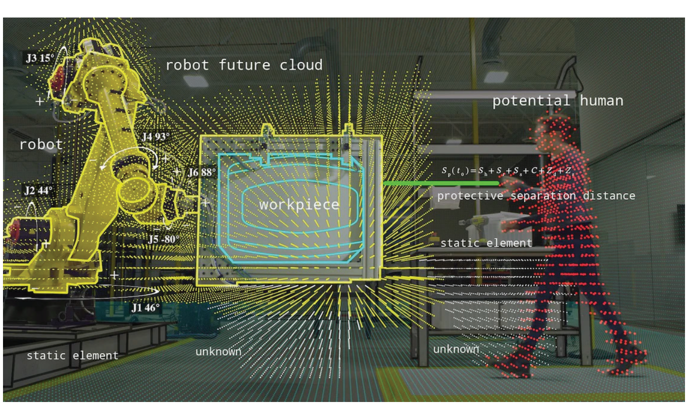


**Figure 3.** The FreeMove system uses 3D sensing to determine where the hazard is

## Veo FreeMove* safety system

Veo Robotics' flagship product FreeMove is a comprehensive 3D safeguarding system for industrial robots that enables dynamic, flexible, and safe human-robot collaboration. FreeMove combines the strength, power, and agility of standard industrial robots with the dexterity, judgment, and ability to reason of a human worker to create a flexible workcell environment.

The FreeMove system is composed of three core components:

- FreeMove Sensors: Up to 8 custom 3D time-of-flight sensors that are positioned around the workcell to capture rich image data of the entire space.
- FreeMove Engine: High-performance industrial computer with a proprietary safety architecture that connects directly to the robot controller and uses 3D data to analyze the workcell to identify the robot, workpieces, humans and occlusions. It implements Speed and Separation Monitoring (SSM) per ISO15066 to slow down and stop the robot.
- FreeMove Studio: Full software suite for configuration and real-time visualization of the system data.


**Figure 4.** Shows the FreeMove Engine and Sensor (Green Box)

## How does the FreeMove* system work?

The FreeMove safety system begins with 3D monitoring of the entire workcell. FreeMove Sensors are positioned on the periphery of the workcell to capture rich image data of the entire space. The FreeMove Engine uses that 3D data to identify every part of the workcell, including the robot, workpiece, human, and occlusions to track and calculate all possible future states of where objects might move next. If a human is closer to the robot than the Protective Separation Distance (PSD), the FreeMove system signals the robot to slow down or stop. When the PSD violation is cleared, the FreeMove system allows the robot to safely restart or speed up.

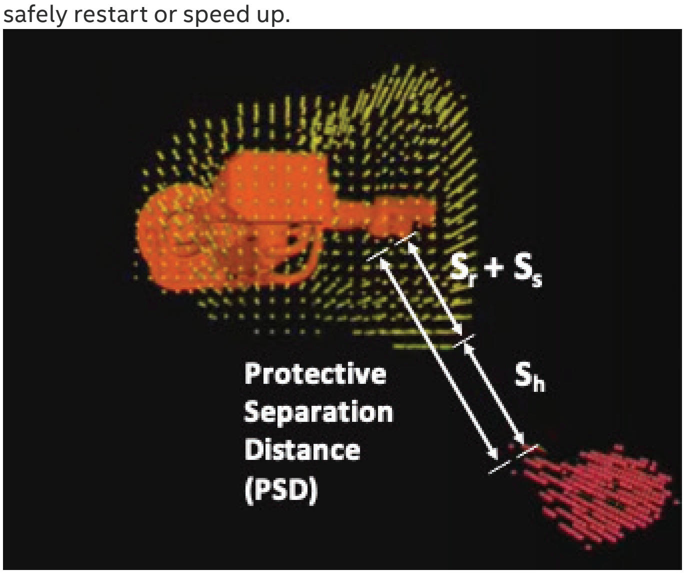


**Figure 5.** Protective Separation Distance

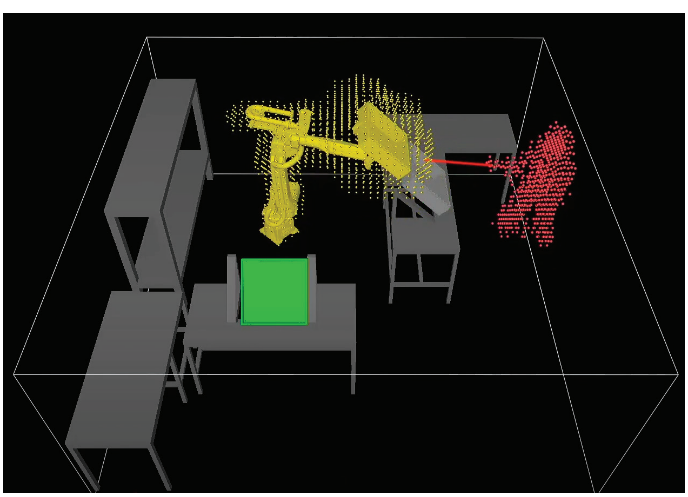

**Figure 6.** Shows FreeMove Studio

Speed and Separation Monitoring, as identified and governed by the International Organization of Standards (ISO), is a method of operation in which a robot system and operator may move concurrently in the same collaborative workspace. Risk reduction is achieved by maintaining at least the PSD between operator and robot at all times. During robot motion, the robot system never gets closer to the operator than the PSD. When the separation distance decreases to a value below the PSD, the robot system slows down or stops. When the operator moves away from the robot system, the robot system can resume motion automatically according to the requirements of this clause while maintaining at least the PSD. When the robot system reduces its speed, the PSD decreases correspondingly.

Simply put, a moving robot never touches the human when in the same workspace, and the PSD between the robot and human is always met. If it's not, the robot halts completely.

## Example scenarios on how the FreeMove system helps in reduced cost and complexity of human-robot collaboration

The FreeMove system promises dramatic results on business ROI. Because the FreeMove system can be used in a wide range of manufacturing and logistics applications, the specific ROI varies. Below are some examples of ROI for specific use cases.

**RE-CONFIGURATION OF A PARTS PRESENTATION WORKCELL**

| | |
|---|---|
| Situation | A high product mix - low volume manufacturer has to reconfigure a parts presentation workcell to change the robot tooling. |
| Before Veo | The manufacturer must tear down the safety system (light curtains and area scanners) along with the machinery and robot inside the workcell, redo the concept, run a new risk assessment, adjust the safety devices, re-test, and sign off. All these steps required a few weeks. |
| After Veo | The manufacturer moved the internal components, machinery and robot as needed for the new application, but did not have to tear down the FreeMove safety system. After building the new workcell, a simple adjustment of the sensors and backgrounding step is required to get the safety coverage of the workcell.<br><br>**Result**<br>Nearly three days of savings while reconfiguring the workcell, faster time to operationalize the workcell, easy risk assessment, testing, and sign off process. |

**FIXTURE LOADING/UNLOADING FOR SUSPENSION KNUCKLE ASSEMBLY**

| | |
|---|---|
| Situation | Assembly of two components that each weigh 10 kg by driving bolts into holes that are difficult to align. |
| Before Veo | Human worker lifts the heavy knuckle and moves it between the dunnage and the table before driving in bolts.<br><br>**Results**<br>Poor ergonomics, long cycle-time, and high non-value-added time. |
| With Veo | Robot performs heavy, non-value-added work (lifting and moving the knuckle) while the human focuses on the task requiring dexterity (bolting).<br><br>**Results**<br>Cycle-time savings of 19 seconds per work item, improved ergonomics, and higher value-added time. |

## Using Intel FPGAs to implement safe sensor data processing

Cyclone V FPGA is used in FreeMove* Sensors in a dual-channel (1oo2, Hardware Fault Tolerant (HFT) = 1) architecture to capture raw time-of-flight data and implement depth compute algorithms. The depth data from FreeMove Sensors that are installed on the perimeter of the workcell are transferred to the FreeMove Engine over UDP protocol, also implemented in firmware running on the FPGA fabric. Additionally a MAX® V CPLD is used in the sensor to ensure eye safety conditions during LiDAR operation.

The Veo Robotics FreeMove Engine ingests this data to calculate Speed and Separation Monitoring (SSM) – implemented on two Intel® Xeon® CPUs in a redundant architecture to provide functional safety. This recognizes when a human or object is too close, and put the robot into a safe state when needed.

During the operation of the FreeMove system, the safety-related error cases are monitored by the safety controller implemented on the FPGA. Speed and reliability were critical to selection of the safety-critical sensor component. The Cyclone V FPGA's low latency deterministic compute and device reliability, backed by certified Failure Modes, Effects, and Diagnostic Analysis (FMEDA) and programming tools, certified device and IP made it the perfect choice. Most of the safety aspects of the operation of the FPGA device are monitored by the dedicated safety IPs are provided with the Intel Functional Safety Data Pack (FSDP).

## Intel FPGA's IEC 61508-certified functional safety data package helps reduce time and effort for system certification

Machine builders including robotics manufacturers are required to certify their end systems to functional safety standards for individual applications. These functional safety standards determine quality, reliability as well functionality of these systems and their behavior in response to a fault. To provide safe operation, each component in the system also needs to comply with functional safety standards.

IEC 61508 defines the international standard for electrical, electronic, and programmable electronic safety related systems – a meta-standard from which use-case specific standards, such as ISO 13849 for robotic safety systems are derived. TÜV Rheinland, a German third-party certification agency, has reviewed and certified Intel FPGA and CPLD products such as Cyclone V FPGA, along with the corresponding software tools and diagnostic intellectual property (IP) for use in systems up to and including Safety Integrity Level Three (SIL3). Intel provides a Functional Safety Data Package (FSDP) with the tools, IP, guidance, and data to analyze and certify the use of FPGA in their end systems.

This Intel FSDP provides a framework and methodology to avoid systematic faults in design. It has the following features and tools:

- Diagnostic IP to help detect random hardware faults that may arise during operation
- Data-driven tools to analyze the resulting coverage and risk-reduction effectiveness of the FPGA safety design
- Safety-certified software programming tools including features such as design partitioning

Specifically, 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 Failure Modes, Effects and Diagnostic Analysis (FMEDA) tool, which analyzes the user's specific FPGA design and safety mitigations to calculate failure rates and safe failure fractions (SFFs) for safety certification.

(3) Safety manuals specifying how to use the Intel® Quartus® Prime Software and Intel FPGA systems consistent 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 report data on Intel FPGAs.

(6) Compliance certificate issued by TÜV Rheinland.

Using the FSDP can help minimize what would be many months of development time from a product schedule, as TÜV Rheinland has already qualified Intel FPGA software suite – including programming and FMEDA tools, select IP and FPGA products for use in safety systems up to and including SIL 3.

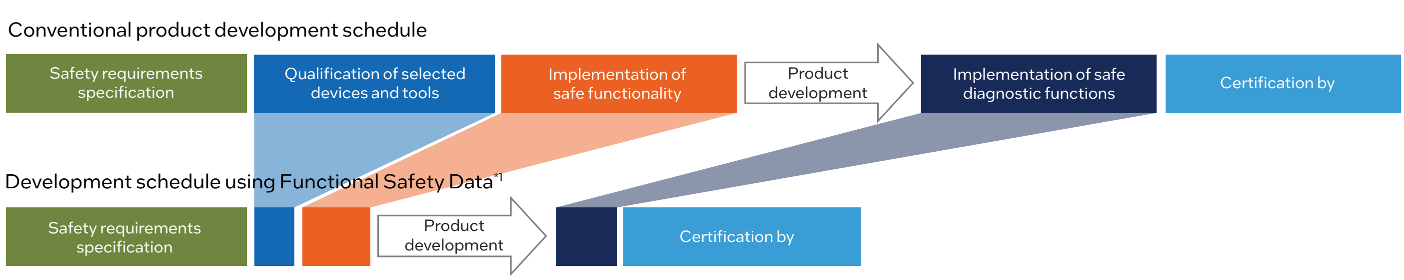


**Figure 7.** Intel FPGA Functional Safety Data Package for Industrial Applications

**FUNCTIONAL SAFETY DATA PACKAGE FOR INTEL FPGAS**[*2]

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

## Achieving functional safety certification of Veo FreeMove* safety system

Veo used the FSDP to accelerate safety design and analysis. Speed and reliability of the design implementation was one of the key metrics for Veo Robotics in selection of the components. Cyclone V FPGA and associated FSDP helped achieve that goal. The FSDP is also used to ensure the FPGA system met the stringent safety coverage and reliability requirements necessary to meet the target safety integrity levels for certification.

In April 2021, the FreeMove system received functional safety certification from TÜV Rheinland, making it a first-of-its-kind technology that deploys dynamic, 3D Speed and Separation Monitoring (SSM) for safeguarding in a robotic workcell. Using Cyclone V FPGAs, the FreeMove system is the only solution on the market today that has been granted safety certification in Performance Level d Category 3 as described in ISO 13849.

*1: The extent to which actual development schedules can be shortened depends on the particular circumstances.

*2: As of October 2020



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