OPTIMUM

OPTimised Industrial IoT and Distributed Control Platform
for Manufacturing and Material Handling

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Evaluation report

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Abstract:	Validation of the domain specific demonstrators are concluded according to the evaluation plan and with the assistance of each demonstrator or use case owner. Quantifiable performances from these evaluation tests are presented in this document. Lessons learnt are already published in D6.4.2

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Executive Summary

An evaluation plan was agreed based on the general and detailed requirements from D1.2. Based on the requirements matrix the detailed requirements were mapped against the general requirements. This built the base for distributing the testing / validation activities between the owners of the demonstrators and the partners who contributed to the demonstrators.

There were four different validation methods agreed on:

1. Inspection "I"
   being the examination of the product or system using basic senses. This means to take one or more looks at it, touch it, smell it (rarely applicable), taste it (even more rarely applicable!). Physical examination and check that all its physical characteristics are as required and that it has all of the controls that it is supposed to have. Similarly, for a software system, we would check that its User Interface (UI) is as required, that it has all of the data entry fields and buttons that it is supposed to have. For a web application, its appearance on different screen sizes is checked.
2. Analysis "A"
   being the validation of a product or system using calculations and models. Analysis will be utilized to make predictions of the product or system's performance based on representative, actual, test results. Analysis can also be used to calculate failure points based on actual test results, without resorting to destructive testing.
3. Demonstration "D"
   is usage of the product or system as it is intended to be used. That way, functional user requirements can be followed and be verified that the product or system is behaving in accordance with the user requirements. Every button and every control in a product are pressed and activated to confirm that the product behaves as specified. For software, entering of data is conducted as users would do to ensure that the software performs the actions described and check that its reports are correct.
4. Test T
   as a more precise and controlled form of demonstration. The tests are conducted to confirm that product / functionality behaves precisely as specified under a set of carefully specified test conditions. Repetition of these operations using different sets of test conditions with precisely specified steps complete the test. Testing is often applied to verify performance requirements.

Depending on the availability of the validation criteria in the different demonstrators, the validation was conducted from one up to four country demonstrators with the support from contributing partners.

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1 Requirement R_Gen_001

Requirement Statement	The system MUST be able to support wired and wireless communication between the control components.

Related reqs.	R-Det-035, R-Det-040, R-Det-043, R-Det-044

This requirement is validated within the context of ERMETAL demonstrator by analysis, but since all demonstrators share the same architecture, validation applies to other demonstrators, too.

This requirement includes the following details:

- The concept of the OPTIMUM architecture, components, etc. (specifically the control architecture) must be developed in a way that allows using different internet communication protocols. Thus, future realization may be done using different technologies depending on the customer's requirements and the level of the latest technological achievements. This will enable future improvements.

This requirement is also validated within the context of MAGTEL/SOTEC demonstrator by experimentation, but since all demonstrators share the same architecture, validation applies to other demonstrators too.

1.1 ERMETAL Demonstrator

Main Responsible	ERSTE
Contributing Partners	DIA, URO
Validation Method	Analysis
Related reqs.	R-DET-40

This requirement includes the following details:

- The communication should be based on an acknowledgment mechanism to guarantee the identification and correction of information losses, i.e., retransmission of data packets after the expiration of a given time-out. If the number of consecutive packet dropout exceeds a certain threshold, the communication should be interrupted and leads to a fault and a machine stop.

This requirement is validated within the context of ERMETAL demonstrator by analysis, but since all demonstrators share the same architecture, validation applies to other demonstrators, too.

OPTIMUM architecture is designed in a way that connection-oriented communication protocols are preferred wherever possible.

For IP (Internet Protocol) based communication TCP (Transfer Control Protocol), which is a connection-oriented protocol, is chosen at transport layer. TCP itself resolves the majority of the problems due to intermittent connection. On top of the transport layer, at the application layer, protocols such as OPC-UA, MQTT and HTTP are used which have their own acknowledgement methods, confirming the successful delivery of the messages.

The IIoT component which implements the external interface of the industrial devices using OPC-UA, has an additional approach regarding the asynchronous activities (i.e., activities that are started and then stop at a time in the future): The client has the ability to subscribe to updates regarding the activity status. Hence, they can react accordingly.

MQTT, which runs on top of TCP too, has its own QoS (Quality of Service) and retention mechanisms to ensure successful delivery of the messages and retransmission/recovery approach in the case of connection disruptions. MQTT is configured in accordance with the nature of each message (e.g., QoS 0 and no retention for frequent messages or QoS 2 for commands, etc.).

For non-IP based communication, either the acknowledgement mechanism of the underlying protocol is used (e.g., CANopen) or whenever this is not possible (e.g., RS 232), application-level approaches, such as heartbeat messages, to check the communication status are used.

1.2 MAGTEL/SOTEC Demonstrator

Main Responsible	MAGTEL
Contributing Partners	SOTEC
Validation Method	Demonstration
Related reqs.	R-DET-035, R-DET-043, R-DET-044

Below are the different components that require communication in the MAGTEL/SOTEC demonstrator.

Figure 1: TP-LINK router with 802.11AC and Gigabit Ethernet connectivity

Figure 2: Robotic arm

Figure 3: Projector connected via HDMI

Figure 4: Connection via HDMI to the main computer

Figure 5: Control panel

There is a set of elements, from top to bottom and left to right, the main communication component, a TP-LINK router with 802.11AC and Gigabit Ethernet connectivity. Following, the robotic arm, connected via Wi-Fi with the main computer (bottom right picture). A projector is connected via HDMI to the same main computer, and finally, the control panel, which consist of three buttons is connected to a Raspberry Pi device, connected to main computer via wireless. The router oversees providing the secure wireless network used by the different devices. In case wireless network, it would not be suitable, alternative connectivity could be established via Ethernet.

1.3 DEMAG MH-Demonstrator

Main Responsible	DEMAG
Contributing Partners	
Validation Method	Demonstration
Related reqs.	R-DET-035, R-DET-043, R-DET-044

The different machines in the Material Handling (MH) demonstrator are mostly connected wirelessly. For the cranes DEMAG has in the portfolio wireless and wired controls that are interoperable.

The pictures below show some in standard available control devices:

Figure 6: Examples of wired controls: DSE and DSC - control pendants

Figure 7: Examples of wireless radio controls: DRC 10, DRC-MJ and DRC-J

The implemented communication protocols for vertical and horizontal communication is OPC UA. The standardization of the OPC UA companion profile for Hoists and Cranes is work in progress at VDMA and will be continued after the conclusion of the OPTIMUM project. Safety and Security requirements are considered and included in the OPC UA protocol specification.

2 Requirement R_GEN_002

Requirement Statement	Wireless communication MUST be highly available.

Related detailed reqs.	R-DET-005

This requirement includes the following details:

- The communication availability must be at least 99.99%, which translates into an unavailability of 53 min p.a. or less.

This requirement is validated within the context of MAGTEL/SOTEC demonstrator, and it has been analysed and tested confirming its operation.

2.1 MAGTEL/SOTEC Demonstrator

Main Responsible	MAGTEL
Contributing Partners	SOTEC
Validation Method	Demonstration

Given that most of the communications established among the diverse items in the demonstrator are based on Wi-Fi, wireless communications must be highly available. To guarantee that this availability is provided, the demonstrator counts with a specific wireless router appropriately configured, that provides a stable and secure network, with coverage to the specific range corresponding to the demonstrator. A fallback mechanism could be introduced in case the main router fails, enabling a secondary access point to provide extra network connectivity.

Figure 8: Wi-Fi Router

2.2 DEMAG Demonstrator

Main Responsible	DEMAG
Contributing Partners	IFAK
Validation Method	Test

For the MH-Demonstrator in the DEMAG Research Factory a 5G-Wireless Network has been implemented. NOKIA provided the hardware for the campus network as private 5G-Network.

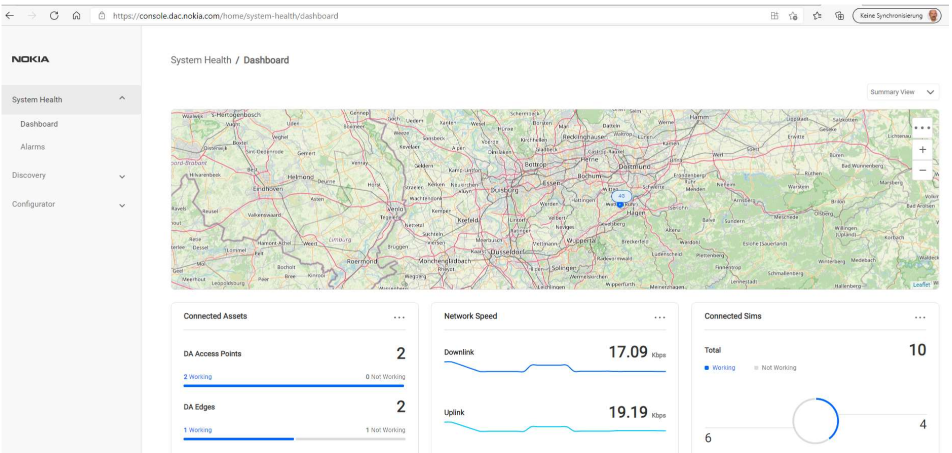


Figure 9: NOKIA Digital Automation Cloud – Online Dashboard

The target was to install and test the **5G-Release 16 technology**, that promise **Ultra-Reliable and Low-Latency Communication (URLLC)**. Unfortunately, until the end of the Project in June 2021 it was not possible to get Rel. 16 from NOKIA. The following Latency Time measurements are done based on Release 15.

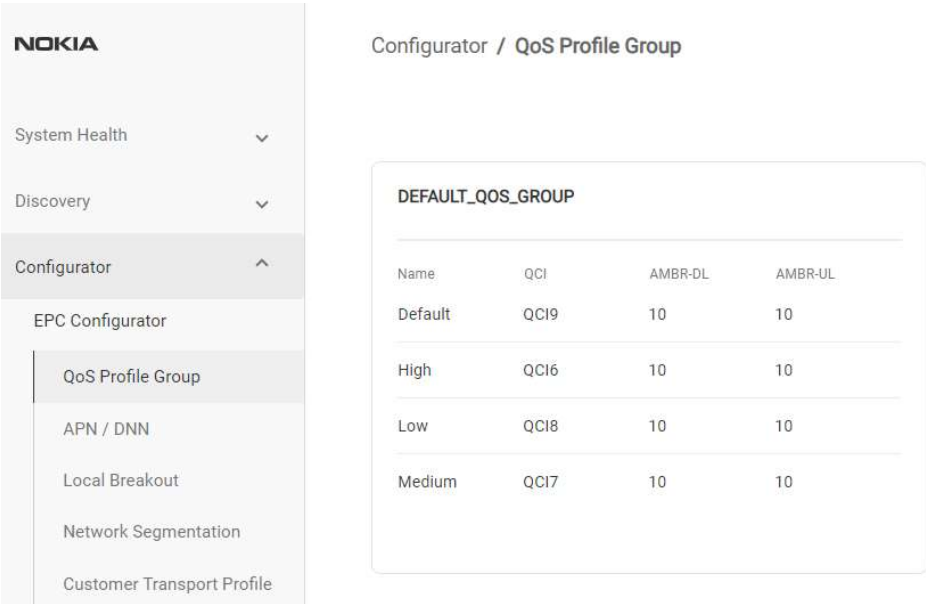
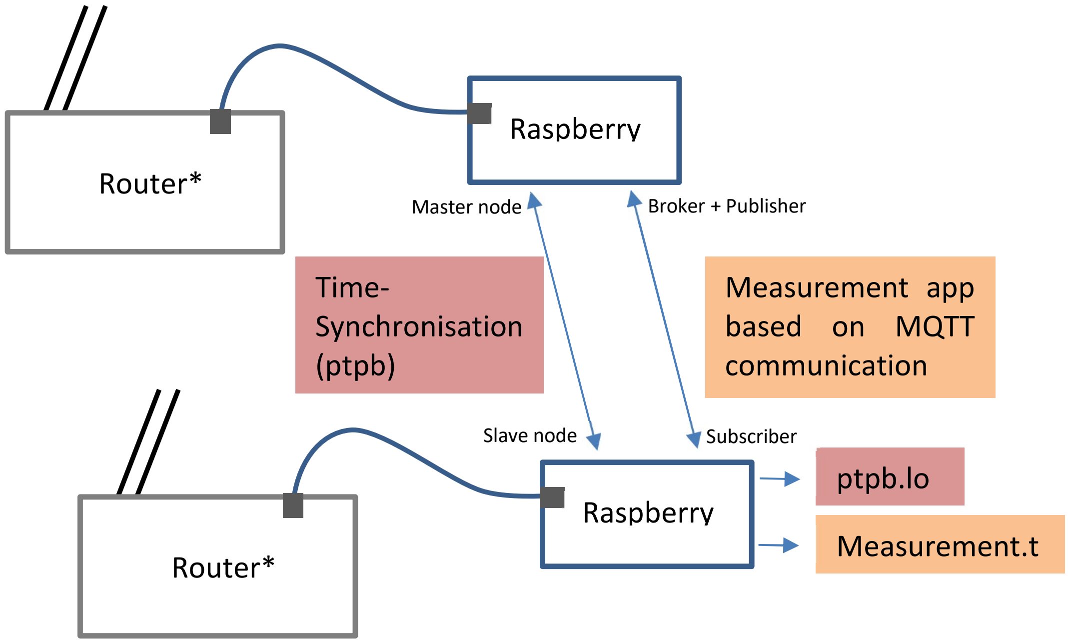


Figure 10: NOKIA QoS Profiles

2.2.1 Test Setup

Table 1 : Test Setup

IP	192.168.188.155	192.168.188.88
OS	Raspberry Pi OS (32-bit); Release: 07.05.2021	Raspberry Pi OS (32-bit); Release: 07.05.2021
ptpd (Time synchronisation tool)	yes	yes
mqtt (measurement)	~/Latenzmessung/mqtt_pub_mosq	~/Latenzmessung/mqtt_sub_mosq



*Sierra Wireless; Model: RV55, LTE-A PRO, Global

Figure 11 Block diagram of the measuring system

2.2.2 SSH Connection setup

SSH can be used to use the Raspberry without a monitor (headless):

1.open terminal

2. connect to the Raspberry:
   *ssh pi@*192.168.188.155 (ssh <username on the Raspberry>@<ip>)

3.enter the password *raspberry*

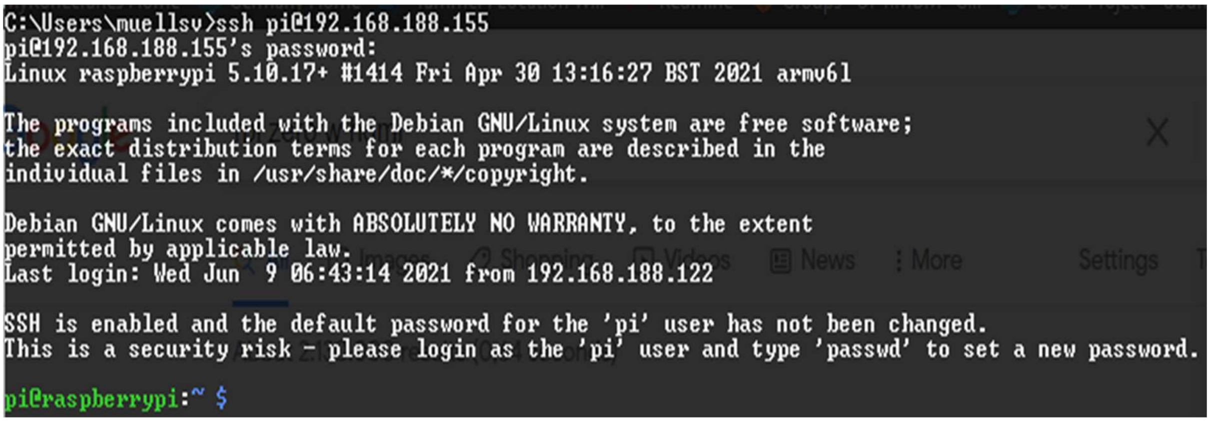


Figure 12: Screenshot Raspberry

2.2.3 Secure Copy

To transfer files to the Raspberry, the Secure Copy command can be used:

scp < File path on the source device> <Username of Raspberry>@<ip>:<Zielordner>

Example:

scp mqtt_sub_mosq pi@192.168.188.155: ~/Latency time measurement

2.2.4 Test result

According to the requirement R-DET-002 the average transmission time at 61.16 ms is quite good and short enough to ensure the targeted reaction time of max. 200ms, but the standard deviation is considerable.

In the following diagram shows further details:

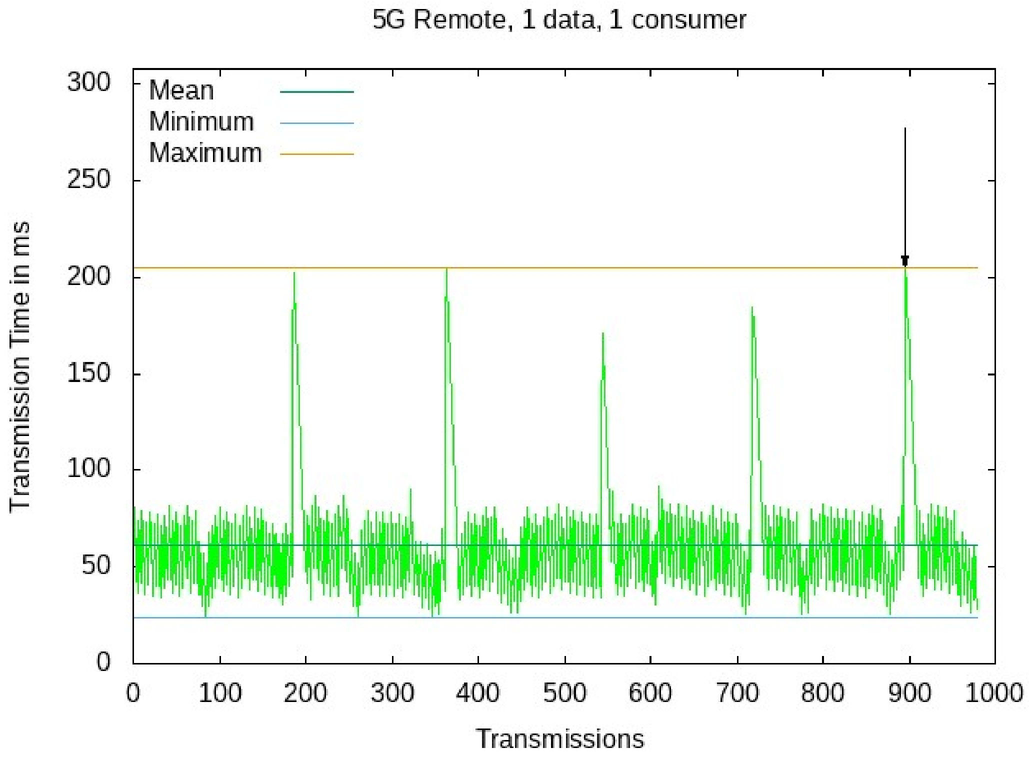


Figure 13: Transmission time diagram

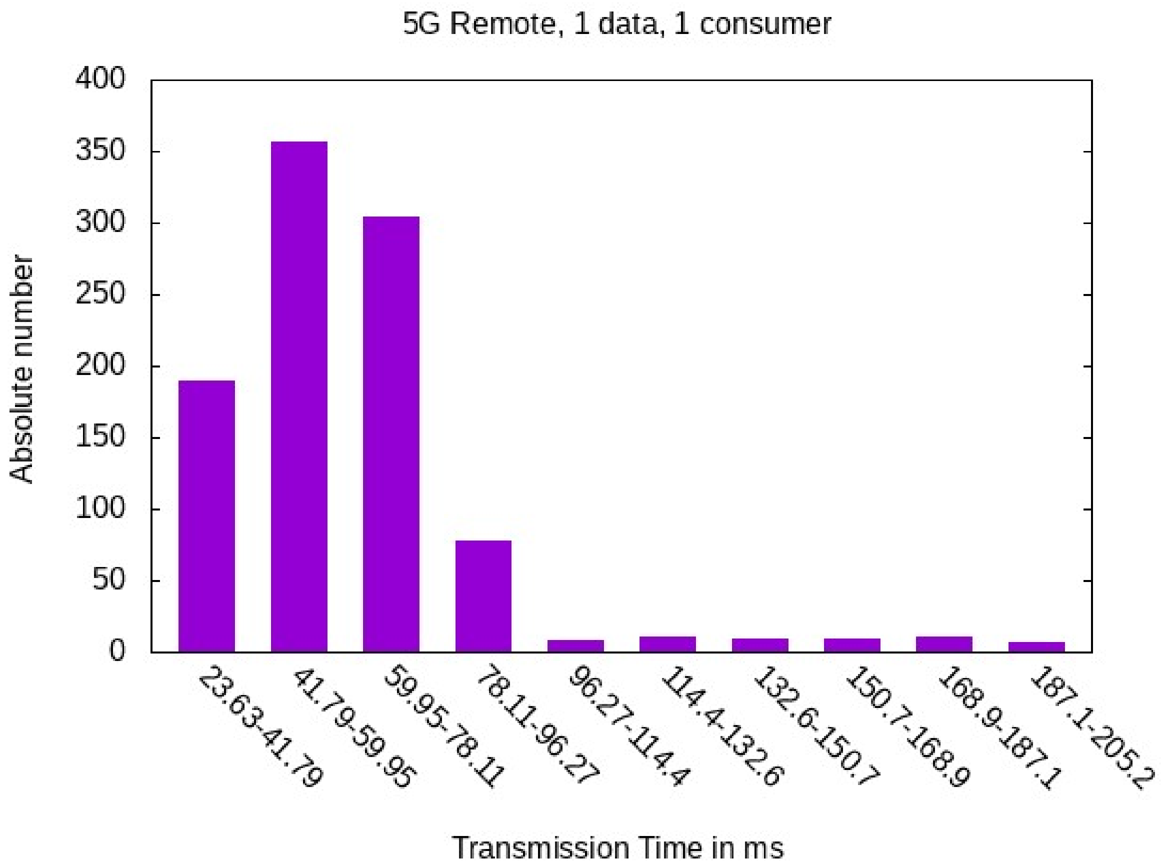


Figure 14: Evaluation of transmission time

Table 2: Summary of measured data

Measurement	Value
Minimum Transition Time:	23.625387
Maximum Transition Time:	205.228387
Mean Value Transition Time:	61.1586
Standard Deviation Transition Time:	60.9718
95th Percentile:	106.424387
98th Percentile:	163.460387
Jitter Sending:	0.0006564
Jitter Receiving:	0.0210948

3 Requirement R_Gen_003

Requirement Statement	System MUST comply with existing safety and security regulations; the control components SHOULD be characterized with a Cat.3 Architecture. Communication MUST be suitable for Safety-Related functions (at least PL d according EN ISO 13849). Secure and safety compliant communication protocols MUST be used to connect wireless control-panels and wireless HMI-devices.

Related reqs.	R-GEN-10, R-DET-009, R-DET-037

Background: For safety related functions of machines a certain min. level of safety (PL = Performance Level or SIL = Safety Integrity Level) shell be realized. When the communication is a means for the realization of a safety related function, also the communication channel must fulfill safety requirements. This requirement is validated within the context of DEMAG MH-demonstrator by analysis, but since all demonstrators share the similar architecture, validation applies to other demonstrators too.

3.1 MH-Demonstrator - DEMAG Research Factory

Main Responsible	DEMAG
Contributing Partners	
Validation Method	Analysis
Related reqs.	R-GEN-10, R-DET-009, R-DET-037

This Analysis is valid also for R-GEN-010: System MUST comply with existing safety and security regulations; The functional safety standard for material handling and smart manufacturing machines (i.e. EN ISO 13849, EN 62061, EN 61508, …) MUST be considered.

Due to the complexity of the topic, the analysis considers different aspects that are structured in chapters as follow:

- State of the Art and normative situation
- Risk assessment of collaborative cranes
- Summary of Results

3.1.1 State of the Art and Normative Situation

According to machinery directive 2006/42/EC, within the European Economic Area, manufacturers, but also distributors or EU importers (usually system integrators), must provide their products with an EC declaration of conformity and a CE mark. This certifies that the product meets the applicable requirements. Prerequisites for the preparation of the EC Declaration of Conformity are the completion of the risk assessment and the implementation of necessary measures for risk reduction.

The risk reduction measures can be of a constructive, organizational and/or control-related nature.

The risk level and requirements for safety-related control functions are described in the standards EN ISO 13849-1 (Performance Level PL) and IEC 62061 (Safety Integrity Level SIL). These standards provide safety requirements and a guideline for the design and integration of safety-related parts of machine control systems, including the development of software.

The properties of these parts that are required to perform the corresponding safety functions are specified. In mechanical engineering, EN ISO 13849-1 is the preferred standard, as it applies to all types of machinery, regardless of the technology used (e.g. electric, pneumatic, hydraulic, mechanic). Therefore, this paper refers to PL (“a” to “e”) as scale for the safety-related performance of the control system.

Further remarks on the state of the art and the normative situation can be found in fml/TUM Research report: “Safety guidelines for automated crane systems in a personnel-accessible environment”- Univ.-Prof. Dr.-Ing. Willibald A. Günthner and Dipl.-Ing. Ingomar Schubert [2013].

The report conclusion is that the existing regulations concerning the safety requirements for automated crane systems in a personnel-accessible environment contains only general proposals, that are not enough to give the manufacturer the assurance that a certificate of conformity issued by the trade supervisory board will be accepted for sale. Based on this situation, there is a need for automatic cranes in a personal access environment to work out for the manufacturer applicable rules and regulations to ensure a safety-related acceptance.

In some cases, machine-specific standards (Type C standards) define minimum PL requirements for some safety-related control functions of these machines.
For cranes and hoists, the relevant Type C standards are EN 15011 "Cranes - Bridge and gantry cranes" and EN 14492-2 "Cranes - Power driven winches and hoists - Part 2: Power driven hoists".

3.1.2 Risk Assessment of Collaborative Cranes

Based on the risk assessments done for the PL requirement definition in the crane C-standards mentioned before, it is possible to specifically consider the aspects relating to the safety concept of a collaborative crane system, with crane assist functions and (semi-) automatic crane movements initiated by operators and /or other machines, that are of importance with regard to a hazard to persons. Solutions must be aimed for which, on the one hand, make it possible to minimize the existing hazards to persons and, on the other hand, restrict operation and flexibility as little as possible.

3.1.2.1 Crane Cycle

Before focusing on collaborative cranes, some more general considerations are listed here:
In order to find solutions from the known dangers and the known risks, it is useful to visualize the occurring dangers by means of a crane cycle. The four partial work steps - Figure 15Figure 15 - can be listed as:

- Crane empty run
- Load pick-up
- Crane load movements and
- Load drop out

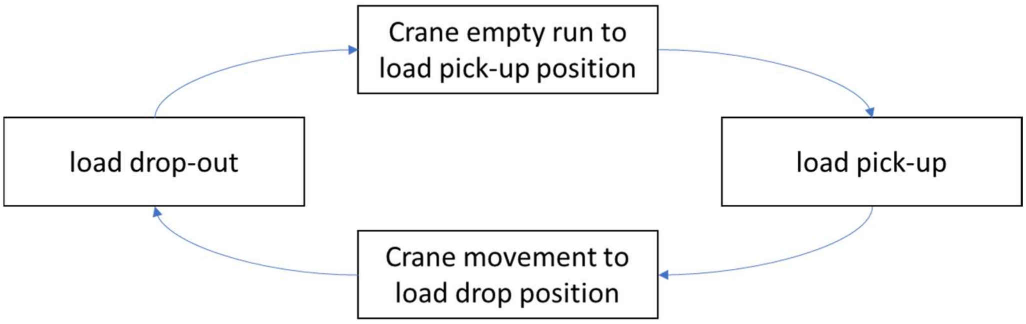


Figure 15: Crane cycle

3.1.2.2 Crane Operation Modes

In addition to the crane cycle to be examined, a distinction must be made as to the ”degree of automation” of the crane: The crane operation mode.
In general, a distinction must be made between the states as shown in Figure 16Figure 16 "manual mode", "semi-automatic mode" and "fully automatic mode".
In the semi-automatic mode, a distinction must be made as to whether the crane only performs an “automated empty run” or also an “automated load run”.

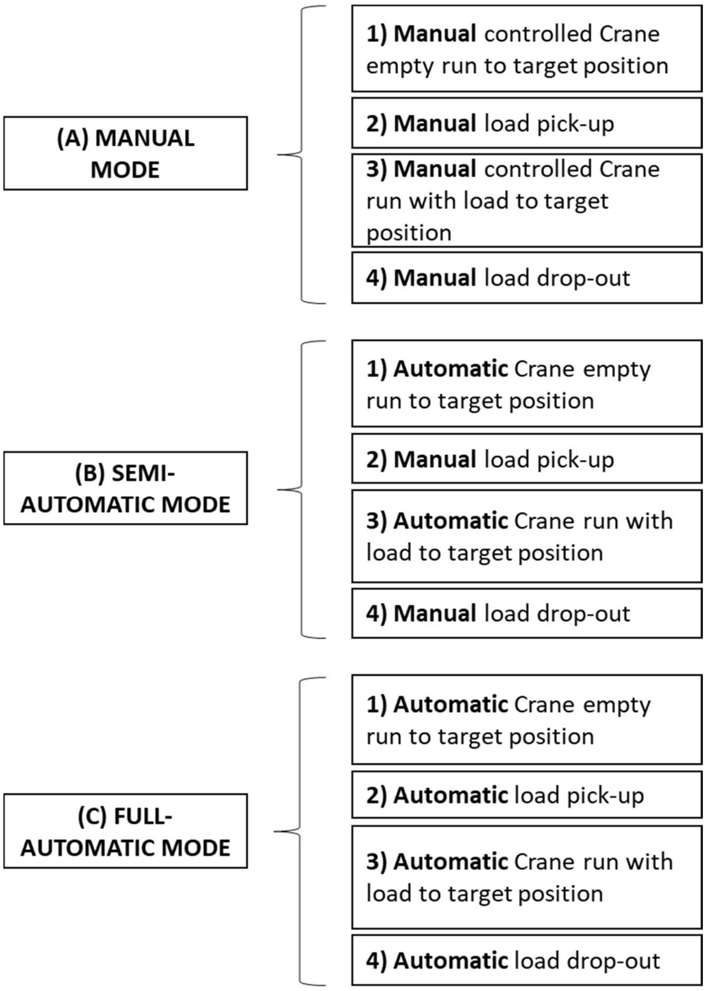


Figure 16: Crane operation modes

For the transitions between the different crane operation modes, appropriate solutions must be found to minimize the risks to persons caused by automated crane operation, i.e. the activation of an assist function.

Collaborative cranes have a crane operation mode according Figure 16Figure 16, (B) Semi-Automatic mode: The load pick-up and the load drop out operations are manually done, due to the fact, that the load attachment is a simple hook. Therefore, the actions for load-handling have the same risks as the in manual-mode driven cranes.

Cranes with specialized load-handling-attachments[1] – have mostly a degree of automation (C) Full-Automatic mode. This type of cranes works in protected areas - blocked for operators and other persons - where it is forbidden for people to be present.
For such areas, an activation of the area protective device immediately brings all crane movements to a standstill.

So, the risk assessment in the context of collaborative cranes can be limited to the crane movements; in crane movement, a distinction can be made between horizontal and vertical movements as well as between empty or with load runs.

The area of purely manual crane operation is only listed here for the sake of completeness. No special safety measures are required for this, as this is a classic crane which is monitored during operation by the crane operator. Same is valid for the cranes in “Full-Automatic” mode, where no humans are permitted to work in the protected area.

The following sections, will therefore focus on the risk assessment of the use cases:

- B1 - Semi-Automatic mode, Automatic crane empty run to target position and
- B3 - Semi-Automatic mode, Automatic crane run with load to target position

As well as the

- Transitions/change between the manual and semi-automatic mode during the activation of assist functions and vice versa (deactivation of assist functions).

3.1.2.3 Crane Movements

In the following section, we consider the risk of automatic crane movements, that happens when some assist functions are started.

A distinction is made between horizontal and vertical crane movements:
Horizontal crane movements occur when the crane is travelling empty or carrying a load.
Vertical crane movements occur before and after a load pick-up or load drop out.
After a load has been attached, the crane, trolley and hoist start moving together or separately after the crane has received a travel signal from the operator pendant/wireless control or an OPTIMUM assist function is activated (manual crane call, i.e.: COME TO ME, FOLLOW ME, …)

[1] Specialized load-handling-attachments are i.e.: vacuum lifter for paper rolls, gripper for steel coils or waste gripper.

Combined simultaneous horizontal and vertical movements are also possible.
To avoid collision with persons or other elements of the environment, horizontal crane movements can be carried out

a) in a collision-free space. To meet this requirement, automatic crane movements shell take place in a space at least 2.7 m above the personnel area. During the movements carrying a load shell be avoided that persons are under the suspended load. In addition, the distance to obstacles in all directions after a stop shall not be less than 0.5 m [12], so that there is no risk of collision with environmental elements. The crane axis braking distance must be considered.
b) in any desired space and load position when surroundings awareness system on the crane performs autonomously the “Collision avoidance” function

In case a): collision-free spaces for moving the crane free of obstacles must be predefined and monitored. Figure 17Figure 17 show the simplest case with load hook in highest position - the upper limit switches shall in this case be activated. The safe area is 3D-rectangular with fixed height.
The monitoring functionality for such safe area can be done by means of limit switches.
Figure 18Figure 18 shows a more generic use case where the safe area may have an irregular shape and horizontal and vertical movements are possible inside of the safe area. The monitoring can be done with localization system or other sensors (i.e.: Laser or Lidar) that are able to detect if the load/load attachment is exceeding the limits of the defined safe area.

A risk analysis for this concept raises the problem of how to prevent the crane from leaving its collision-free space unintentionally.

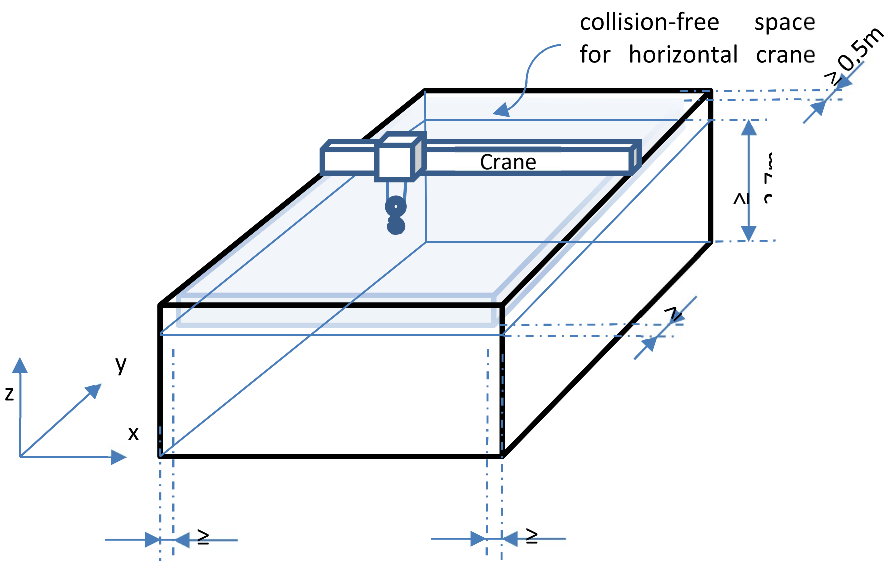


Figure 17: Collision-free space for horizontal crane movements

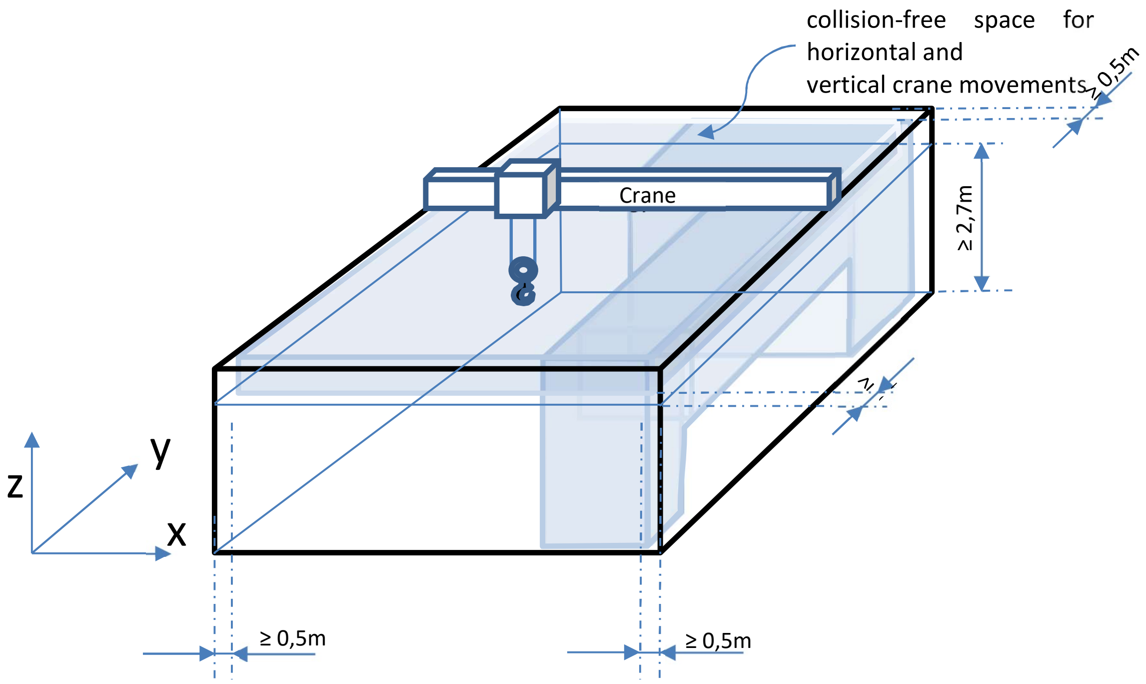


Figure 18: Collision-free space for horizontal and vertical crane movements

3.1.2.4 Risk Assessment for Crane Assist Functions

According the considerations done in the previous chapters, the related risk level of assist functions can be classified depending on:

- load conditions
  - with or
  - without load
- load (load attachment) position
  - inside or
  - outside of a collision-free space
- source for command activating movements
  - operator or
  - machine

The activation of Semi-Automated mode is needed for the realization of crane assist-functions (also called “smart functions” or “smart features”) like i.e.:

- **GO TO / TARGET POSITIONING** reduce the need for operator's manual crane operation. With only a single button, target positioning brings the load to a predefined target position.
- **COME TO ME** enables the operator to call a crane near to his actual position
- **COME TO MACHINE** enables a machine to call a crane near to its actual position
- **FOLLOW ME** the crane can be moved continuously based on operator moving location.
- **FOLLOW MACHINE** the crane can be moved continuously based on machine moving location.

- **TANDEM CRANES MODE** the cranes/trolleys and hoists movements are electrically interlocked.
- **ANTI SWAY CONTROL** limits load swing by controlling the bridge and trolley acceleration and deceleration.
- **PROTECTED AREAS** allow to define protected zones such as production machinery or storage areas, where the crane is not allowed to enter.

This function list does not claim to be complete; it is rather to be expected that many additional assistance functions will be added in the future.
All these assist functions have in common the need of autonomous crane axis movements that lead to the required functionality.

When an assist function is initiated by the crane operator, the operator is aware of this, can observe the movement and initiate a stop command, if needed. This is not the case when machines are activating assist functions w/o requiring a manual release of the requested assist function from operator.

In principle an actual well known and standardized crane safety related function like "overload protection" and "end zone protection" are also a kind of assist function for the crane operator. The PL required for these above-mentioned functions is given in the related standards mentioned in Chapter 2. This helps to define the risk level also for the new assist functions.

Table 3Table 3 Table 3: Risk level of some OPTIMUM related Assist functionsgives an overview of the estimated risk for some OPTIMUM related assist functions:

Table 3: Risk level of some OPTIMUM related Assist functions

		Risk level			
		no load		with load	
initiated by	Assist function	inside collision-free space	outside collision-free space	inside collision-free space	outside collision-free space
Operator	GOTO	LOW	MID	MID	HIGH
	COME TO ME	LOW	MID	MID	HIGH
	FOLLOW ME	LOW	MID	MID	HIGH
Machine	COME TO MACHINE	MID	HIGH	HIGH	HIGH & anti collision system needed
	FOLLOW MACHINE	MID	HIGH	HIGH	HIGH & anti collision system needed

3.1.3 Summary of Results

Summarizing the validation of requirements related to functional safety cannot be finalized in a research project. Because existing regulations concerning the safety requirements for collaborative machines in a personnel-accessible environment contains only general proposals, it is already a challenge to define suitable required performance level for the innovative assist functions. Therefore, we have initiated an FEM work group for discussion and clarification with other crane builder companies, that will continue to work also after OPTIMUM.

Furthermore, the prototypical implementation of several demonstrator's components does not allow a complete and final calculation of the reached performance level.

Nevertheless, we have spent a lot of effort considering safety related aspects and requirements for the MH-demonstrator and the innovative machine assist functions. Some components are already fulfilling basic requirements (i.e.: a redundant control architecture and method for diagnosis like plausibility-checks), but not all components can be validated for safety level in this development stage.

Especially about a safety evaluation of assist functions we stated that the existing normative status is not considering our OPTIMUM approach for collaborative cranes and the related assist functions: We found out that this is not just the case for the domain of industrial cranes, but also for ports and constructions cranes. For this reason, we started a "FEM PG CLE Assistance Systems Ad-Hoc Group" under the umbrella of VDMA that is also part of our OPTIMUM related standardization activities.

The aim of the ad-hoc group on assistance systems is to:

- Develop a guideline as basis for common understanding in Europe.
- Find consensus on definitions / issues on assistance and warning devices
- Give guidance on implementing Machinery Directive and connecting requirements from standards to examples.

The work was started in June 2020 and will continue also after the OPTIMUM project conclusion.

3.2 MAGTEL/SOTEC Demonstrator

Main Responsible	MAGTEL
Contributing Partners	SOTEC
Validation Method	Demonstration
Related reqs.	R-DET-037

The different items in the demonstrator can communicate with each other via secure channels, but to enhance the overall safety of the system, critical components such as the robotic arm, have been enhanced with sensors, so if there is a communication loss, the safety related functions do not get compromised.

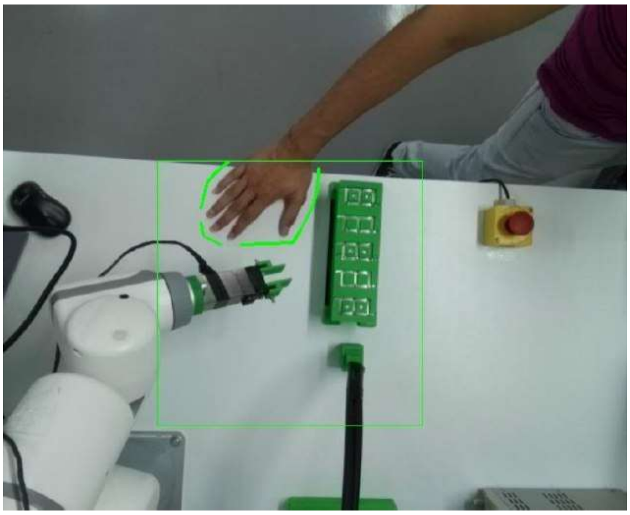


Figure 19: Top view of robotic arm with sensors

Figure 20: Control Panel

4 Requirement R_Gen_004

Requirement Statement	Communication data rate MUST be suitable for the defined Use Cases.

Related reqs.	R-DET-082, R-DET-086

This requirement includes the following details:

- Control system installed sensors like video, Wi-Fi, UWB must have functionality to collect data according to sensors' sample rate as real-time processing. Control system may take some strategies such as using sliding windows, static sampling rate, dynamic sampling rate (missed/failed data) rate to monitor and right analysing from input data.

This requirement is validated within the context of MAGTEL/SOTEC demonstrator, and it has been analysed and tested confirming its operation.

4.1 MAGTEL/SOTEC Demonstrator

Main Responsible	MAGTEL
Contributing Partners	SOTEC
Validation Method	Demonstration
Related reqs.	R-DET-082

The bandwidth required for the whole system is close to 2000 Kbps in total. The router is configured to provide about 300 Mbps via 802.11n (via Wi-Fi), and 1 Gbps (via Ethernet). Several load tests were performed transmitting the maximum amount of data, and in no case the channel was saturated.

4.2 DEMAG MH-Demonstrator

Main Responsible	DEMAG
Contributing Partners	IFAK, URO
Validation Method	Demonstration
Related reqs.	R-DET-082, R-DET-086

This requirement is validated within the context of DEMAG MH-demonstrator, and it has been tested confirming its operation. The main challenge for the MH-demonstrator is not the bandwidth, but the low latency time - actually, there is no camera systems on cranes.

The CAN-Safety bus requires a strictly real time behavior. Delay times longer than 200 ms leads to communication errors and crane stops.

5 Requirement R_Gen_005

Requirement Statement	Planning and installation SHOULD be possible with reduced effort.
Related reqs.	-

This requirement includes the following details:

- The planning and installation should be supported by PC-based tools for modelling, visualisation, and simulation. These tools will systematically support the actors in the different lifecycles from the beginning with product sales through to installation, commissioning and later with product maintenance.

This requirement is validated within the context of MAGTEL/SOTEC demonstrator by tested.

5.1 MAGTEL/SOTEC Demonstrator

Main Responsible	MAGTEL
Contributing Partners	SOTEC
Validation Method	Tested
Related reqs.	-

In the case of the physical demonstrator (smart factory component, CPS), the elements are modular and lightweight, with fixed positions where to be placed, so the installation can be performed in less than an hour.

Regarding the logical components, mainly related to the telemetry platform (INDIGO), by having adopted a microservice-based architecture, using Docker, the full deploy of the platform takes between 20 and 40 seconds.

Figure 21: Physical demonstrator MAGTEL/SOTEC

6 Requirement R_Gen_006

Requirement Statement	Interoperability with existing machines and machines from other manufactures SHOULD be guaranteed.

Related reqs.	R-DET-019
	The system should be able to work with machines that are already available on site, i.e. existing machines do not need to be replaced. The system should be able to work with machines from other manufacturers.

This requirement includes the following details:

- The system should be able to work with machines that are already available on site, i.e. existing machines do not need to be replaced. The system should be able to work with machines from other manufacturers.

This requirement is validated within the context of ERMETAL demonstrator by analysis, but since all demonstrators share the same architecture, validation applies to other demonstrators too.

6.1 DEMAG MH Demonstrator

Main Responsible	DEMAG
Contributing Partners	IFAK
Validation Method	Demonstration
Related reqs.	R-DET-019

The DCP Hardware is installed “on top” of the existing crane (machine) control. The standard machine functions are still implemented in the original machine control, just the innovative advanced machine functions are in the DCP. The only precondition that must be fulfilled is a suitable interface between the control units. In the MH-demonstrator this interface is a CAN-Bus.

Also, the AGV control has a CAN-Bus connection to the DCP. In principle also other industrial serial busses – like Profibus or Profinet – are possible.

Figure 22 shows the block diagram of the distributed control for a crane:

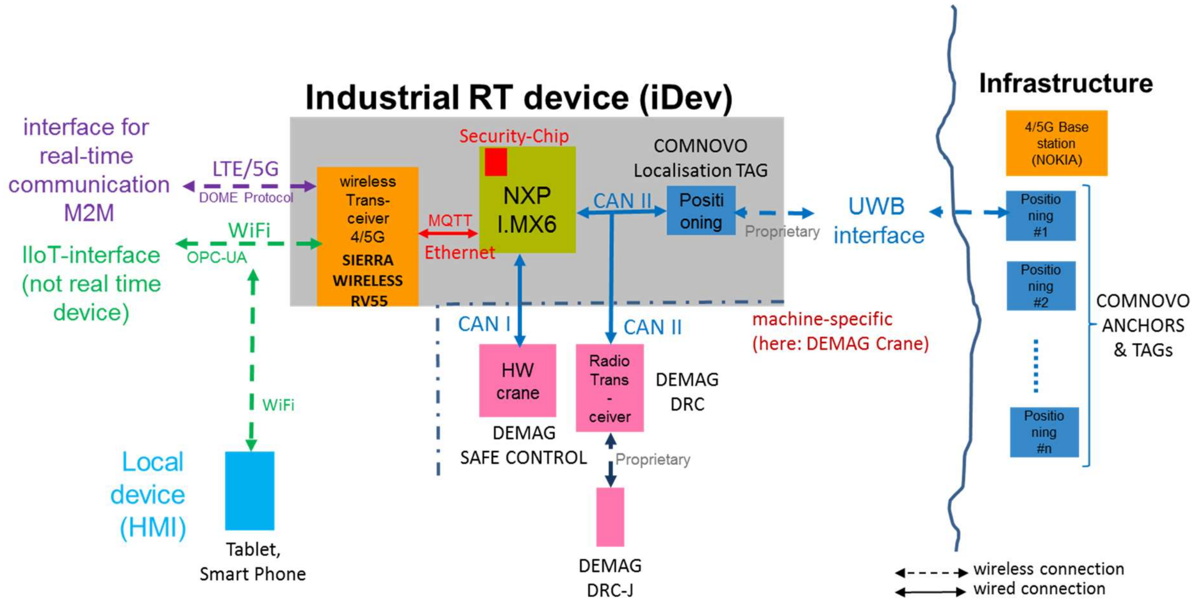


Figure 22: Block diagram of DCP

The Industrial Device (iDev) in the grey box represents the distributed control platform.
All actors (machines & operators) involved in the material flow are equipped with iDevs.
The iDevs communicates with each other utilizing the OPTIMUM-infrastructure.
This infrastructure consists in 5G wireless communication devices and UWB-localization system with anchors and tags.

6.2 Ermetal Demonstrator

Main Responsible	ERSTE
Contributing Partners	DIA, ERMETAL
Validation Method	Analysis

OPTIMUM architecture is designed in a way that

1. it can make use of existing machines to fulfill the system functionalities,
2. it provides the necessary means to interoperability with other machines.

For these purposes an OPTIMUM Device (see D2.2), which basically runs DCP and IIoT components, works like an adapter to add aimed smart functionalities to the existing machines.

Control Application Objects (CAO), which run as part of DCP uses the provided control interfaces of the machine to make the functionalities of the machine available to the rest of the components in the system.

On the other hand, IIoT provides an interface to the external nodes using the OPC-UA, which is a self-descriptive protocol, so that the basis for the interoperability with machines from other manufacturers is provided.

The ERMETAL demonstrator has 2 different variants: desktop and bigger scale. These variants use different types of crane control mechanisms. Due to the aforementioned design approach, implementing a new CAO to control the crane system in bigger scale demonstrator during the transition from desktop demonstrator. Although the machine interfaces, which the corresponding CAOs deal with, are different, since they provided the same internal interface, it was possible to use the other software components as they are.

7 Requirement R_Gen_007

Requirement Statement	System MUST provide cooperation between operators and machines

Related reqs.	R-DET-084
	specific events surrounding machine can be defined as like threshold of distance between machine and machine, obstacles, moving people, etc. The events are used to trigger for emergency alerting

This requirement includes the following details:

- Data exchange MUST be possible between different machines as well as between machines and human operators

This requirement is validated within the context of ETRI/HANDYSOFT demonstrator by demonstration, but since all demonstrators share the same architecture, validation applies to other demonstrators too.

7.1 ETRI/HANDYSOFT Demonstrator

Main Responsible	ETRI
Contributing Partners	HANDYSOFT
Validation Method	Demonstration
Related reqs.	R-DET-084

Below is the environment of ETRI/HANDYSOFT demonstration.

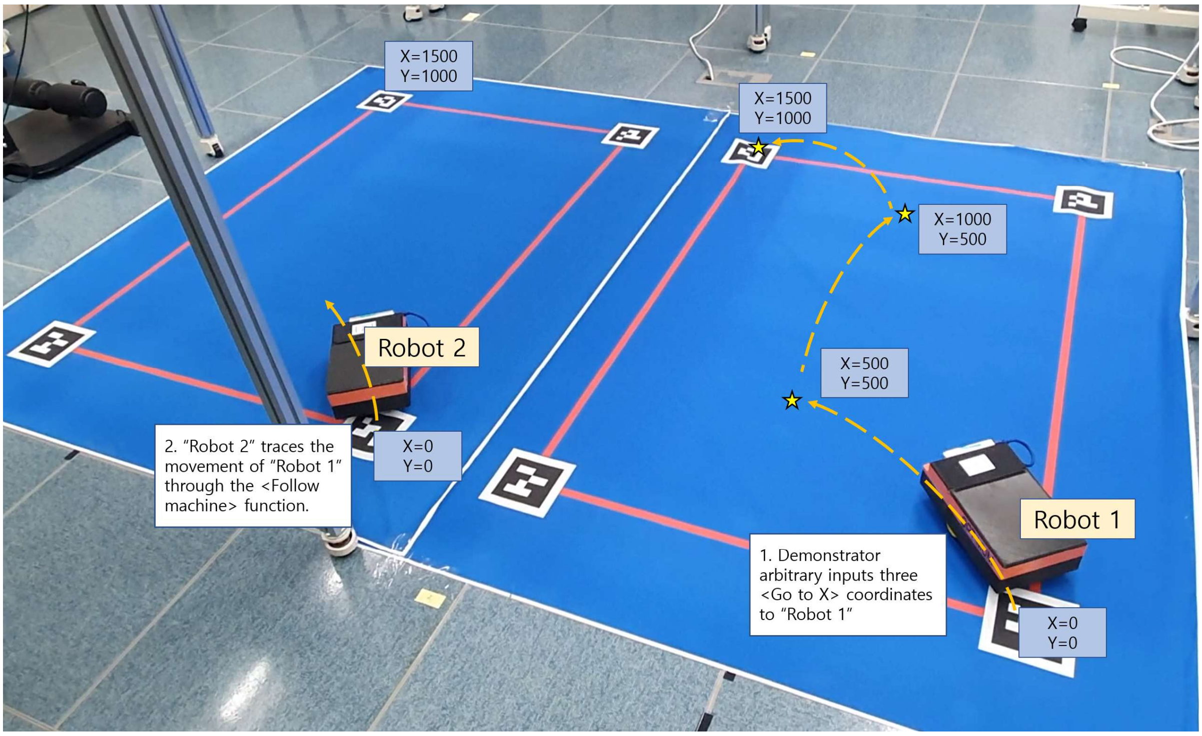


Figure 23: Environment of ETRI/HANDYSOFT demonstration

We implemented two robots, each of which moves in an independent coordinate system. The demonstrator moves "Robot 1" to the final destination by using the <Go to X> function, and inputs two arbitrary stop points. “Robot 1” and “Robot 2” share their current position and heading angle information through optimum architecture. “Robot 2” traces the movement of “Robot 1” using the <Follow machine> function by periodically receiving the current position and heading angle, which are the context information of “Robot 1”.

7.2 MAGTEL/SOTEC Demonstrator

Main Responsible	MAGTEL
Contributing Partners	SOTEC
Validation Method	Demonstration
Related reqs.	R-DET-084

The demonstrator contains different interaction mechanisms (manual and AI-based), that allow the cooperation between operators and machines. Testing has been conducted to verify that all the possible operations are conducted flawlessly.

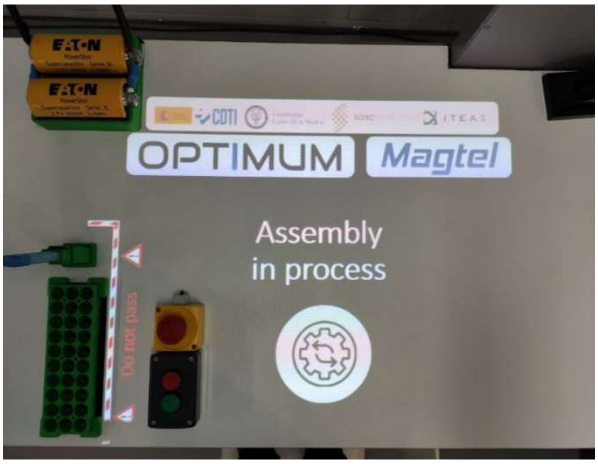


Figure 24: Control Panel and Top view of demonstrator

7.3 ERMETAL Demonstrator

Main Responsible	ERSTE
Contributing Partners	DIA, ERMETAL
Validation Method	Analysis / Demonstration

ERMETAL demonstrator is designed and implemented in a way that the resulting system supports the human operator where computationally complex activities are required (e.g., computing steps to store a coil or remove a coil from the storage area), close attention is required for long periods of time (e.g., monitoring the availability of the shearing machine and checking the shearing work orders to feed the shearing machine) or the operator should be away from the heavy loads (e.g., coil stacking). On the other hand, human abilities are required to take high level decision of when to accomplish coil storage or shearer feeding activities or high precision coil handling with inaccurate coil locations. The whole ERMETAL demonstrator is a good example of human-machine cooperation.

7.4 DEMAG MH-Demonstrator

Main Responsible	DEMAG
Contributing Partners	IFAK, URO
Validation Method	Demonstration
Related reqs.	R-DET-084

With the implementation of the OPTIMUM innovative assist functions DEMAG demonstrated that operators and machines are co-working.

8 Requirement R_Gen_009

Requirement Statement	The overall system MUST be modular and scalable.

Related reqs.	R-DET-045, R-DET-046, R-DET-047, R-DET-048

This requirement includes the following details:

- Hardware-id, machine type, specific limitations must be reported.

This requirement is validated within the context of MAGTEL/SOTEC demonstrator, and it has been analysed and tested confirming its operation.

8.1 MAGTEL/SOTEC Demonstrator

Main Responsible	MAGTEL
Contributing Partners	SOTEC
Validation Method	Demonstration
Related reqs.	R-DET-045

In the case of the physical demonstrator (smart factory component, CPS), the elements are modular and lightweight, with fixed positions where to be placed, so that the installation can be performed in less than an hour. In the logical level, every piece of equipment is identified univocally via a specific ID, and the semantic representation for the different items provides information such as the machine types and their corresponding characteristics and operation ranges.

Regarding the logical components, mainly related to the telemetry platform (INDIGO), by having adopted a microservice-based architecture, using Docker, the system can be extended and deployed with a high horizontal scalability level.

9 Requirement R_Gen_010

Requirement Statement	System MUST comply with existing safety and security regulations.

Related reqs.	R-DET-049, R-DET-050, R-DET-051, R-DET-053, R-DET-054, R-DET-55, R-DET-056, R-DET-057, R-DET-058

This requirement includes the following details:

- Collision avoidance is a functional safety related function.
- As required from standard safety requirement.
- This requirement is related to the collision avoidance functionality.
- When the control system detects malfunctions that leads to dangerous situation, the machine movements will stop.

This requirement is validated within the context of MAGTEL/SOTEC demonstrator, and it has been analysed and tested confirming its operation. R-DET-055 has just been validated by inspection.

9.1 MAGTEL/SOTEC Demonstrator

Main Responsible	MAGTEL
Contributing Partners	SOTEC
Validation Method	Demonstration and Inspection
Related reqs.	R-DET-050, R-DET-055, R-DET-057, R-DET-058

The demonstrator contains different interaction mechanisms (manual and AI-based), that allow a safe and secure cooperation between operators and machines. A demonstration has been conducted to verify that all the possible operations are conducted safely and flawlessly.

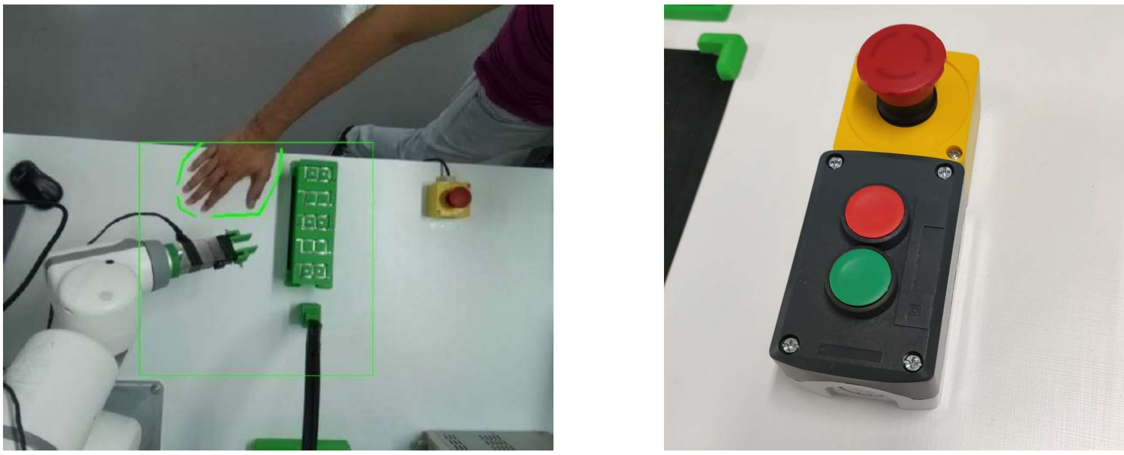


Figure 25: Top view Demonstrator and Control Panel

9.2 DEMAG MH-Demonstrator

Main Responsible	DEMAG
Contributing Partners	IFAK
Validation Method	Demonstration
Related reqs.	R-DET-050, R-DET-057

General statements about safety compliance with existing safety regulations are described for R_GEN_003. Regarding R-DET-050 and R-DET-57 DEMAG has built a 3D-printed crane model to evaluate “Collision avoidance” and “Path finding” algorithms.

Figure 26: 3D printed crane model

The methods for collision avoidance and path finding have been prototypical implemented and tested. A program has been developed, that finds the most favourable path between two points in a hall. The path must maintain an adjustable safety distance from all obstacles in the room. The geometry of the obstacles is known at the start of the program; there are both static and moving obstacles in the hall. The position and orientation of the moving obstacles can be read from the data of the UWB-localisation sensors. The data structure of the obstacles as well as rules for interpreting the localisation data has been defined.

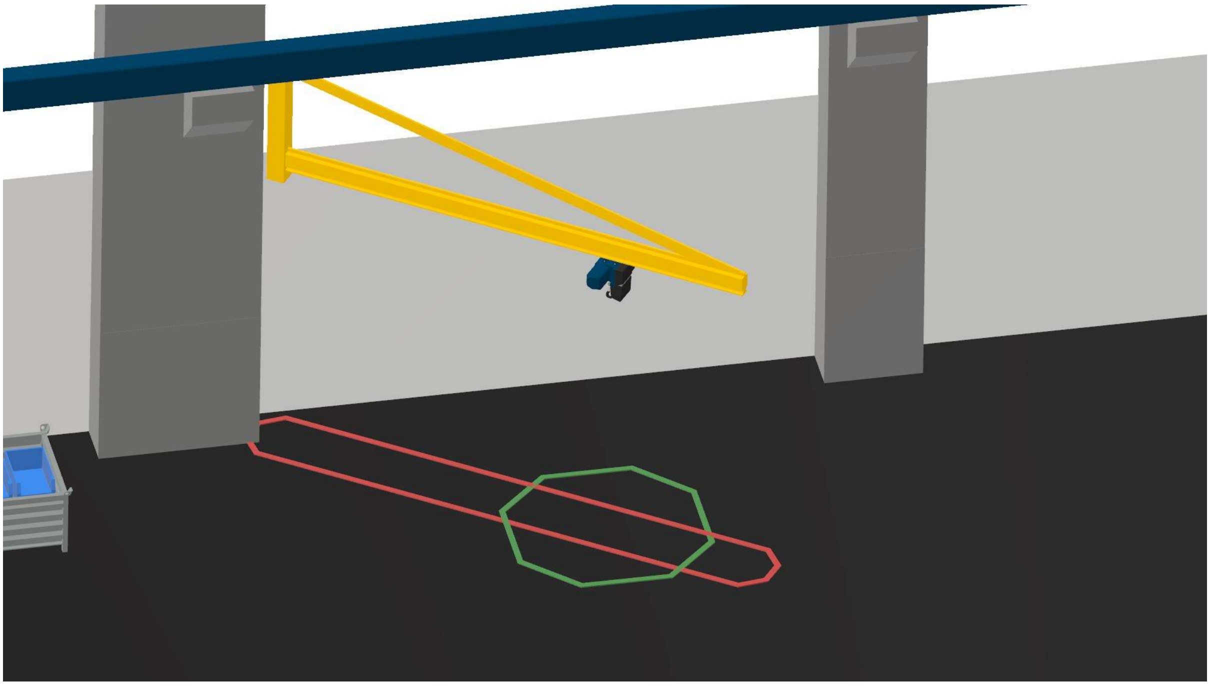


Figure 27: 2D Obstacle polygons for a wall-mounted slewing crane with hoist

The measurements were made for a scenario with 5 obstacles. Each movement type is represented in the 5 obstacles. In total, the transformed obstacles have 57 corner points. By overlapping the polygons, the number of waypoints can be reduced to approximately 25-50. During the measurement, the tags of the obstacles as well as the start and target points were moved.

The offset varied in the tests between 0.1 and 25. The following pictures shows the different movements, a change of the offset and the overlapping of polygons.

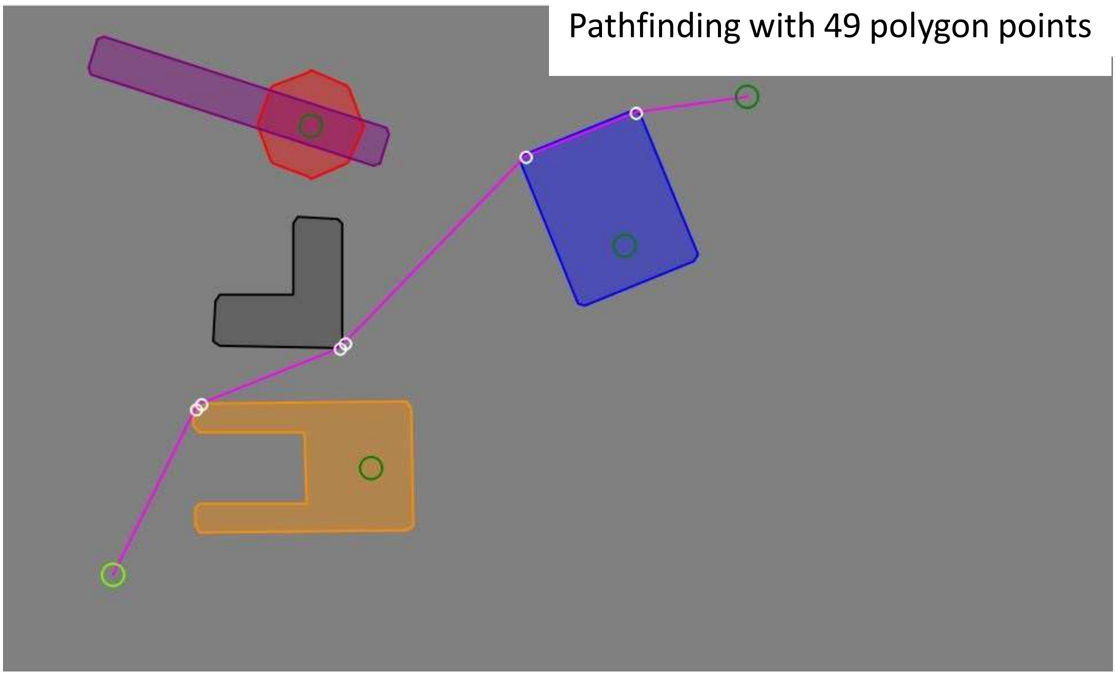


Figure 28: Pathfinding with 48 polygon points

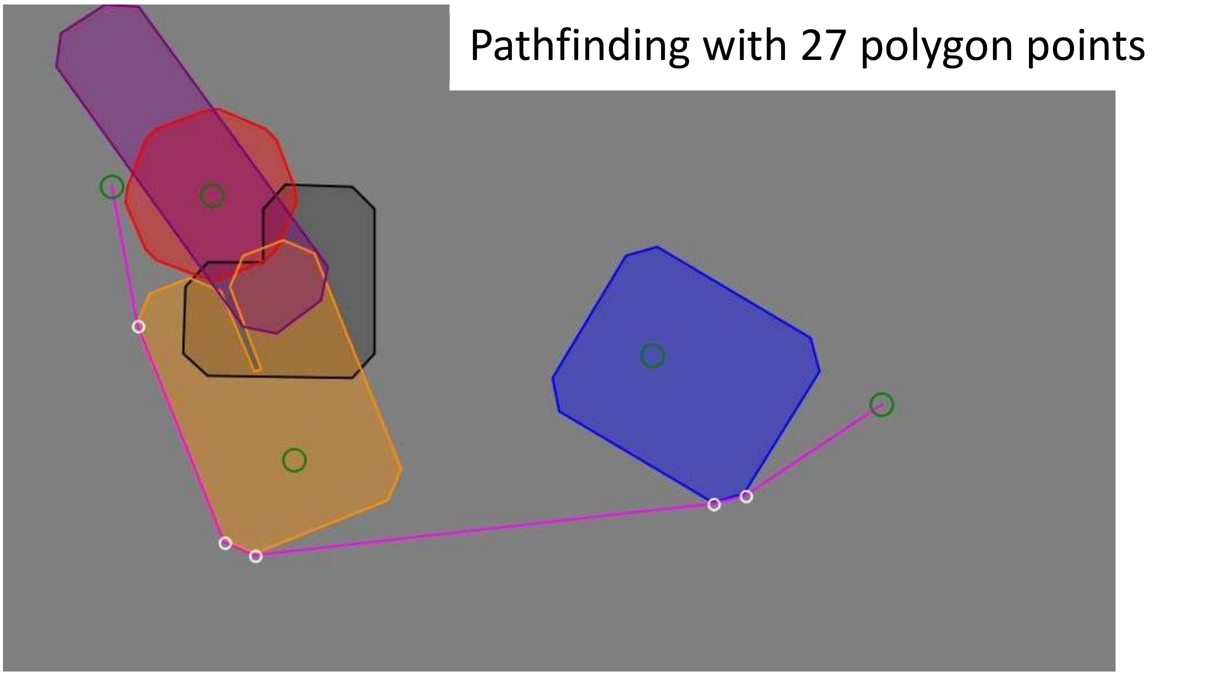


Figure 29: Pathfinding with 27 polygon points

By using obstacle polygons, an optimal graph for wayfinding is formed. The obstacles can move in the runtime by changing tag positions. Different movement types allow the movement behaviour of people, vehicles and other obstacles to be interpreted correctly. In addition, the safety distance between the crane and all obstacles can be set as desired. From the list of all obstacle polygons, only those polygon points that could be relevant for wayfinding are kept.

The wayfinding algorithm generates the graph based on this reduced list of points, thus only the nodes and edges needed in the algorithm are calculated. The program can already be used to calculate 2D-paths for indoor cranes and AGVs.

9.3 ERMETAL Demonstrator

Main Responsible	ERSTE
Contributing Partners	DIA, ERMETAL
Validation Method	Demonstration
Related reqs.	R-DET-49, R-DET-50, R-DET-57, R-DET-67, R-DET-68

In ERMETAL demonstrator, for the collision avoidance, an Object Detection Subsystem (ODS) is developed. ODS is capable of scanning the circumference of the crane/tong to sense the objects in the vicinity. Basically, it generates angle-distance pairs. For example, (10°, 55cm) means there is an object (or part of an object) in the direction 10°, 55 cm away from the corresponding sensor. Below is a photo of ODS (not installed on crane/tong) and a top view drawing how it is installed on tong. See D4.5 for more details on ODS.

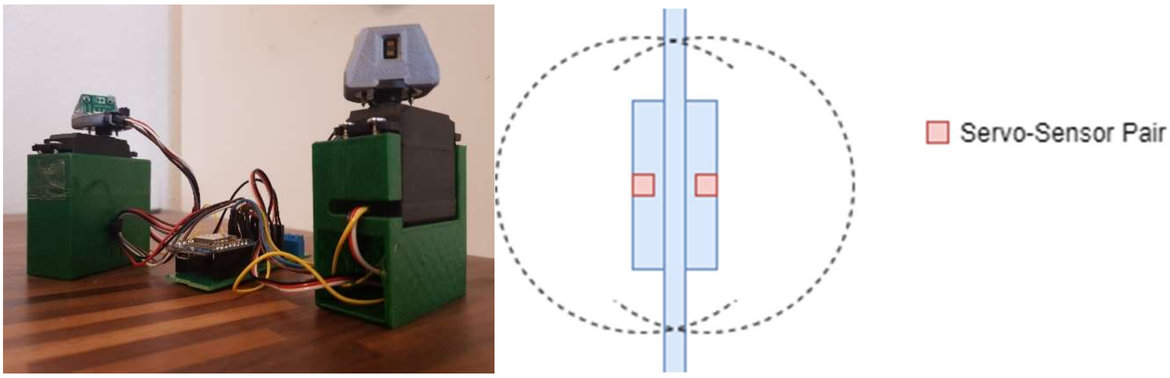


Figure 3130: Object Detection Subsystem (ODS) and top view drawing of installation on tong

ODS is used for collision avoidance with both stationary and moving obstacles. The main advantage of the approach is that, it does not require a sensor at the obstacle side. Furthermore, the data obtained from ODS is used in collision avoidance both for manually controlled movement and (semi-)autonomous movement.

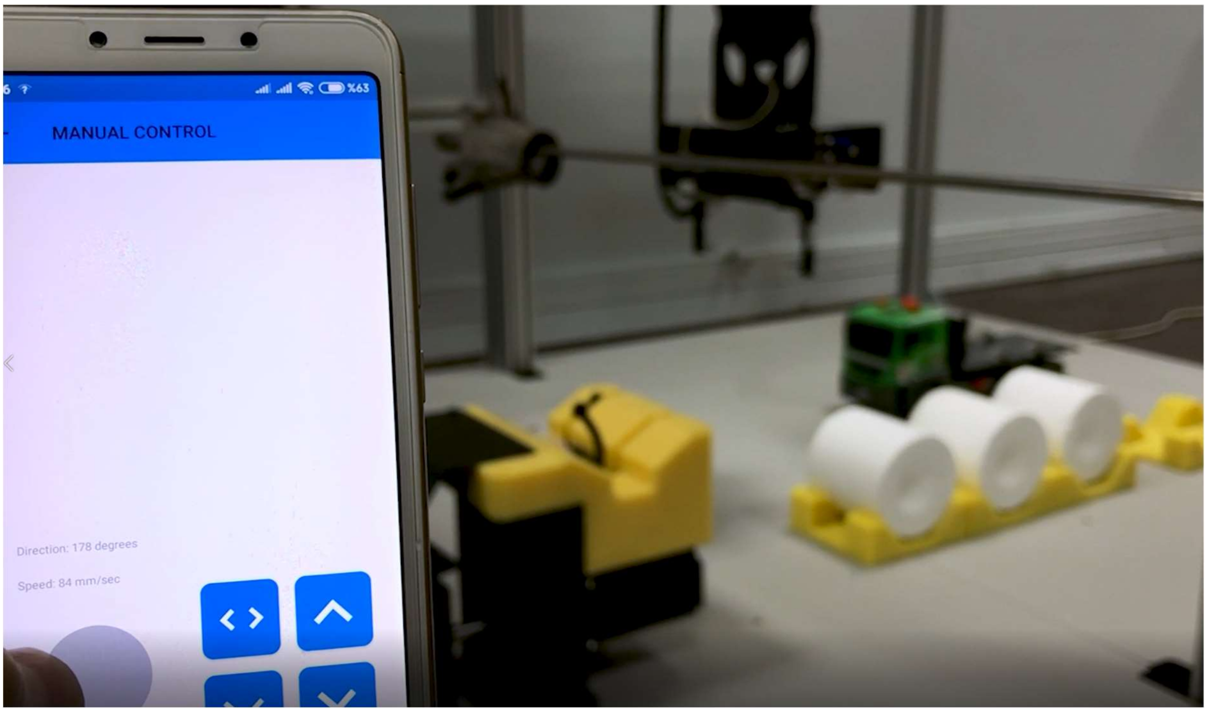
In the manual control, the following approach is used

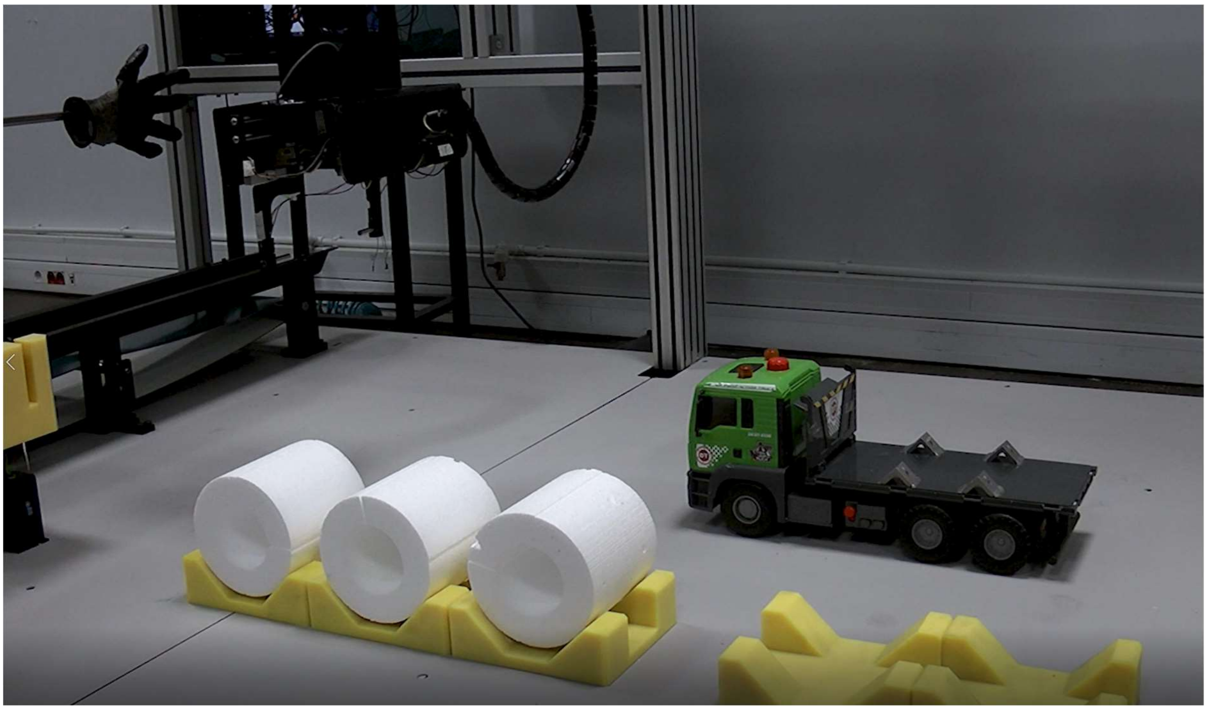
1. The direction and speed of the manual movement requests are monitored
2. At every change (either in manual movement command or readings from the ODS) check if there is a collision possibility (between the whole tong and the object) if the tong moves in the direction of the command.
3. Halt the movement if there is such possibility, let the tong move as commanded otherwise.

In (semi-)autonomous movement, during the “follow path” command execution,

1. Check on which section of the waypoints the tong is on
2. Compute the direction of the current movement (as angle)
3. At every change (change in the location of the tong or readings from the ODS) check if there is a collision possibility (between the whole tong and the object) if the tong moves in the computed direction.
4. Halt the movement if there is such possibility, let the tong move as commanded otherwise.

Below are some photos from the demonstration.


MANUAL CONTROL
Direction: 178 degrees
Speed: 84 mm/sec



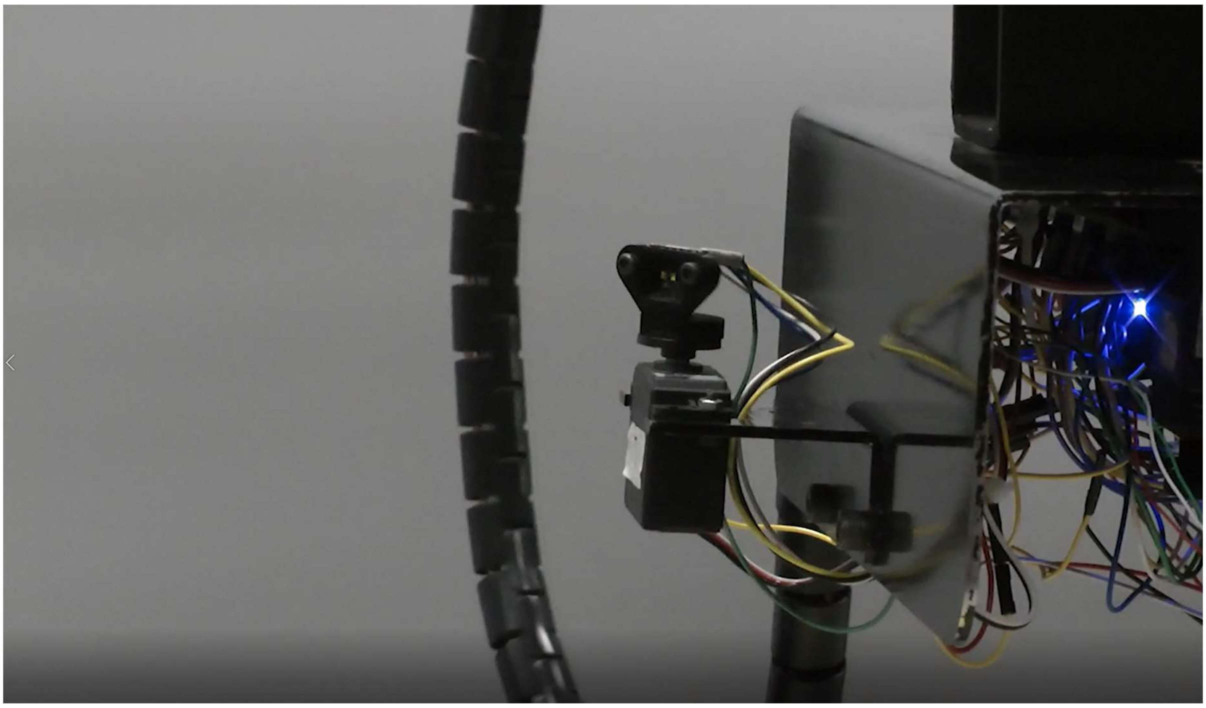


Figure 3231: Photos from ERMETAL demonstrator

10 Requirement R_Gen_012

Requirement Statement	System SHOULD support machine data collection, data management, and data communication to/from machines

Related reqs.	R-DET-062, R-DET-063, R-DET-064, R-DET-067, R-DET-068, R-DET-069, R-DET-071, R-DET-072, R-DET-073, R-DET-074, R-DET-075, R-DET-076, R-DET-104, R-DET-118

This requirement includes the following details:

- Machines MUST be able to avoid collisions with other stationary machines, operators and obstacles (R-DET-067)
- Machines MUST be able to avoid collisions with other moving machines and moving operators (R-DET-068)

This requirement is validated within the context of ETRI/HANDYSOFT demonstrator by demonstration, but since all demonstrators share the same architecture, validation applies to other demonstrators too.

10.1 ETRI/Handysoft Demonstrator

Main Responsible	ETRI
Contributing Partners	HANDYSOFT
Validation Method	Demonstration
Related reqs.	R-DET-067, R-DET-068

Below is the demonstration of <Collision avoidance> function.

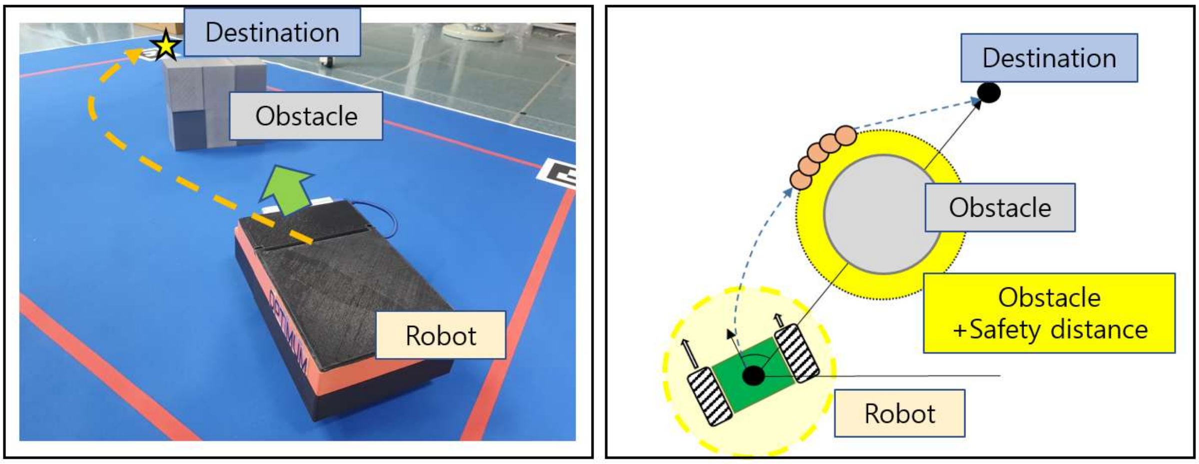


Figure 3332: Demonstration of <Collision avoidance> function

A Robot creates the shortest route to the destination point when a destination is determined. If an obstacle area is included in the shortest route, the robot defines a collision-free path. To create a collision-free path, information about the size of the robot, the safety distance, and the size of the obstacle area are required. It moves by creating a route that passes through the curved circumference of the obstacle area with the safety distance. The path is created periodically. Therefore, even if new obstacles are found during the movement of the changed path, it creates a collision-free path again in real time and moves to the destination.

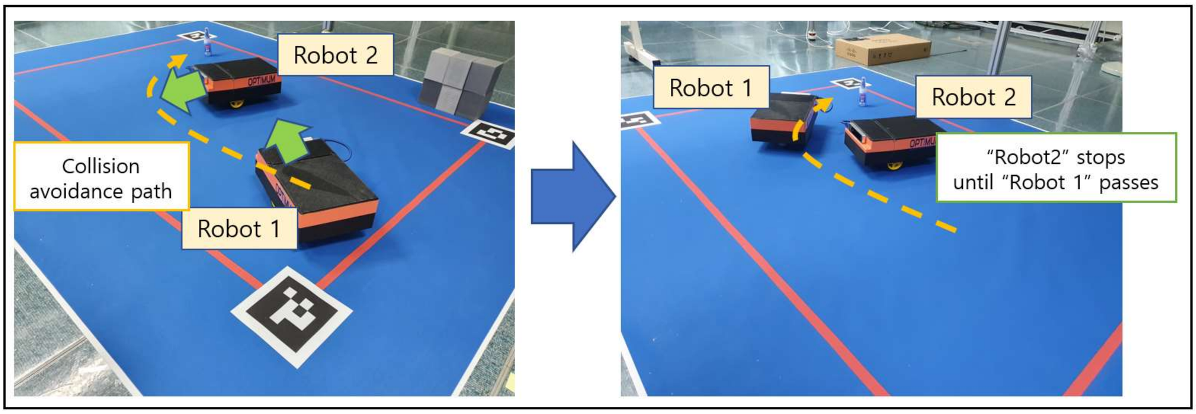


Figure 3433: Robots – Collision avoidance path

Collision avoidance function can also be performed between moving robots by applying a method of creating a collision-free path for a stationary object. When moving "Robot 1" and "Robot 2" encounter each other, it is performed as follows. The two robots are aware of each other's location through real-time communication while moving. If the distance between the robots is less than the safety distance, the robot with a lower priority among the two robots stops moving. And the robot with high priority regards another robot as a stationary obstacle and creates a collision-free path through the <Collision avoidance> function. In Figure 34Figure 32, "Robot 1", which has a high priority, creates a collision-free path and moves to the destination first. When the distance between the two robots is longer than the safety distance "Robot 2" moves to the destination in the original path.

10.2 MAGTEL/SOTEC Demonstrator

Main Responsible	MAGTEL
Contributing Partners	SOTEC
Validation Method	Demonstration
Related reqs.	R-DET-068, R-DET-069

Communications between the different IoT devices have been implemented through the open-source Node-Red platform. In addition, the MQTT protocol has been used for sending and receiving signals. The connection with the INDIGO platform is made through the OPC-UA communication protocol, and all the data received is logged into such platform.

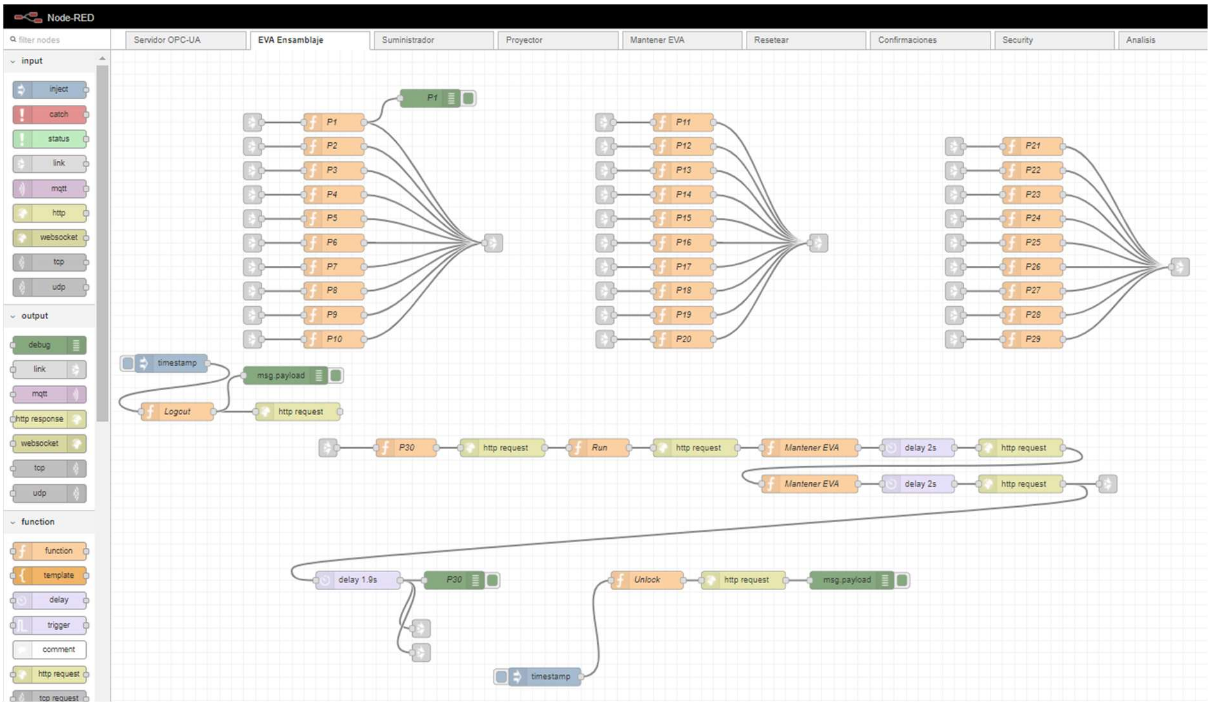


Figure 3534: Caption Magtel/Sotec

11 Requirement R_Gen_013

Requirement Statement	An Indoor localization of machines and operators MUST be implemented as well as anti-collision strategies.

Related reqs.	R-DET-063, R-DET-064, R-DET-065

This requirement includes the following details:

- An Indoor localization of machines and operators MUST be implemented as well as anti-collision strategies.
- The machine must be able to self-determine its position.

This requirement is validated within the context of MAGTEL/SOTEC demonstrator by analysis and testing.

11.1 MAGTEL/SOTEC Demonstrator

Main Responsible	MAGTEL
Contributing Partners	SOTEC
Validation Method	Analysis / Tested
Related reqs.	R-DET-065

The demonstrator contains different interaction mechanisms (manual and AI-based), that allow a safe and secure cooperation between operators and machines. The camera provides a continuous stream of video that is analysed with AI algorithms to determine whether a collision may appear, and strategies to prevent such situation are carried out.

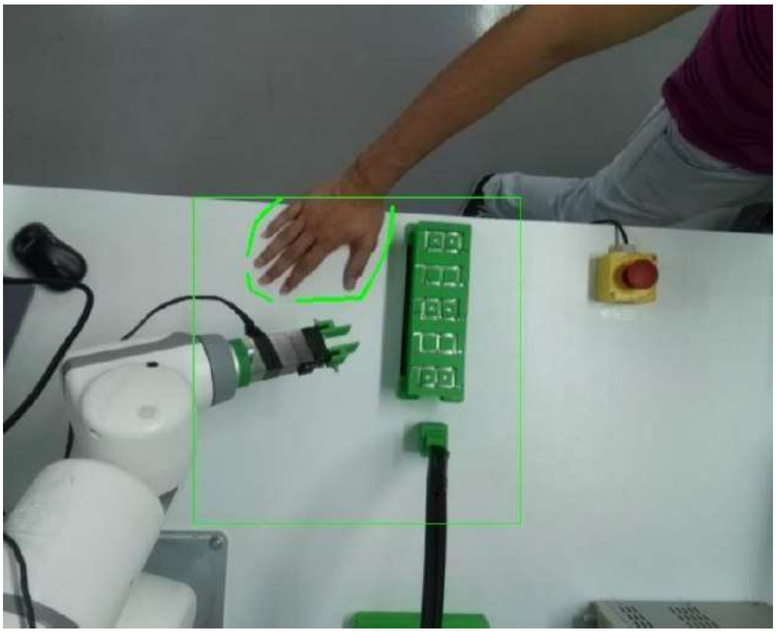


Figure 3635: Top view Spanish demonstrator

11.2 DEMAG MH-Demonstrator

Main Responsible	DEMAG
Contributing Partners	COMNOVO
Validation Method	Analysis / Tested
Related reqs.	R-DET-063, R-DET-064, R-DET-065

R-DET-063	Localization	Deterministic guarantee of positioning MUST be given	It is described by the 2-sigma std. Deviation, where 2-sigma < mean positioning error
R-DET-064	Localization	Refresh time of position information (UWB localization system) MUST be as quantified	Refresh time is depending on the use case, especially on the speed of movement of the machine
R-DET-065	Localization	Self-localization MUST be possible	The machine must be able to self-determine its position

The indoor localization system utilized in the DEMAG Research factory for the MH-Demonstrator is based on the UWB-components of COMNOVO.
To be able to measure the accuracy of the position information we defined first reference points P1 – P8 on the factory floor:

Figure 3736: Sketch of the DEMAG Research Factory with reference points, not scaled

The X/Y-Coordinates of each reference point have been measured with a laser distance meter (Measuring accuracy: +/- 1.5 mm) – see Table 4.

Table 4: X/Y -Coordinates of reference points

Point	X [mm]	Y [mm]
P1	1460	3360
P2	4850	5430
P3	2370	7770
P4	6900	9050
P5	3170	12300
P6	6570	12580
P7	2960	17650
P8	6250	18190

With a "Go-To" command for the crane - and the related trolley - different reference points were defined as target positions. For each target we have repeated the procedure several times and from different directions as illustrated in Figure 37Figure 35.

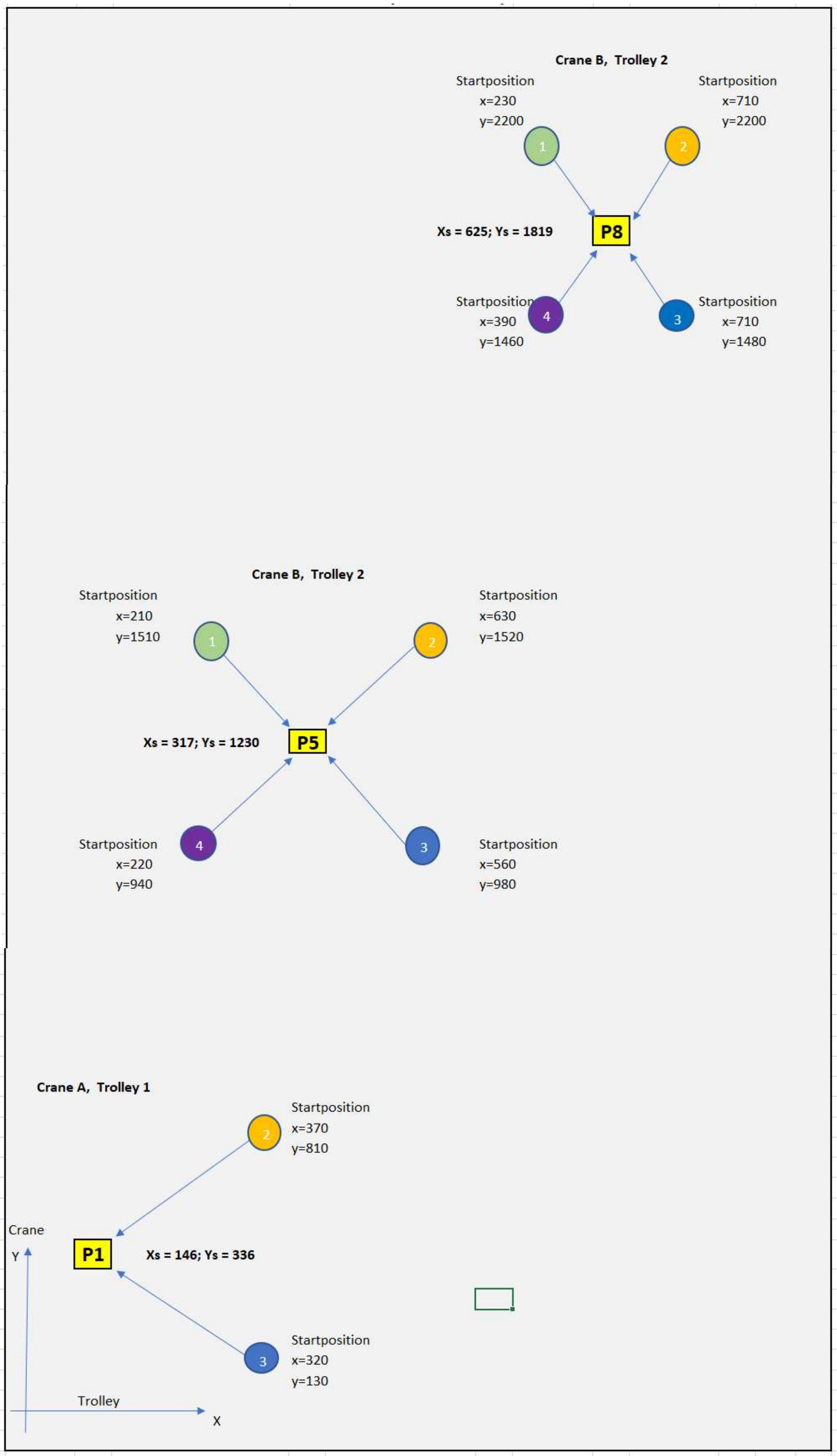


Figure 3837: Overview reference points

All measurements and the evaluation results are listed in Table 5.
The X/Y-deviation mean values have been calculated for each of the four different approaching directions as shown in Figure 38Figure 36. For P1 was only possible to approach the target from the right side because there was not enough space on left side of the hall.

Table 5: Measurements and evaluation results for each approaching direction

MEASUREMENTS Xi, Yi / **EVALUATION**

P8		
	Xs	625
	Ys	1819

Startposition		Xi - Xs [cm]	Yi - Ys [cm]	Xi-Xs Mittelwert [cm]	Δx_mw	-0,80
	1	19	8	I Xi-Xs I Max [cm]	Δx_max	19,00
1	2	-1	-21	X-Standardabweichung	σx	12,19
	3	-2	-8	Yi-Ys Mittelwert [cm]	ΔY_mw	-6,80
	4	-6	-13	I Yi-Ys I Max [cm]	Δy_max	21,00
	5	-14	0	Y-Standardabweichung	σy	11,26

Startposition		Xi - Xs [cm]	Yi - Ys [cm]	Xi-Xs Mittelwert [cm]	Δx_mw	11,20
	1	15	-10	I Xi-Xs I Max [cm]	Δx_max	25,00
2	2	15	-22	X-Standardabweichung	σx	11,05
	3	25	-2	Yi-Ys Mittelwert [cm]	ΔY_mw	-12,60
	4	5	-19	I Yi-Ys I Max [cm]	Δy_max	22,00
	5	-4	-10	Y-Standardabweichung	σy	7,99

Startposition		Xi - Xs [cm]	Yi - Ys [cm]	Xi-Xs Mittelwert [cm]	Δx_mw	14,00
	1	17	8	I Xi-Xs I Max [cm]	Δx_max	25,00
3	2	15	14	X-Standardabweichung	σx	12,88
	3	21	13	Yi-Ys Mittelwert [cm]	ΔY_mw	11,60
	4	-8	5	I Yi-Ys I Max [cm]	Δy_max	18,00
	5	25	18	Y-Standardabweichung	σy	5,13

Startposition		Xi - Xs [cm]	Yi - Ys [cm]	Xi-Xs Mittelwert [cm]	Δx_mw	-18,80
	1	-15	28	I Xi-Xs I Max [cm]	Δx_max	45,00
4	2	-14	29	X-Standardabweichung	σx	15,87
	3	-2	11	Yi-Ys Mittelwert [cm]	ΔY_mw	23,00
	4	-18	12	I Yi-Ys I Max [cm]	Δy_max	35,00
	5	-45	35	Y-Standardabweichung	σy	10,84

P5	Xs	317
	Ys	1230

1

	Xi - Xs [cm]	Yi - Ys [cm]
1	10	-6
2	-6	-7
3	-9	15
4	-21	-12
5	6	10

Xi-Xs Mittelwert [cm]	Δx_mw	-4,00
I Xi-Xs I Max [cm]	Δx_max	21,00
X-Standardabweichung	σx	12,39
Yi-Ys Mittelwert [cm]	ΔY_mw	0,00
I Yi-Ys I Max [cm]	Δy_max	15,00
Y-Standardabweichung	σy	11,77

2

	Xi - Xs [cm]	Yi - Ys [cm]
1	6	-13
2	36	-2
3	-40	3
4	36	-6
5	-6	-33

Xi-Xs Mittelwert [cm]	Δx_mw	6,40
I Xi-Xs I Max [cm]	Δx_max	40,00
X-Standardabweichung	σx	31,86
Yi-Ys Mittelwert [cm]	ΔY_mw	-10,20
I Yi-Ys I Max [cm]	Δy_max	33,00
Y-Standardabweichung	σy	14,02

3

	Xi - Xs [cm]	Yi - Ys [cm]
1	2	63
2	17	35
3	31	11
4	10	32
5	28	8

Xi-Xs Mittelwert [cm]	Δx_mw	17,60
I Xi-Xs I Max [cm]	Δx_max	31,00
X-Standardabweichung	σx	12,14
Yi-Ys Mittelwert [cm]	ΔY_mw	29,80
I Yi-Ys I Max [cm]	Δy_max	63,00
Y-Standardabweichung	σy	22,15

4

	Xi - Xs [cm]	Yi - Ys [cm]
1	32	24
2	-2	13
3	8	15
4	-3	40
5	-2	26

Xi-Xs Mittelwert [cm]	Δx_mw	6,60
I Xi-Xs I Max [cm]	Δx_max	32,00
X-Standardabweichung	σx	14,89
Yi-Ys Mittelwert [cm]	ΔY_mw	23,60
I Yi-Ys I Max [cm]	Δy_max	40,00
Y-Standardabweichung	σy	10,74

P1	Xs	146
	Ys	336

2

	Xi - Xs [cm]	Yi - Ys [cm]
1	24	-4
2	13	-2
3	15	-19
4	19	-9
5	20	0

Xi-Xs Mittelwert [cm]	Δx_mw	18,20
I Xi-Xs I Max [cm]	Δx_max	24,00
X-Standardabweichung	σx	4,32
Yi-Ys Mittelwert [cm]	ΔY_mw	-6,80
I Yi-Ys I Max [cm]	Δy_max	19,00
Y-Standardabweichung	σy	7,60

3

	Xi - Xs [cm]	Yi - Ys [cm]
1	13	19
2	29	3
3	18	16
4	25	15
5	23	30

Xi-Xs Mittelwert [cm]	Δx_mw	21,60
I Xi-Xs I Max [cm]	Δx_max	29,00
X-Standardabweichung	σ_x	6,23
Yi-Ys Mittelwert [cm]	ΔY_mw	16,60
I Yi-Ys I Max [cm]	Δy_max	30,00
Y-Standardabweichung	σ_y	9,66

Table 6: Evaluation results over all measurements

Variable	Symbol	Value	Unit
deviation mean value X	Δx_mw	5,38	cm
deviation mean value Y	ΔY_mw	8,76	cm
standard deviation X	σ_x	35,55	cm
standard deviation Y	σ_y	28,77	cm
Max. deviation X	Δx_max	45,00	cm
Max. deviation Y	Δy_max	63,00	cm

The deviation means values Δx_mw and Δy_mw are better than the stated target at the beginning of the project of 50 cm (R-DET-063) and they amount over all datas is approx. 5 cm for X (Trolley axis) and 9 cm for Y (Crane axis). Unfortunately, the standard deviations σx and σy (σ is a measure of the divergence of the values of a random variable around its mean value) is quite high, so that in some cases the target is over- or underachieved quite much.
The maximum deviation in X- was 45 cm and in Y-direction 63 cm – See Table 6.

The measured deviation from the target does not depend just on the accuracy of the localization system, but also from the control and drives equipment. The Refresh time of position information (UWB localization system) is 100ms.
However, it was our intention to get an "overall" result about the position accuracy of the complete systems installed in the MH-demonstrator – as shown in Figure 39Figure 37.

Figure 39~~38~~: MH-Demonstrator in the Demag Research Factory

12 Requirement R_Gen_015

Requirement Statement	System MUST provide embedded control panels to support the new functions of the machines

Related reqs.	R-DET-022, R-DET-023, R-DET-024, R-DET-025, R-DET-026, R-DET-027

This requirement includes the following details:

- Human Machine Interface (HMI) devices are provided as control panels to control the machines and their functionalities
- The devices must support old system functions as well as provide and support new system functions and/or high-level tasks"

This requirement is partially or fully validated within the context of MAGTEL, ETRI, ERMETAL, DEMAG demonstrators by analysis, demonstration, and test, based on share of the same architecture among all demonstrators.

12.1 ETRI/HANDYSOFT Demonstrator

Main Responsible	ETRI
Contributing Partners	Handysoft
Validation Method	Demonstration
Related reqs.	R-DET-022, R-DET-023, R-DET-024, R-DET-027

Below is main display of HMI device to control the machines and their functionalities.

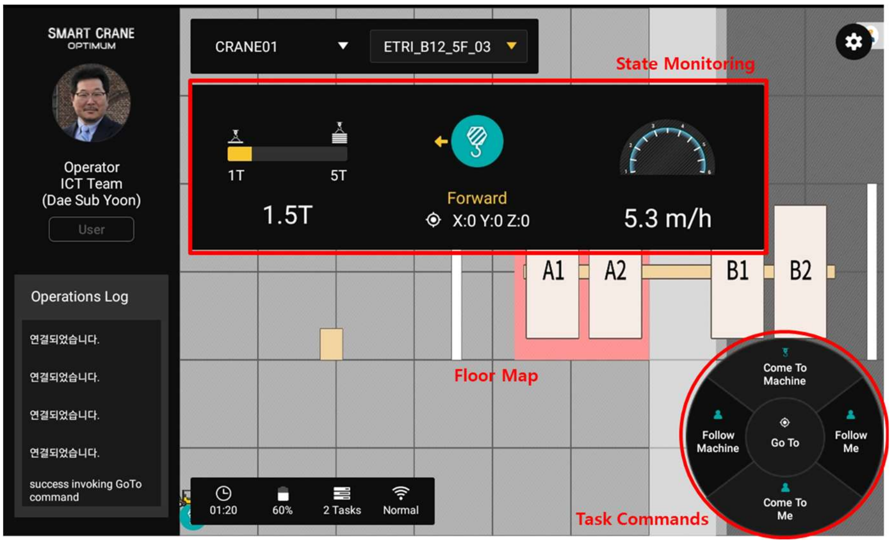


Figure 4039: Main display of HMI device

The developed HMI device provides a user-friendly GUI interface including floor map, command buttons, status information, device list, connection status, etc., according to the specified requirements, and the operator can control the target device wirelessly via the HMI.

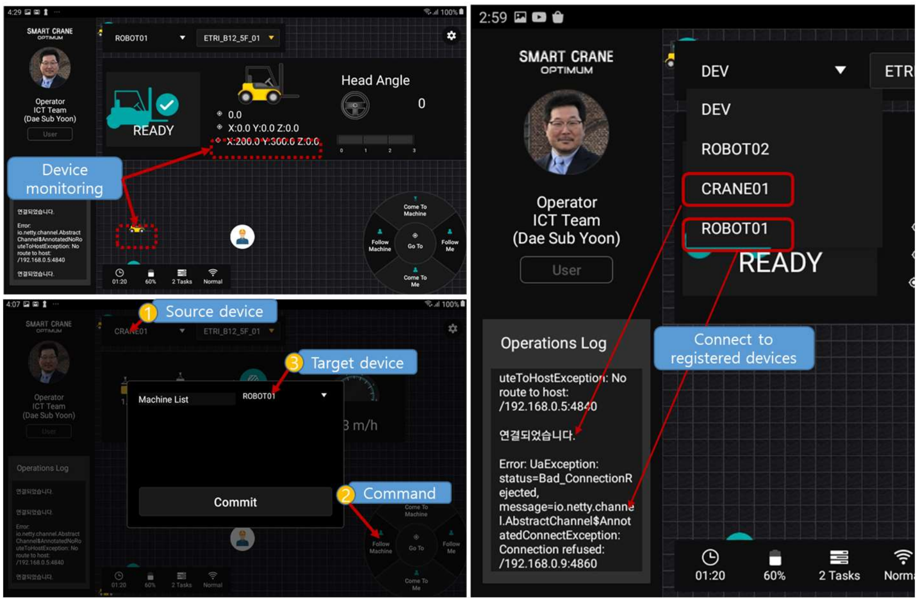


Figure 41~~40~~: Main display of HMI device

In details, The Operator can order a specific task command such as “Go To”, “Come to Machine”, and “Follow Machine” to the target crane using the provided HMI device and monitor the status and location information of the target device. This HMI has limitation that is not provided to support the new functions of the machines.

12.2 MAGTEL/SOTEC Demonstrator

Main Responsible	SOTEC
Contributing Partners	MAGTEL
Validation Method	Demonstration
Related reqs.	R-DET-022

The physical demonstrator provides some HMI elements, such as a button panel to confirm or interrupt the operations, and as a projected display that shows the status of the processes. Both have been validated and tested in every step of the manufacturing process.

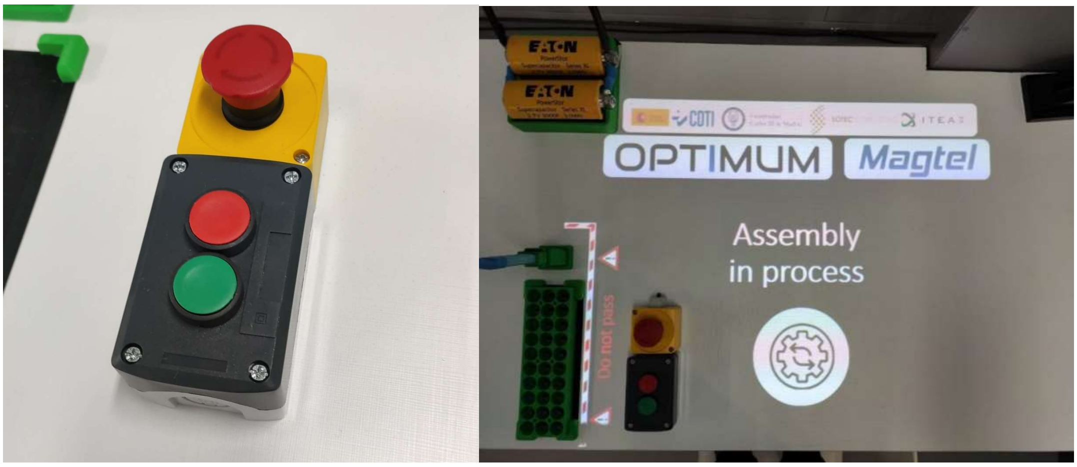


Figure 4241: Control Panel and Top view of the demonstrator

12.3 ERMETAL Demonstrator

Main Responsible	ERMETAL
Contributing Partners	ERSTE, DIA
Validation Method	Demonstration
Related reqs.	R-DET-022, R-DET-023, R-DET-025

As part of the ERMETAL demonstrator a modern HMI is developed which is capable of running on an Android device. The HMI communicates with IIoT using OPC-UA protocol and communicated with the ERP (simulator) system using a HTTP RESTful API.

Using the HMI, provides interface for the following functionality to the user

- To add new coils to the system or list the existing coils
- To send command store desired new coils and monitor steps during the coil storage
- To switch system to “Feed Shearer” mode, so that system feeds the shearing machine as it is available and there is new coil shearing order from the ERP as well as monitor steps of the ongoing feed shearing activity
- To control tong manually (move in x, y, z axes and grab/release tong)
- To park the crane to the designated safe location

Following are the screenshots from the HMI, running on a mobile phone. The HMI is developed in a way that it adjusts itself depending on the screen size and resolution.

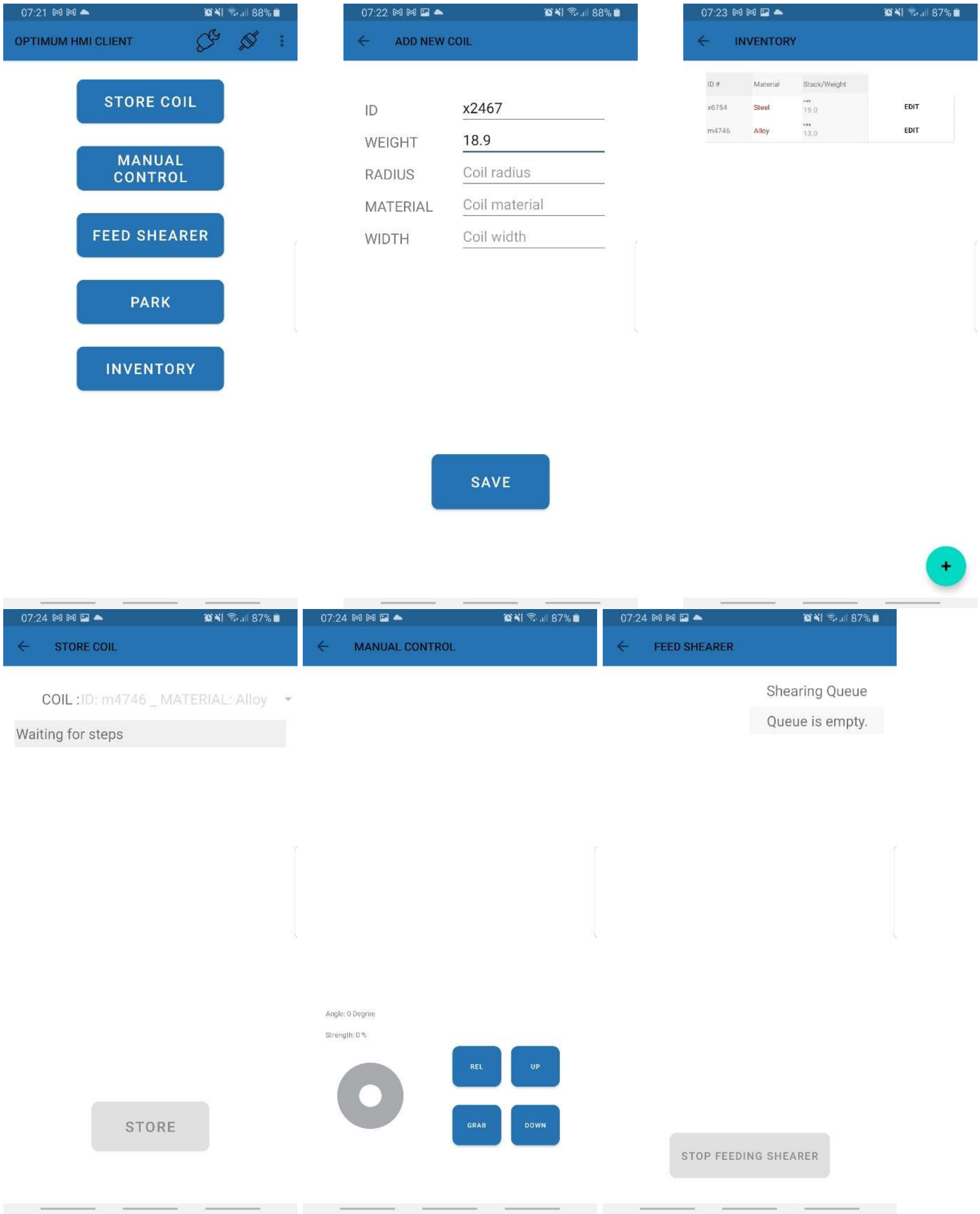


Figure 4342: Screenshots from the HMI, running on a mobile phone

13 Requirement R_Gen_017

Requirement Statement	Data consistency between engineering tools SHOULD be achieved.

Related reqs.	-

This requirement includes the following details:

- Reusable data files for the whole Lifetime Cycle of the system and for different engineering tools SHOULD be considered.

This requirement is validated within the context of MAGTEL/SOTEC demonstrator.

13.1 MAGTEL/SOTEC Demonstrator

Main Responsible	SOTEC
Contributing Partners	MAGTEL
Validation Method	Demonstration
Related reqs.	-

The logical part of the demonstrator, i.e., the INDIGO platform, uses a well-defined, long-lasting set of data structures, together with a Postgres database to represent the information, and store it during the whole Lifetime Cycle of the project.

14 Requirement R_Gen_019

Requirement Statement	The data communication MUST be secured from unauthorized access.

Related reqs.	-

This requirement includes the following details:

- Security Level 3 - It should not be possible to manipulate or steal payload data. User request for protection of sensible data and methods to avoid manipulation.

This requirement is validated within the context of MAGTEL/SOTEC demonstrator by analysis and testing.

14.1 MAGTEL/SOTEC Demonstrator

Main Responsible	SOTEC
Contributing Partners	MAGTEL
Validation Method	Analysis / Testing
Related reqs.	-

The Ethernet connections are directly connected among the items that use them, without offering any possibility of being compromised. On the other hand, wireless security mechanisms based in WPA2-PSK (AES) are configured in the WiFi communication network. Moreover, a tool that provides a honeypot, named "secure factory" is used to prevent hacking attempts from unauthorized and unknown devices.

15 Requirement R_Gen_020

Requirement Statement	Machines MUST be self-described.

Related reqs.	-

This requirement includes the following details:

- Self-descriptive objects enable interoperable M2M communication. Using self-description machines can announce themself and can find other machines.

This requirement is validated within the context of MAGTEL/SOTEC demonstrator by testing.

15.1 MAGTEL/SOTEC Demonstrator

Main Responsible	SOTEC
Contributing Partners	MAGTEL
Validation Method	Testing
Related reqs.	-

The different CPSs in the smart factory use the OPC-UA communication protocol. In this protocol, they use diverse fields to identify themselves and to provide self-descriptions against the monitoring/telemetry platform (INDIGO).

16 Requirement R_Gen_022

Requirement Statement	Collision avoidance between transported loads and human operators MUST be implemented.

Related reqs.	-

This requirement includes the following details:

- During the entire process from START to END, crane and transported load MUST be avoided from collision to human operators, in either manual or automatic operating mode.

This requirement is validated within the context of MAGTEL/SOTEC and ERMETAL demonstrators and it has been analysed and tested confirming its operation.

16.1 MAGTEL/SOTEC Demonstrator

Main Responsible	MAGTEL
Contributing Partners	SOTEC
Validation Method	Demonstration
Related reqs.	-

The demonstrator contains different interaction mechanisms (manual and AI-based), that allow collisions avoidance between transported loads and human operators. A demonstration has been conducted to verify that all the possible operations are conducted flawlessly.

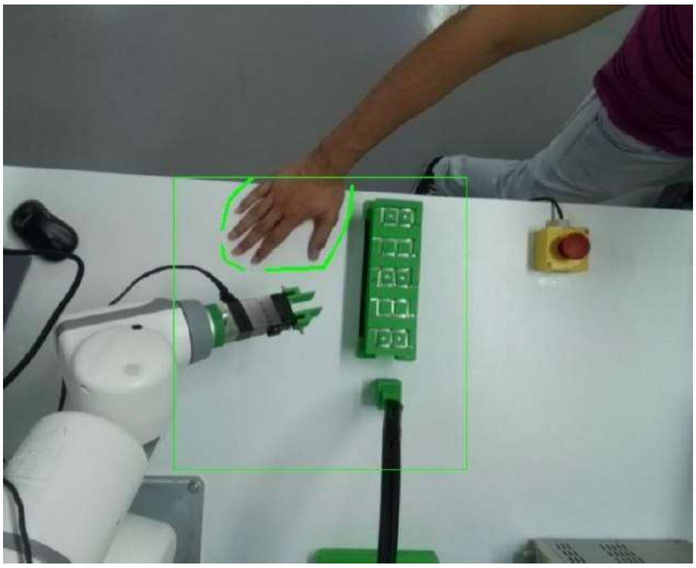


Figure 4443: Top view Spanish demonstrator

16.2 ERMETAL Demonstrator

Main Responsible	ERSTE
Contributing Partners	DIA, ERMETAL
Validation Method	Demonstration

See R_DET_49 for the validation of this requirement.

17 Requirement R_GEN_023

Requirement Statement	Collision avoidance between transported loads and other machines or obstacles MUST be implemented

Related reqs.	

This requirement includes the following details:

- During the entire process from START to END, crane and transported load must be avoided from collision with the other machines or coils, in either manual or automatic operating mode. To fulfill this requirement, the following items need to be under control
  - Carrying height
  - Height of the coils stacked.
- The crane should be able to detect the coils that exceed this height.

17.1 ERMETAL Demonstrator

Main Responsible	ERSTE
Contributing Partners	DIA, ERMETAL
Validation Method	Demonstration

See R_DET_117 for the validation of this requirement.

18 Requirement R_Gen_027

Requirement Statement	When the crane completes a work order, a new work order in the sequence SHOULD be automatically assigned to the crane.

Related reqs.	-

This requirement includes the following details:

- The crane can receive and know the work orders issued. After the crane finishes its current task (work order), it should automatically go to a new task, with the assistance and supervision of a human operator.

This requirement is validated within the context of MAGTEL/SOTEC demonstrator by analysis and testing.

18.1 MAGTEL/SOTEC Demonstrator

Main Responsible	SOTEC
Contributing Partners	MAGTEL
Validation Method	Analysis / Testing
Related reqs.	-

The control system in the smart factory automatically performs a new work order request after finishing the current one. The whole process is monitored in real-time via the INDIGO telemetry platform.

18.2 ERMETAL Demonstrator

Main Responsible	ERSTE
Contributing Partners	DIA, ERMETAL
Validation Method	Demonstration

Both in Desktop and Bigger-Scale ERMETAL demonstrators, it has been shown that in “Feed Shearer” mode, the system is constantly monitoring 2 conditions

1. Shearer availability
2. Next work order existence

If the shearer is available *and* if there is a work order in the queue, then the crane/tong carries the required coil to the shearer. For that purpose, the following (sub-)state chart is executed in the Crane Manager component.

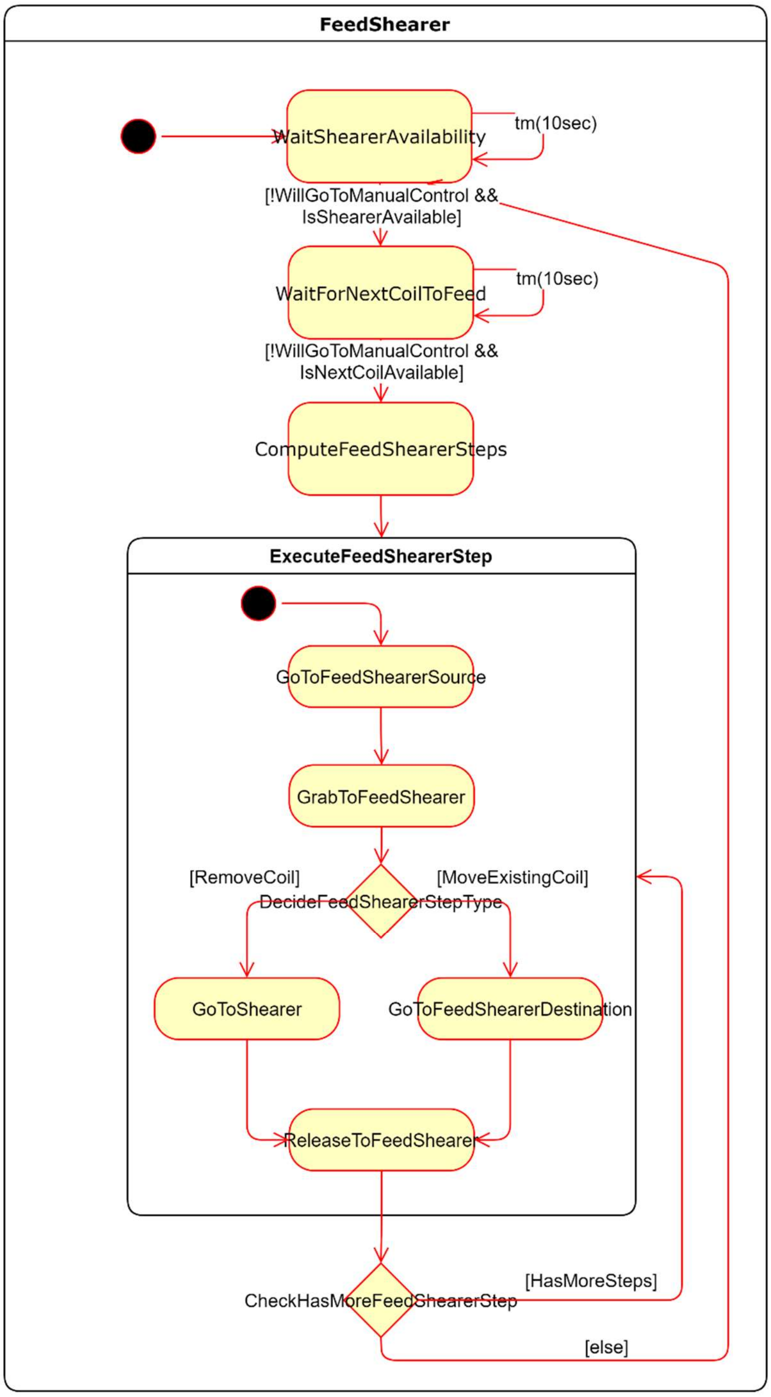


Figure 4544: State chart diagram

19 Requirement R_Gen_030

Requirement Statement	System should provide a mechanism to verify if the welding has been properly conducted.

Related reqs.	-

This requirement includes the following details:

- Once the robot has applied the welding point to the battery cell, a specific sub-system based on artificial vision, should verify if this welding point is OK or defective.

This requirement is validated within the context of MAGTEL/SOTEC demonstrator, and it has been analysed and tested confirming its operation.

19.1 MAGTEL/SOTEC Demonstrator

Main Responsible	MAGTEL
Contributing Partners	SOTEC
Validation Method	Demonstrator
Related reqs.	-

Using a program written in Python, and two photographs taken before and after welding the cells, it is verified that the placement of the cells is correct.

Analisis_Soldaduras.py

```
foto_3 = io.imread("/home/pi/Desktop/foto_3.jpg",as_gray=False)
#Foto 4
#camera.start_preview()
camera.zoom=(0.32,0.28,0.400,0.400)
sleep(0.5)
camera.capture('/home/pi/Desktop/foto_4.jpg')
#sleep(0.5)
#camera.stop_preview()
foto_2 = io.imread("/home/pi/Desktop/foto_4.jpg",as_gray=True)
foto_4 = io.imread("/home/pi/Desktop/foto_4.jpg",as_gray=False)

#Proceso imagen
for a in range(1,31):
    exec("res{} = 0".format(a))

for b in range(1,61):
    exec("suma{} = 0".format(b))

#i=Y // j=X
#Pila 1
for i in range(46,76):
    for j in range(564,594):
        suma1 = foto_1[i,j] + suma1
        suma2 = foto_2[i,j] + suma2
#Pila 2
for i in range(43,73):
    for j in range(627,657):
        suma3 = foto_1[i,j] + suma3
        suma4 = foto_2[i,j] + suma4
#Pila 3
for i in range(46,76):
```

Figure 46~~45~~: Example of Python program code

20 Requirement R_Gen_031

Requirement Statement	If a cell is not properly welded, the system should warn the operator.

Related reqs.	-

This requirement includes the following details:

- After the verification process, if the welding is detected as wrong, a noticeable warning event should be triggered to notify the operator.

This requirement is validated within the context of MAGTEL/SOTEC demonstrator, and it has been analysed and tested confirming its operation.

20.1 MAGTEL/SOTEC Demonstrator

Main Responsible	MAGTEL
Contributing Partners	SOTEC
Validation Method	Demonstrator
Related reqs.	-

The following message will be displayed on the table through the projector when there is a problem with the welds made by the robot.

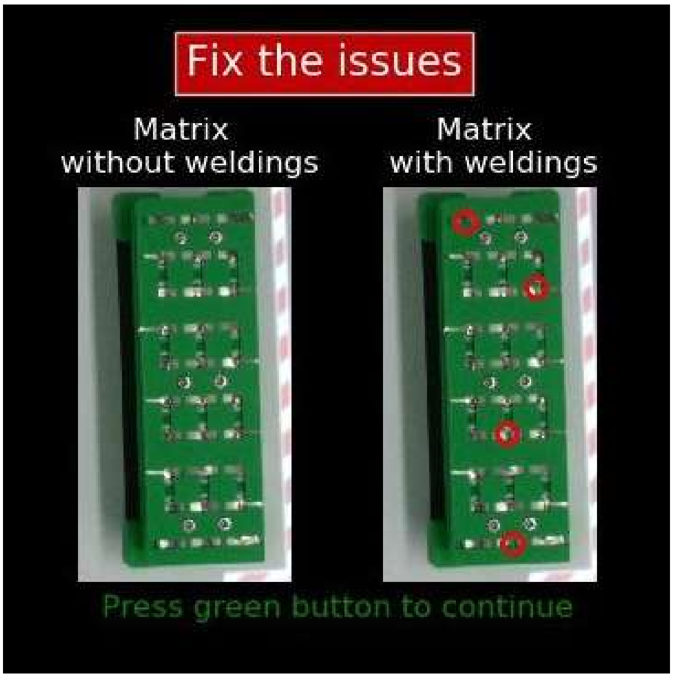


Figure 4746: Optical inspection results

21 Requirement R_Gen_032

Requirement Statement	System should provide a mechanism to verify if the set of cells has been properly assembled by the robot.

Related reqs.	-

This requirement includes the following details:

- Once the robot has applied collected the different cells in a single pack, a specific sub-system based on artificial vision, should verify if the assembly is correct.

This requirement is validated within the context of MAGTEL/SOTEC demonstrator, and it has been analysed and tested confirming its operation.

21.1 MAGTEL/SOTEC Demonstrator

Main Responsible	MAGTEL
Contributing Partners	SOTEC
Validation Method	Demonstrator
Related reqs.	-

Using a program written in Python, and two photographs taken before and after placing the cells, it is verified that the placement of the cells is correct.

Analisis_Pilas.py

```
import numpy as np
import matplotlib.pyplot as plt
from matplotlib.patches import Wedge
from skimage import io

#Foto HD
from picamera import PiCamera
from time import sleep
camera = PiCamera()
camera.rotation=180
camera.resolution=(1280,720)

#Selecciono imagen
#Foto 1
foto_1 = io.imread("/home/pi/Desktop/foto_1.jpg",as_gray=True)
foto_3 = io.imread("/home/pi/Desktop/foto_1.jpg",as_gray=False)
#Foto 2
#camera.start_preview()
camera.zoom=(0.32,0.28,0.400,0.400)
sleep(0.5)
camera.capture('/home/pi/Desktop/foto_2.jpg')
#sleep(0.5)
#camera.stop_preview()
foto_2 = io.imread("/home/pi/Desktop/foto_2.jpg",as_gray=True)
foto_4 = io.imread("/home/pi/Desktop/foto_2.jpg",as_gray=False)

#Proceso imagen
lim=0.32
for a in range(1,31):
```

Figure 48~~47~~: Example of Python program code

22 Requirement R_Gen_033

Requirement Statement	If a cell is missing in the pack, the system should properly warn the operator.

Related reqs.	-

This requirement includes the following details:

- During the assembly process, if a cell is detected as missing, a noticeable warning event should be triggered to notify the operator.

This requirement is validated within the context of MAGTEL/SOTEC demonstrator, and it has been analysed and tested confirming its operation.

22.1 MAGTEL/SOTEC Demonstrator

Main Responsible	MAGTEL
Contributing Partners	SOTEC
Validation Method	Demonstrator
Related reqs.	-

The following message will be displayed on the table through the projector when there is a problem in the cell assembly.

Figure 4948: Optical inspection results

23 Requirement R_Gen_034

Requirement Statement	The system must provide a system to assess the polarity and voltage of the batteries in a blister prior to their assembly.

Related reqs.	-

This requirement includes the following details:

- To assemble the batteries in a proper manner, the blister that contains the cells must notify the robot about the next cell position (polarity) and its voltage, to act accordingly.

This requirement is validated within the context of MAGTEL/SOTEC demonstrator, and it has been analysed and tested confirming its operation.

23.1 MAGTEL/SOTEC Demonstrator

Main Responsible	MAGTEL
Contributing Partners	SOTEC
Validation Method	Demonstrator
Related reqs.	-

The cell supplier measures the voltage and polarity of each battery before it is picked up by the robot to place it in its corresponding place. In addition, this cell analysis system acts as a quality control in case of detecting cells with a low voltage, discarding them by the robot.

Figure 5049: Cell polarity test

Open detailed Requirements

24 Requirement R_Det_001

Requirement Statement	R-DET-001

This requirement includes the following details:

- Control components MUST be cost effective. "Basic" control system for Material Handling applications W/o sensors for localization.

This requirement is validated within the context of MAGTEL/SOTEC demonstrator by experimentation, but since all demonstrators share the same architecture, validation applies to other demonstrators too.

24.1 MAGTEL/SOTEC Demonstrator

Main Responsible	MAGTEL
Contributing Partners	SOTEC
Validation Method	Analysis

During the design phase, the control system elements were carefully selected to provide the maximum performance with the least possible cost. Also, easy-to-get components were preferred over hard-to-find ones.

25 Requirement R_Det_002

Requirement Statement	R-DET-002

This requirement includes the following details:

- Control system MUST have short reaction times (real-time capabilities).

This requirement is validated within the context of MAGTEL/SOTEC demonstrator by experimentation, but since all demonstrators share the same architecture, validation applies to other demonstrators too.

25.1 MAGTEL/SOTEC Demonstrator

Main Responsible	MAGTEL
Contributing Partners	SOTEC
Validation Method	Demonstration

The microcontrollers that implement the control system provide real-time capabilities, ensuring that the different CPSs fulfil the hard time constraints imposed for the manufacturing process.

26 Requirement R_Det_004

Requirement Statement	R-DET-004

This requirement includes the following details:

- The control components MUST support short set up time (ramp-up time after power-on of the control until readiness for the required control functionality).

This requirement is validated within the context of MAGTEL/SOTEC demonstrator by experimentation, but since all demonstrators share the same architecture, validation applies to other demonstrators, too.

26.1 MAGTEL/SOTEC Demonstrator

Main Responsible	MAGTEL
Contributing Partners	SOTEC
Validation Method	Demonstration

The whole demonstrator, considering the smart factory CPSs components and the entire deployment and execution of the INDIGO telemetry platform, takes less than one and a half minutes.

27 Requirement R_Det_008

Requirement Statement	R-DET-008

This requirement includes the following details:

- The communication system SHOULD support fast communication set up time. Initiation time for a communication link. When a machine / operator involved in the material flow arrives in the hall, it'll be automatically integrated into the OPTIMUM-communication system / Rules for communication participants log IN and OUT to be defined in WP2.

This requirement is validated within the context of MAGTEL/SOTEC demonstrator by experimentation, but since all demonstrators share the same architecture, validation applies to other demonstrators too.

27.1 MAGTEL/SOTEC Demonstrator

Main Responsible	MAGTEL
Contributing Partners	SOTEC
Validation Method	Demonstration

The router that provides the communication between components, and external access (if required) by the telemetry platform (INDIGO) takes a few seconds to start (no more than 30 seconds) and to provide proper channels between CPSs, control systems, and telemetry systems. The setup time from the devices and platforms connected do not exceed half a minute.

28 Requirement R_Det_011

Requirement Statement	R-DET-011

This requirement includes the following details:

- Control system MUST be modular and scalable. The distributed control components shall be modular and scalable to be able to adapt to the different applications regarding performance and cost efficiency.

This requirement is validated within the context of MAGTEL/SOTEC demonstrator by experimentation, but since all demonstrators share the same architecture, validation applies to other demonstrators, too.

28.1 MAGTEL/SOTEC Demonstrator

Main Responsible	SOTEC
Contributing Partners	MAGTEL
Validation Method	Inspection

The control system is based on microcontrollers/microcomputers (such as the Raspberry Pi), which are easily replaced by new or novel components. The telemetry platform was designed following a microservices architecture. This approach allows the rapid development and maintenance of new and existing modules and their speedy deployments without impacting the existing platform.

29 Requirement R_Det_013

Requirement Statement	R-DET-013

This requirement includes the following details:

- The control system should allow deterministic guarantees. For functional and safety reasons the behaviour of the system - crane or MH-component - shall be deterministic depending on the surrounding conditions and operator's input. The same conditions will always produce the same output.

This requirement is validated within the context of MAGTEL/SOTEC demonstrator by experimentation, but since all demonstrators share the same architecture, validation applies to other demonstrators, too.

29.1 MAGTEL/SOTEC Demonstrator

Main Responsible	MAGTEL
Contributing Partners	SOTEC
Validation Method	Inspection / Demonstration

The smart factory designed for the Spanish demonstrator contains a robotic arm that follows deterministic automata. All the conditions have been tested and validated, and the transitions between states work flawlessly. All the cases (inputs) have been tested against the corresponding outputs.

30 Requirement R_Det_016

Requirement Statement	R-DET-016

This requirement includes the following details:

- System should provide machine cooperation functions. A movement-synchronization of machines should be possible, e.g., tandem function with two or more machines simultaneously.

This requirement is validated within the context of MAGTEL/SOTEC demonstrator by experimentation, but since all demonstrators share the same architecture, validation applies to other demonstrators, too.

30.1 MAGTEL/SOTEC Demonstrator

Main Responsible	MAGTEL
Contributing Partners	SOTEC
Validation Method	Demonstration

The smart factory presents a variety of items, as a battery blister, a robotic arm, an AI enhanced camera, a projector, a control panel (among others) that in some cases can work together. This is, for instance, the case of the robotic arm and the battery blister, in which movements are coordinated. The validation was conducted by following multiple welding processes in different situations.

31 Requirement R_Det_031

Requirement Statement	R-DET-031

This requirement includes the following details:

- The system can store and manage data for data analysis and reporting. The system can provide functions for storing historical data about the machines as reported in R-DET-30. Collected data can be stored at the enterprise level, and they can be used for analysis, reporting, maintenance, automatic diagnostic, failure prediction.

This requirement is validated within the context of MAGTEL/SOTEC demonstrator by experimentation, but since all demonstrators share the same architecture, validation applies to other demonstrators, too.

31.1 MAGTEL/SOTEC Demonstrator

Main Responsible	MAGTEL
Contributing Partners	SOTEC
Validation Method	Demonstration

The logical part of the Spanish demonstrator consists of a telemetry platform, INDIGO, enhanced with a versatile semantic representation of various CPSs, that can be part of the system. All the signals received from such devices are tracked, logged, and classified in INDIGO for further analysis, monitoring and review.

32 Requirement R_DET_033

Requirement Statement	System SHOULD allow remote firmware updates

Related reqs.	-

This requirement is validated within the context of ERMETAL demonstrator by demonstration, but since all demonstrators share the same architecture, validation applies to other demonstrators, too.

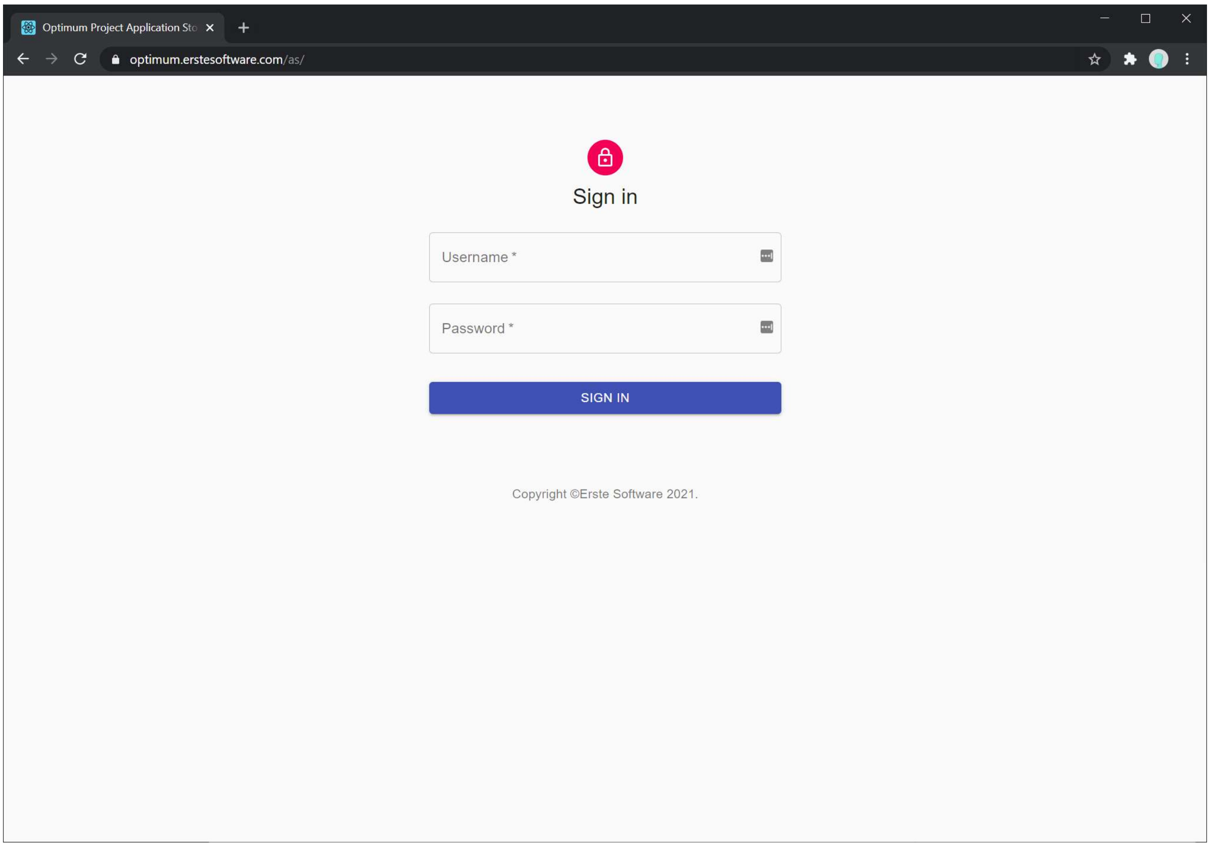
32.1 ERMETAL Demonstrator

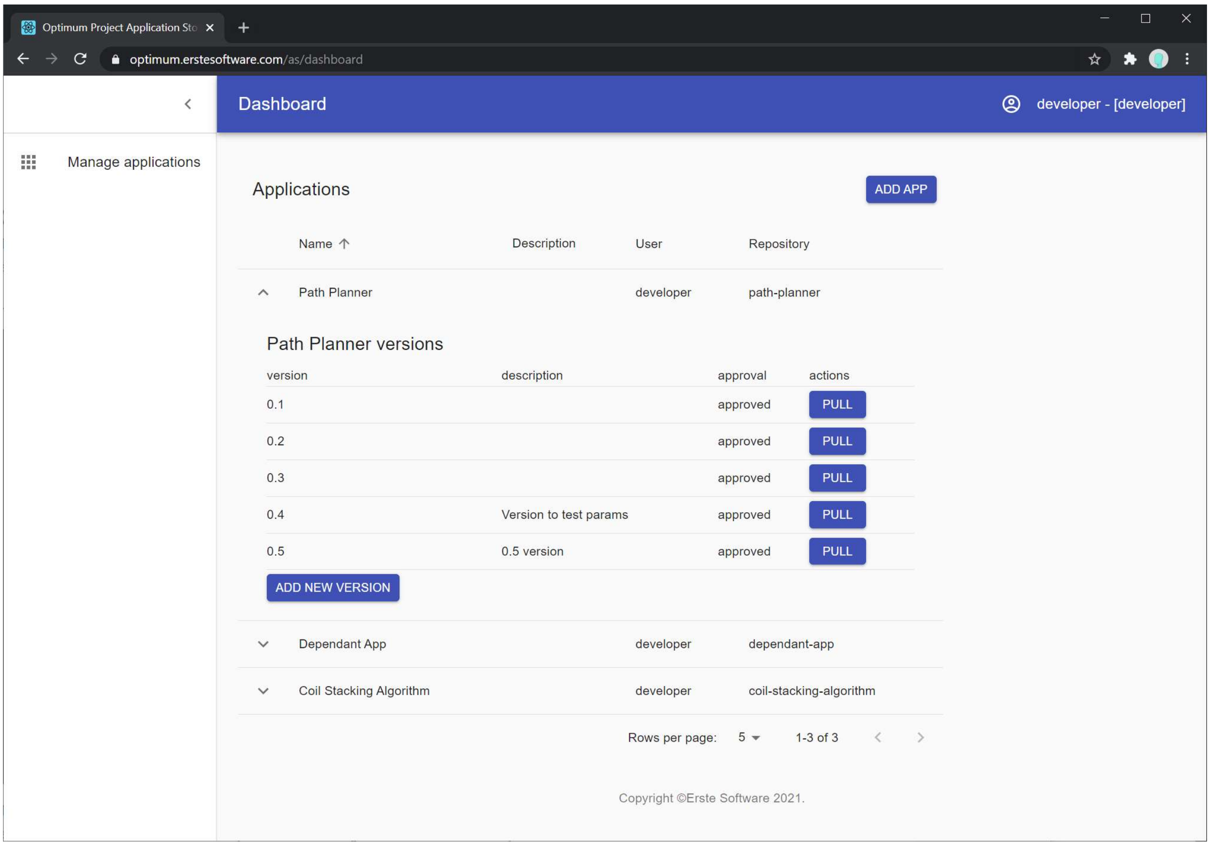
Main Responsible	ERSTE
Contributing Partners	DIA, ERMETAL
Validation Method	Demonstration

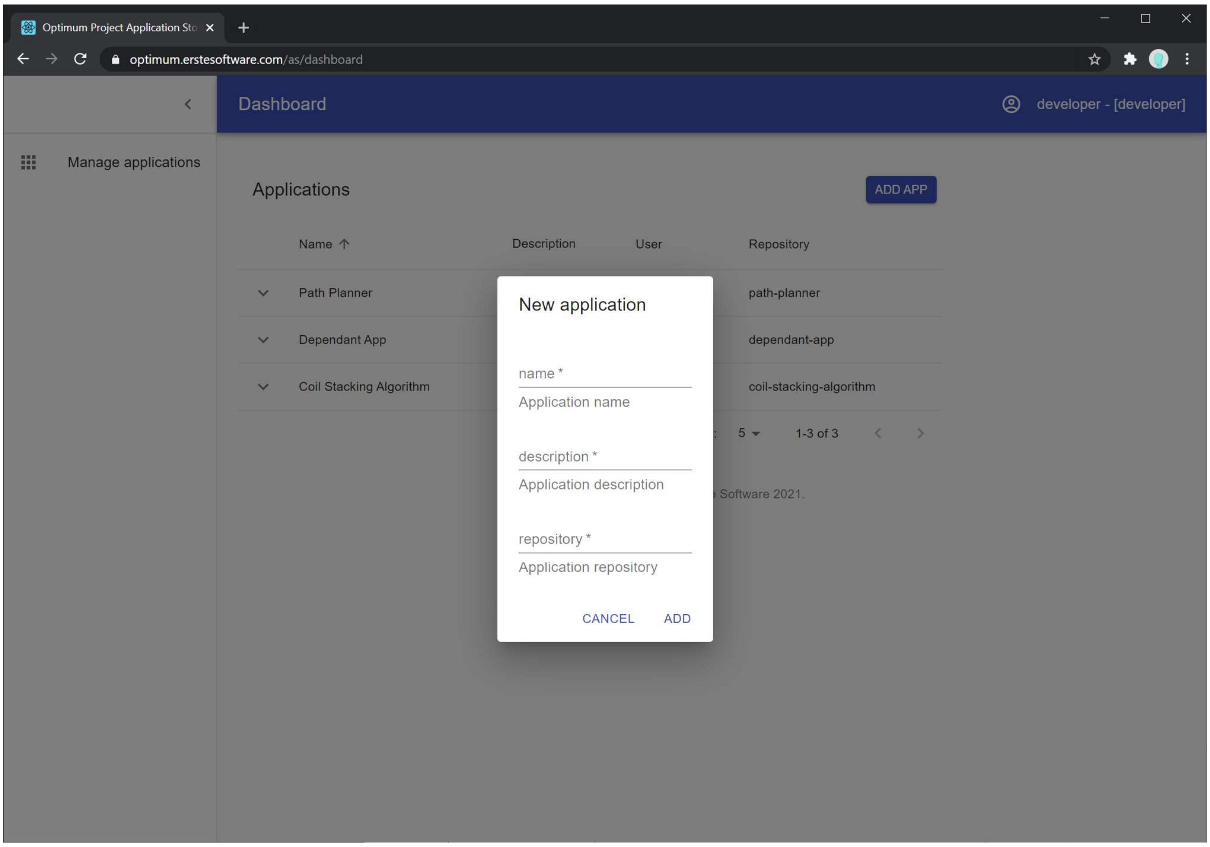
In OPTIMUM architecture, software components developed to run on OPTIMUM device are bundled as Docker images and they run as Docker containers. These OPTIMUM software components are considered as firmware for the OPTIMUM device and used to modify or extend the functionalities of OPTIMUM industrial machines.

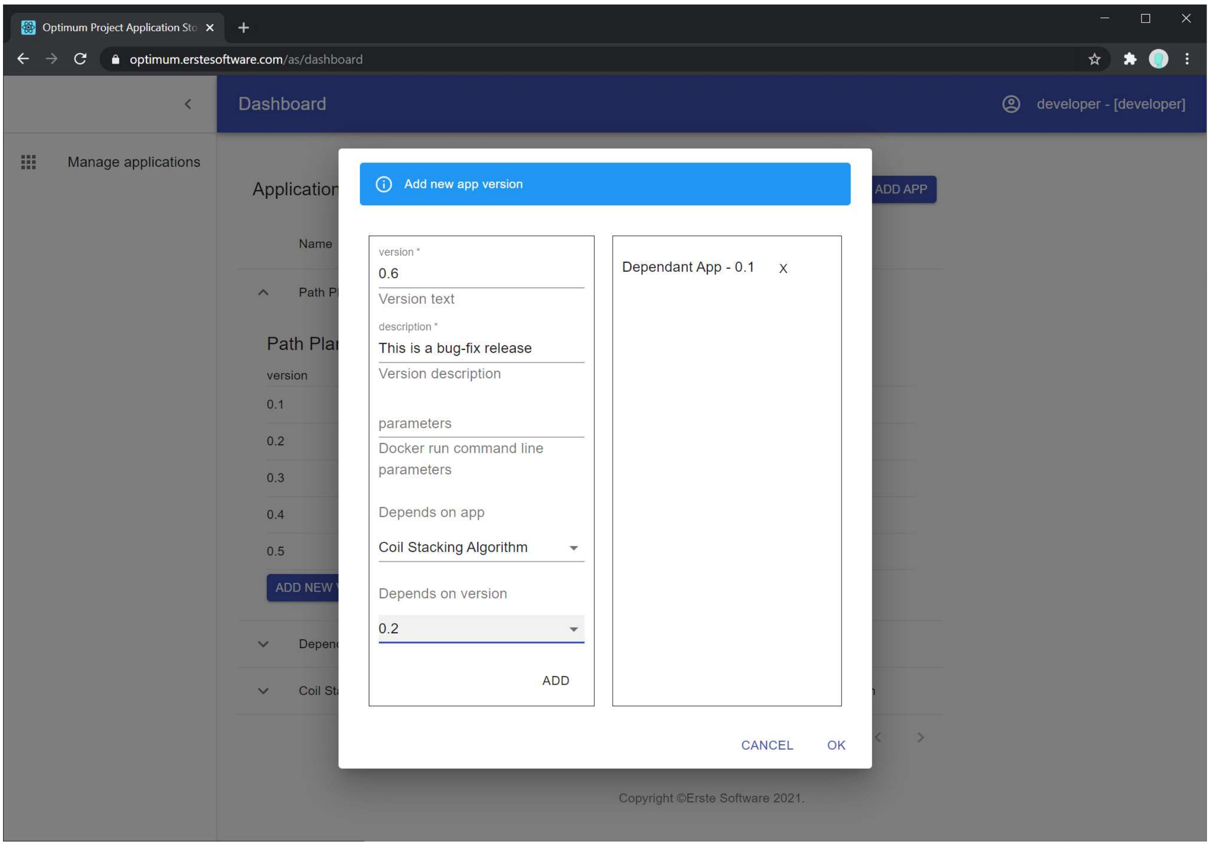
As part of the OPTIMUM project, a development environment, which can be used to develop OPTIMUM software components (see D4.6 and D4.7), has been provided. Furthermore, an Application Store to manage the application proposal, supervision and install/update/uninstall of OPTIMUM applications has been developed.

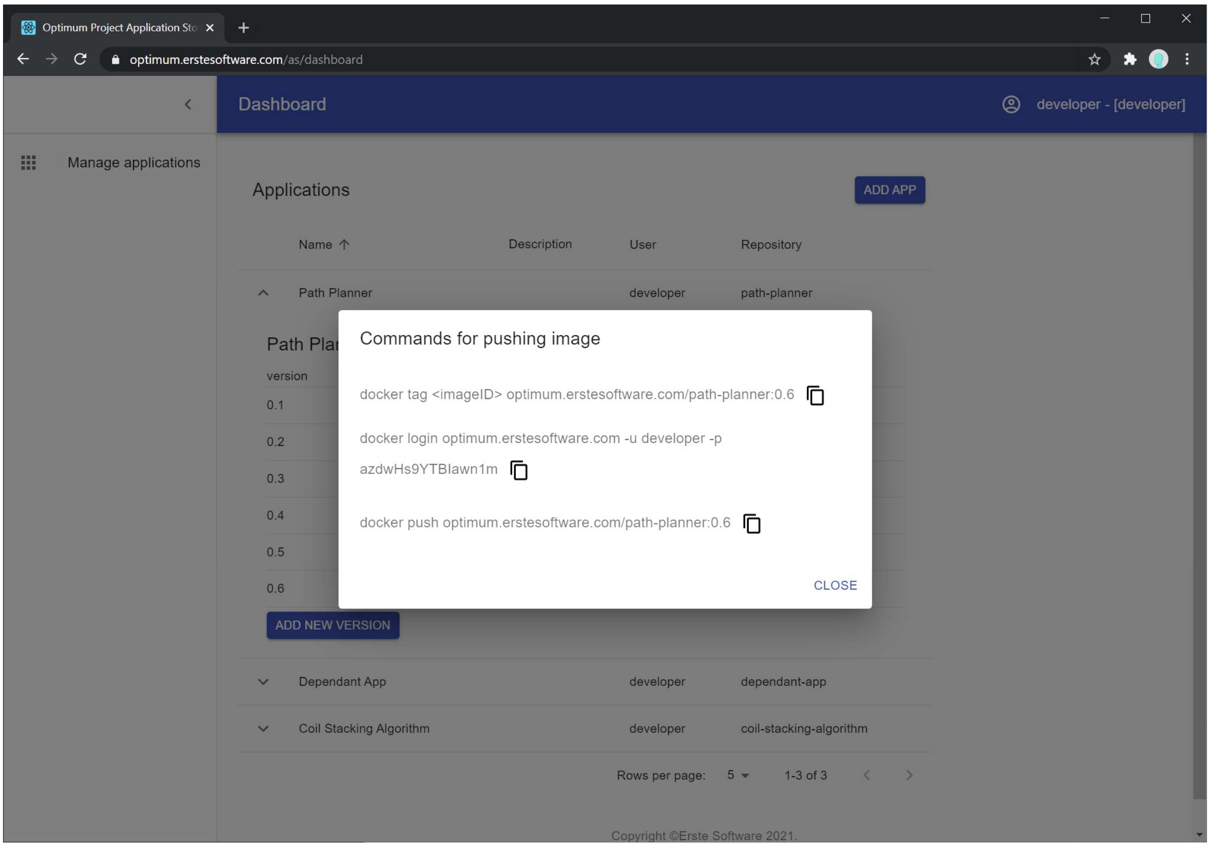
Below are some screenshots of the OPTIMUM Application Store. For more detailed information please refer to D4.6 and D4.7.


Optimum Project Application Sto
optimum.erstesoftware.com/as/
Sign in
Username *
Password *
SIGN IN
Copyright ©Erste Software 2021.


Optimum Project Application Sto
optimum.erstesoftware.com/as/dashboard
Dashboard
developer - [developer]
Manage applications
Applications
ADD APP
Name
Description
User
Repository
Path Planner
developer
path-planner
Path Planner versions
version
description
approval
actions
0.1
approved
PULL
0.2
approved
PULL
0.3
approved
PULL
0.4
Version to test params
approved
PULL
0.5
0.5 version
approved
PULL
ADD NEW VERSION
Dependant App
developer
dependant-app
Coil Stacking Algorithm
developer
coil-stacking-algorithm
Rows per page: 5
1-3 of 3
Copyright ©Erste Software 2021.


Optimum Project Application Sto
optimum.erstesoftware.com/as/dashboard
Dashboard
developer - [developer]
Manage applications
Applications
ADD APP
Name
Description
User
Repository
Path Planner
path-planner
Dependant App
dependant-app
Coil Stacking Algorithm
coil-stacking-algorithm
New application
name *
Application name
description *
Application description
repository *
Application repository
CANCEL
ADD
5
1-3 of 3


Optimum Project Application Sto
optimum.erstesoftware.com/as/dashboard
Dashboard
developer - [developer]
Manage applications
Add new app version
version *
0.6
Version text
description *
This is a bug-fix release
Version description
parameters
Docker run command line parameters
Depends on app
Coil Stacking Algorithm
Depends on version
0.2
ADD
Dependant App - 0.1
x
CANCEL
OK
ADD APP
Copyright ©Erste Software 2021.


Optimum Project Application Sto
optimum.erstesoftware.com/as/dashboard
Dashboard
developer - [developer]
Manage applications
Applications
ADD APP
Name
Description
User
Repository
Path Planner
developer
path-planner
Path Plan
version
0.1
0.2
0.3
0.4
0.5
0.6
ADD NEW VERSION
Commands for pushing image
docker tag <imageID> optimum.erstesoftware.com/path-planner:0.6
docker login optimum.erstesoftware.com -u developer -p
azdwHs9YTBlawn1m
docker push optimum.erstesoftware.com/path-planner:0.6
CLOSE
Dependant App
developer
dependant-app
Coil Stacking Algorithm
developer
coil-stacking-algorithm
Rows per page: 5
1-3 of 3
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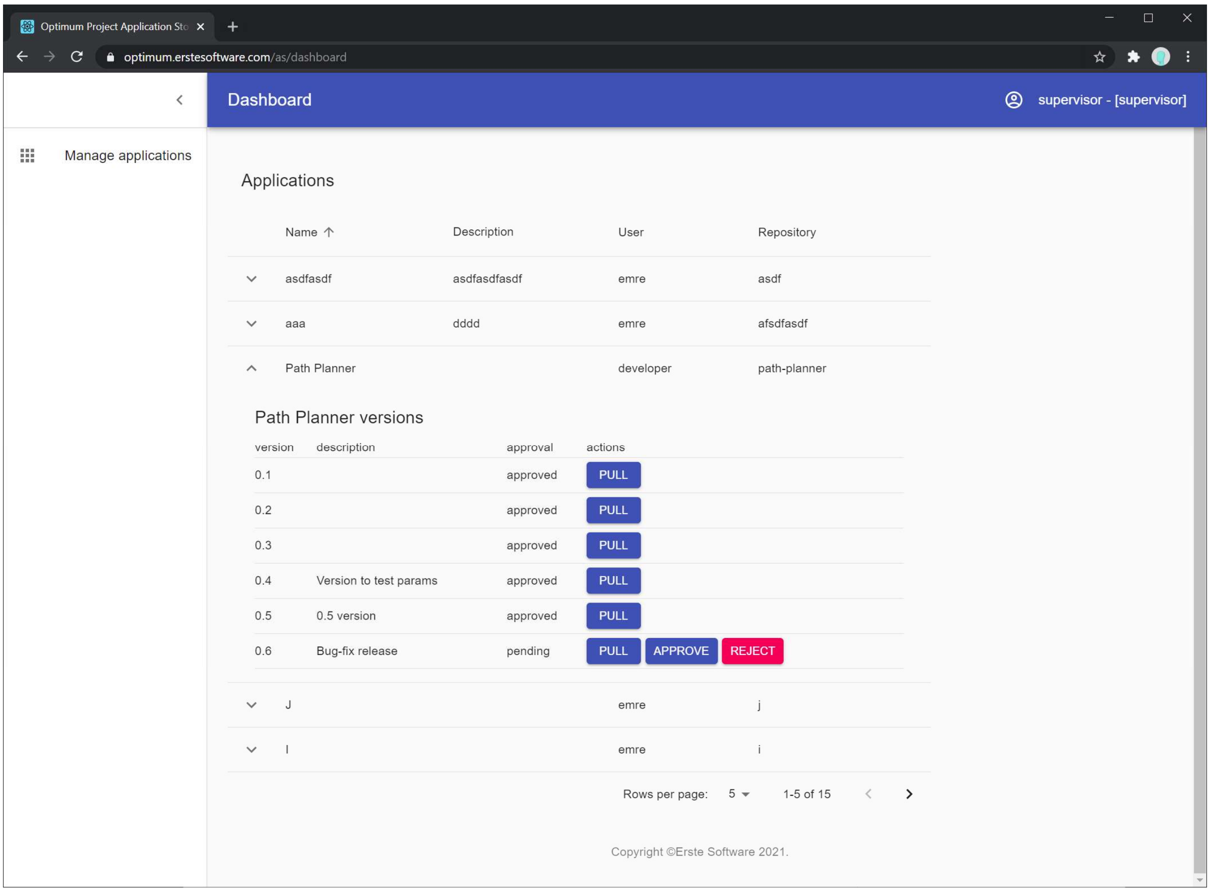
Optimum Project Application Sto
optimum.erstesoftware.com/as/dashboard
Dashboard
supervisor - [supervisor]
Manage applications
Applications
Name
Description
User
Repository
asdfasdf
asdfasdfasdf
emre
asdf
aaa
dddd
emre
afsdfasdf
Path Planner
developer
path-planner
Path Planner versions
version
description
approval
actions
0.1
approved
PULL
0.2
approved
PULL
0.3
approved
PULL
0.4
Version to test params
approved
PULL
0.5
0.5 version
approved
PULL
0.6
Bug-fix release
pending
PULL
APPROVE
REJECT
J
emre
j
I
emre
i
Rows per page: 5
1-5 of 15
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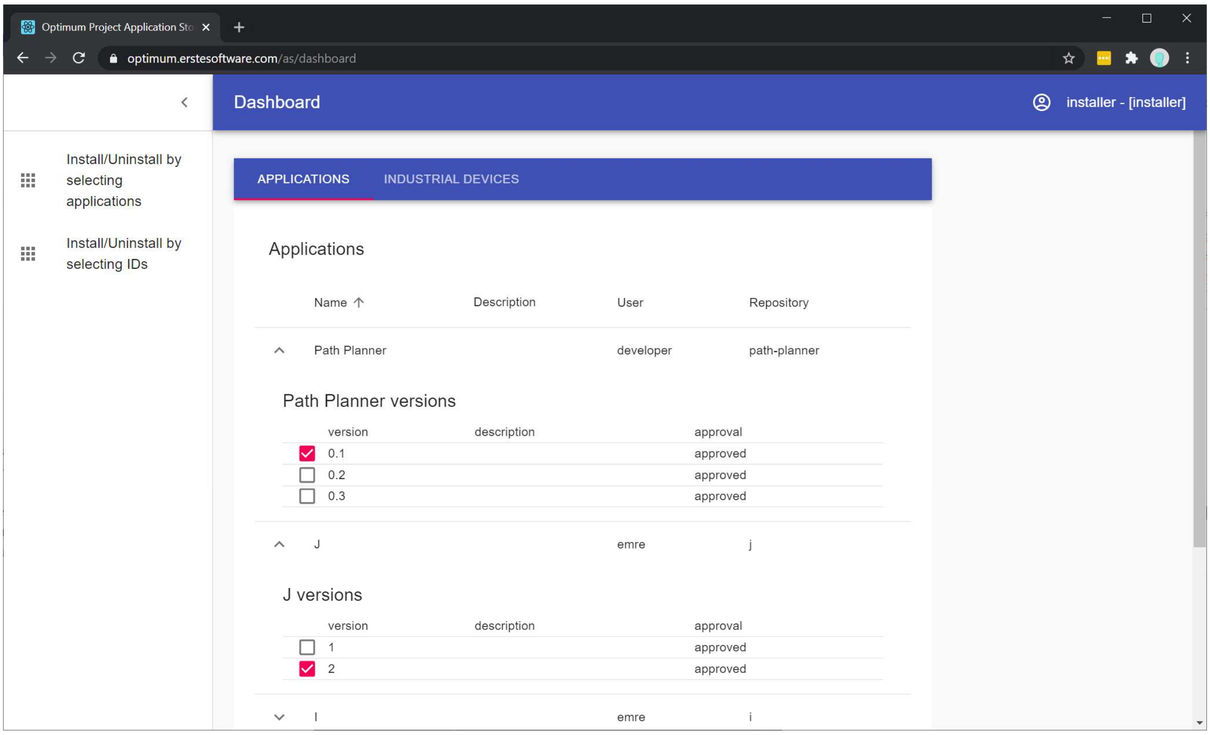
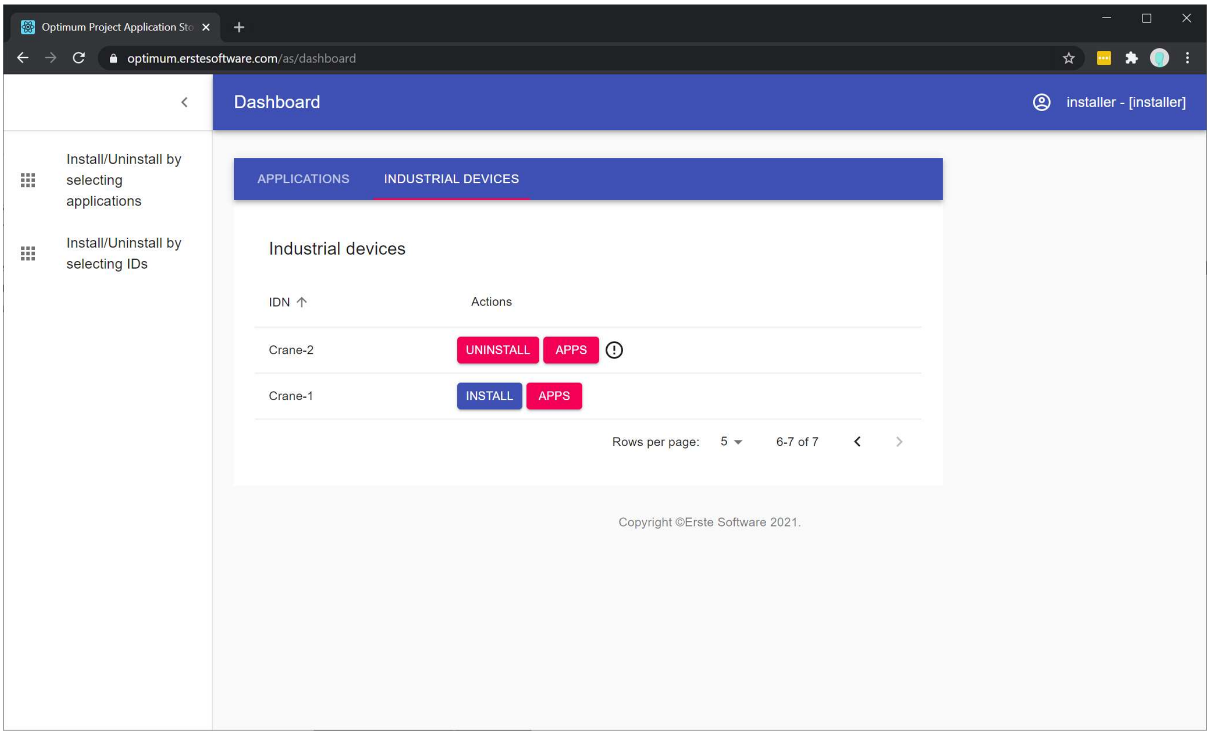

Optimum Project Application Sto
optimum.erstesoftware.com/as/dashboard
Dashboard
installer - [installer]
Install/Uninstall by selecting applications
Install/Uninstall by selecting IDs
APPLICATIONS
INDUSTRIAL DEVICES
Applications
Name
Description
User
Repository
Path Planner
developer
path-planner
Path Planner versions
version
description
approval
0.1
approved
0.2
approved
0.3
approved
J
emre
j
J versions
version
description
approval
1
approved
2
approved
I
emre
i


Optimum Project Application Sto
optimum.erstesoftware.com/as/dashboard
Dashboard
installer - [installer]
Install/Uninstall by selecting applications
Install/Uninstall by selecting IDs
APPLICATIONS
INDUSTRIAL DEVICES
Industrial devices
IDN
Actions
Crane-2
UNINSTALL
APPS
Crane-1
INSTALL
APPS
Rows per page:
5
6-7 of 7
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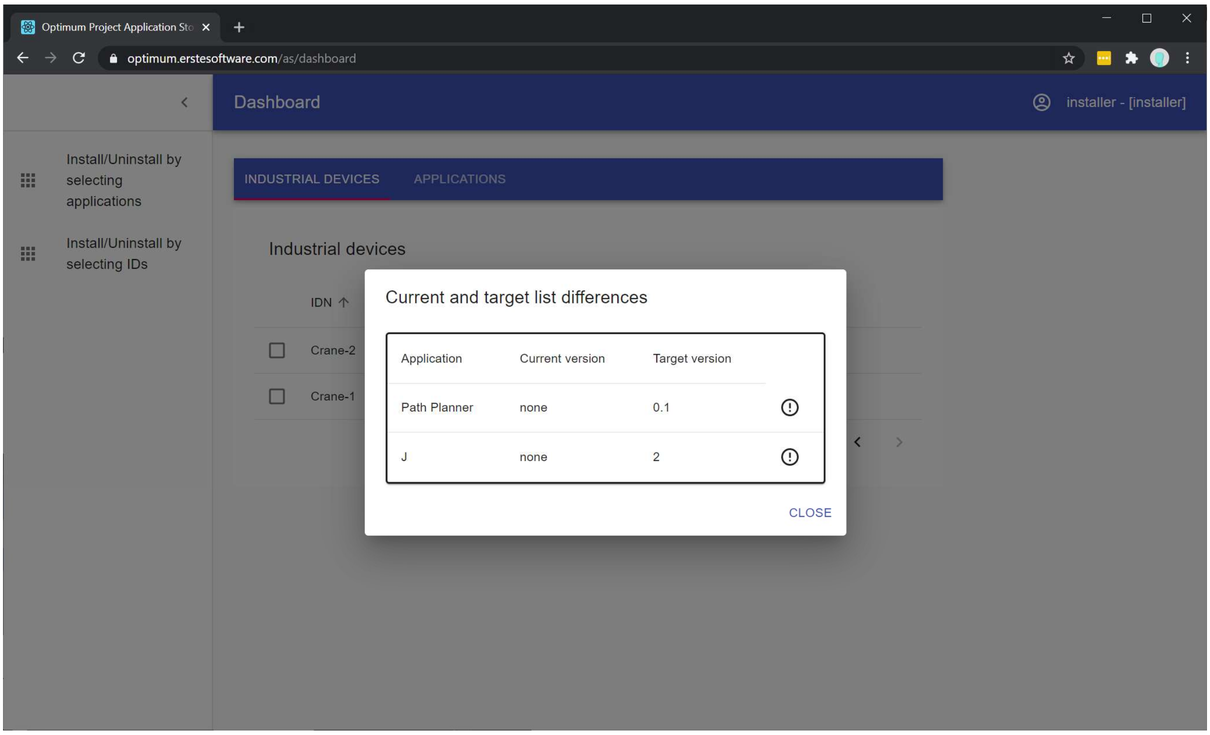

Figure 5150: Screenshots of the OPTIMUM Application Store

33 Requirement R_DET_116

Requirement Statement	HMI for coil handling MUST be installed

Related reqs.	-

This requirement includes the following details:

- Operator shall be able to monitor the process with the help of some safety indicators (such as warning lights) on the control panel or pendant, so that operator can stop the process in case of any emergency.

33.1 ERMETAL Demonstrator

Main Responsible	ERSTE
Contributing Partners	DIA, ERMETAL
Validation Method	Demonstration

For HMI for coil handling, see R_GEN_15 for the validation of this requirement. But the HMI does not provide an emergency STOP functionality.

34 Requirement R_DET_117

Requirement Statement	Collision avoidance between transported loads and other machines, human operators or obstacles MUST be implemented.

Related reqs.	-

This requirement includes the following details:

- The crane should not go below a certain height while carrying the load.

34.1 ERMETAL Demonstrator

Main Responsible	ERSTE
Contributing Partners	DIA, ERMETAL
Validation Method	Demonstration

For the collision avoidance in the horizontal plane, see R_DET_49 for the validation of this requirement.

To avoid collision with the known obstacles, the path to be followed is computed accordingly. During the path planning, all the obstacles from the starting XY coordinates to the destination XY coordinates are computed. Then the highest of these obstacles are found, and finally the path is planned to start with the right upward movement in z axis to avoid this highest obstacle.

35 Abbreviations

AES	Advanced Encryption Standard
AGV	Automated Guided Vehicle
AI	Artificial Intelligence
API	Application Programming Interface
CAN	Controller Area Network
CAO	Control Application Objects
CPS	Cyber-physical system
DCP	Distributed Control Platform
DET	Detailed
ERP	Enterprise Resource Planning
EU	European Union
GEN	General
GUI	Graphical User Interface
HDMI	High Definition Multimedia Interface
HMI	Human Machine Interaction
HTTP	The Hypertext Transfer Protocol
ID	Identifier
iDev	Industrial Device
IIoT	Industrial Internet of Things
IoT	Internet of Things
IP	Internet Protocol
M2M	Machine-to-Machine
MH	Material Handling
MQTT	Message Queuing Telemetry Transport
ODS	Object Detection Subsystem
OPC-UA	OPC Unified Architecture
OS	Operating System
PL	Performance Level
QoS	Quality of Service
SIL	Safety Integrity Level
SSH	Secure Shell
TCP	Transfer Control Protocol
URLLC	Ultra-Reliable and Low-Latency Communication
UWB	Ultra Wide Band
VDMA	Verband Deutscher Maschinen- und Anlagenbau e. V.
WP	Work package