iMOCO4.E

Intelligent Motion Control under Industry 4.E

D3.1 Perception and instrumentation Layer requirements and specifications (first iteration)

Due Date: M11 – 2022-07-31

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Abstract:

From the Use Cases, Pilots and Demos obtained, global requirements need to be derived which will serve as constraints for the development of new hardware and instrumentation at Layer 1: sensor and actuator development and their design needs to be aimed on the interaction with the higher layer levels: 2, 3 to 4. It poses requirements in the embedded software stack to enable compatibility and hardware-software co-development.

From the Use Cases, Pilots and Demos information observed, it can be noted that the divergence in requirements is large, when centralized controlled motion is compared to smart distributed sensing, smart distributed control, and smart distributed actuation. Also, the level of interfacing is (still) broad, varying from analogue (0-10 V, 4-20 mA), to SPI, USB, and all kinds of other digital interfaces. The main backbone communication is via EtherCAT or CAN-Open (or similar real-time bus up to DMA).

The variety in the required control loop speed is large too: ITEC doing 100 kU/hour down to vibration and swing control of a few Hz. The requirement for consumed power is limited by the battery-operated sensors systems versus the wired or contactless powered sensor applications.

What is an open issue is the amount of 'new' data that is required beyond the functional set-point data exchange? This kind of data will be required for BB-5 to BB-9 and needs to be developed i.e., integrated into new hardware layer designs.

How smart does a sensor, encoder, controller, drive and actuator need to (or can) be to create motion systems more effectively and suited for AI and Digital Twining? The design platform and architecture need to be changed accordingly and many of the BB defined need to be re-defined (and re-developed or adjusted) with the second revision.

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EDI	Relation to the BB, Pilot, Demo or Use-Case involved
INL	Relation to the BB, Pilot, Demo or Use-Case involved
ECS,	Relation to the BB, Pilot, Demo or Use-Case involved
IMST	Relation to the BB, Pilot, Demo or Use-Case involved
OROLIA	Relation to the BB, Pilot, Demo or Use-Case involved

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Abbreviations

Abbreviation	**Explanation**
AI	Artificial Intelligence
BB	Building Block
CCN	Complex Communication Needs
COTS	Commercial Off-The-Shelf
DMA	Direct Memory Access
ECU	Electronic Control Unit
FW	Firmware
HW	Hardware
HMI	Human Machine Interface
I-Mech	Intelligent Motion Control Platform for Smart Mechatronic Systems
IMU	Inertial Measurement Unit
IRT	Information Resources and Technology
kUPH	Kilo Units per Hour
MIMO	Multiple Input Multiple Output
MoSCoW	M - Must have, S - Should have, C - Could have, W - Won't have
PC	Personal Computer
SDK	Software Development Kit
SW	Software
ToF	Time of Flight
WSN	Wireless Sensor Networks

Executive Summary

Task 3.1 Instrumentation Layer 1 requirements and specifications

Leader: **EMC**; involved: SCC, UWB, EDI, ROV, TUE, ING, TNL, GMV, ITML, INL, NXP, TECO, CNET, OE, TNO, ECS, UMO, EVI, IKE, COR, TNI, VIS

The aim of Work package 3 "Perception and instrumentation Layer 1, based on AI at the edge" is dedicated to the development of smart sensing, actuating components and drive ECUs of the earlier established I-MECH platform (the 'Layer 1' elements) and their proper interconnection with the higher levels of the motion control system. It deals with novel communication interfaces for fast and reliable data acquisition by means of various wired and wireless sensors providing high fidelity information about the actual state of the controlled plant. Power electronics and low-level control of various actuator types will be developed as well. The Instrumentation Layer 1 building blocks lay foundations for the employment of advanced software algorithms of the higher Motion Control Layers which are pursued in WP4.

Task 3.1 will precise and update the instrumentation layer 1 requirements briefly sketched in Task 2.3. The task outputs will also be influenced by communication with both consortium and external industrial partners (through WP2). The collected requirements will grow into detailed specifications on Instrumentation layer (**D3.1**, D3.2 - iterative process described in Task 2.3). The final requirements are tightly related to Pilot, Demo and Use Case app needs (outputs of Task 7.1) and to initial testing results of BB sub-systems (partly adopted from liked projects) as outputs from Tasks 6.2 and 6.3. The work will be broken into the following subtasks:

1. Analysis of interaction/ interferences with other mature facilities and equipment (i.e., re-used existing modules, Tab. 8)
2. Requirements and specifications for signal and image processing algorithms based on relevant pilots, further linked to Task 3.3 (UWB, EDI, TUE, TNL, ITML, CNET, GEF, IKE, TNI)
3. Requirements and specifications for sensors (e.g., velocity, acceleration, acoustic, cameras, etc.) and actuators (e.g., piezo movers, reluctance actuators, etc.), further linked to Task 3.2 (INL, EMC, ECS, SIE, TNO, OE)
4. Wireless requirements analysis and technology evaluation, specification for robust and reliable WSN, further linked to Task 3.4 (UWB, EDI, TNL, INL, OE, ECS, UMO, IKE, COR, TNI, VIS)
5. Requirements and specifications for high-speed vision sub-components, further linked to Task 3.5 (TNO, SCC, UWB, INL, NXP, UMO)
6. Requirements and specification for smart servo drive ECUs, further linked to Task 3.6 (SCC, ING, TNL, EMC)
7. Requirements and specification for multi-many-core embedded control HW, further linked to Task 3.7 (SCC, TUE, ING, TNL, FAG, NXP, SIE, IMA, UMO, EVI)

1. Introduction

1.1 Purpose of the Document

The purpose of the document is to collect the foreseen needs in specifications and requirements for Layer 1: "Instrumentation Layer design and development". Task 3.1 is dedicated to the development of smart sensing, actuating components and drive ECUs of the IMOCO4.E platform (the 'Layer 1' elements) and their proper interconnection with the higher levels of the motion control system.

1.2 Structure of the Document

The initial structure of the document is straight forward means to collect the requirements and specifications of the partners involved. In a second upgrade, before release T3.1, the requirements and specifications will be grouped for the partners dealing with the developments in WP3.

1.3 Requirements gathering process

The partners of **all** IMOCO4.E Pilots, Demos and Use Cases, who have dedicated needs w.r.t. the Layer 1 developed components, to be incorporated in their Pilots, Demos and Use Cases applications have been asked for inputs.

Based on the least common nominator of these collected requirements, a selection shall be made w.r.t. the requirements which can be implemented by the partners involved in the development of Layer 1 contributions.

1.4 Intended readership

During the process of gathering the specifications and requirements all partners of IMOCO4.E are requested to read and give their input and comments to this document. Thereafter, the resulting and condensed specifications and requirements will be leading for the partners involved in WP-3. Furthermore, all partners of IMOCO4.E will be informed about which specifications and requirements will most likely be met and which specifications and requirements need to be resolved in another manner.

2. IMOCO4.E Layer structure

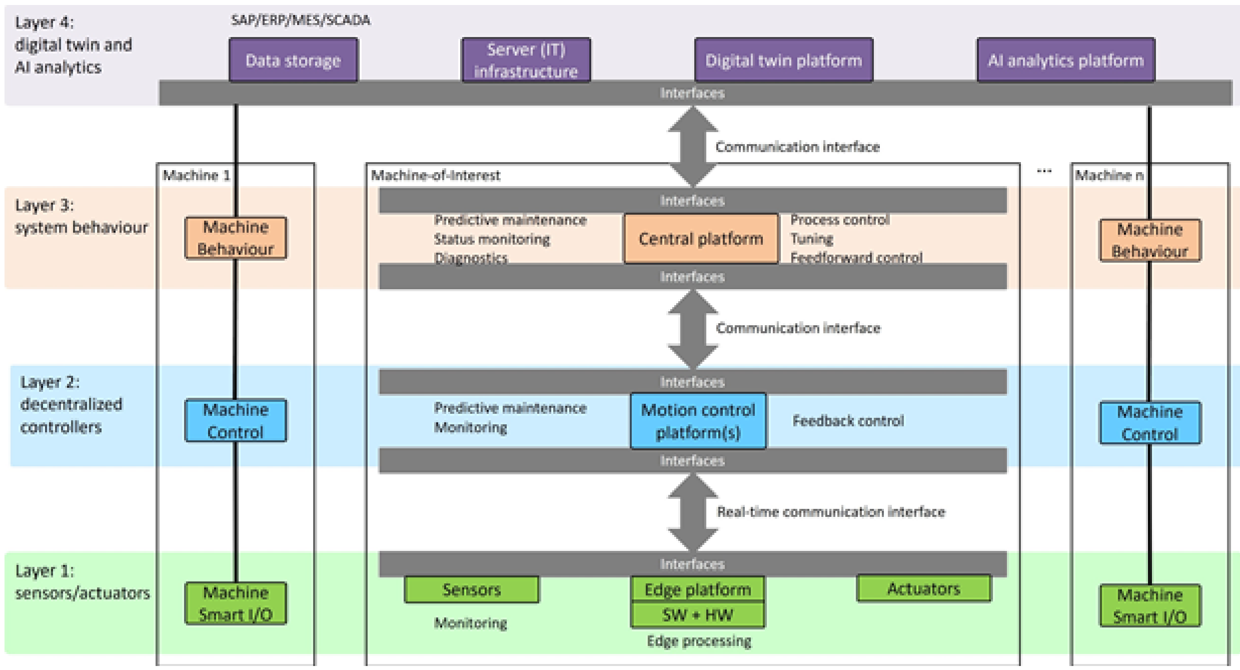

Figure 1 – The IMOCO4.E layer structure

At layer 1, the necessary electronic hardware (including its embedded software) related and needed for the interaction between the sensors and actuators and the mechanical motion system to be controlled is given. The necessary hardware needed for the computational efforts at the layers 2 to 4 are excluded from the specifications and requirements in this deliverable.

Part of the interfaces need to be wired for the fast exchange of high amounts of data and power, and part of the interfaces are wireless to enable more mechanical freedom and/or require less power for their operation such that these can be battery-operated, contactless charged while in their homing position or even continuously supplied through wireless power transfer.

As part of the electronic hardware used within the IMOCO4.E project is COTS available, no emphasis is given to the specifications and requirements that were applied to these sensors, controllers, motion drives and actuators with their build-in encoders, etc.

3. Requirements specification for IMOCO4.E

3.1 Requirements gathering process

The process for gathering the specifications and requirements is crucial for the development of the WP3 tasks as 'commitments' need to be made and understood from both sides: the end-users (what to expect), dealing with the Pilots, Demos and Use Cases as well as the participants involved with the developments in WP3 (what to develop). When the two parties mutually agree on their requirements and specifications, a win-win will result as a (WP3) designer's push and a user's (Pilots, Demos and Use Cases) demand is achieved.

From a requirements and specifications gathering's point of view, one should be able to ask either side of the project as their requirements should align. There should also be a tempting and teasing element in these specifications and requirements to challenge both sides too.

3.2 Instrument layer requirements classification

We classify the requirements using the following characteristics (partially derived from the ISO 25010 standard on software and data quality):

1. Interfaces and connectivity
2. Maintainability - represents the degree of effectiveness and efficiency with which a product or system can be modified to improve it, correct it or adapt it to changes in environment, and in requirements. This characteristic is composed of the following sub-characteristics
    a. Modularity - A system is modular when it can be decomposed into several components that may be mixed and matched in a variety of configurations. The components can connect, interact, or exchange resources, by adhering to a standardized interface.
    b. Analysability – Each and every element needs to have built-in options to allow separate analysis to enable debugging (c) and to be able to derive the transfer function for that element in the motion control chain
    c. Testability - Each and every element needs to have built-in options to allow enable functional debugging and testing (prior to integration)
3. Performance
4. Compatibility - Degree to which a product, system or component can exchange information with other products, systems, or components, and/or perform its required functions while sharing the same hardware or software environment.
    a. Interoperability - Degree to which two or more systems, products or components can exchange information and use the information that has been exchanged.
    b. Co-existence
5. Usability - Degree to which a product or system can be used by specified users to achieve specified goals with effectiveness, efficiency, and satisfaction in a specified context of use.
    a. Operability - Degree to which a product or system has attributes that make it easy to operate and control.
6. Reliability - Degree to which a system, product or component performs specified functions under specified conditions for a specified period-of-time.
7. Security - Degree to which a product or system protects information and data so that persons or other products or systems have the degree of data access appropriate to their types and levels of authorization.
8. Portability - IMOCO4.E methodology will enable each machine to maintain excellent performance under slight variations in machine conditions, with the use of ML and advanced learning control. This enables the portability of production processes across multiple machines since processes will run almost identically on these machines.
    a. Adaptability - Degree to which a product or system can effectively and efficiently be adapted for different or evolving hardware, software or other operational or usage environments.
9. Cost
10. Scalability
11. Tools/toolchains

12. Safety

3.3 Requirement coding scheme

Each requirement ID is prefixed with Req, the deliverable ID (D3.1 for this deliverable), the applicable IMOCO4.E relation(s),

- Lx: layer x
- Bx: BB x
- Px: pilot x
- Dx: demonstrator x
- Ux: Use Case x

the optional reference framework-specific relation,

- hw: hardware
- sw: software
- fw: firmware
- com: communication

and the optional requirement classifier.

- SAF: safety
- SEC: security
- DAT: data protection

E.g., Req-D3.1-L1-1, Req-D3.1-P2-hw-SAF-2, Req-D3.1-P2-3

We make sure that the requirement IDs are unique so that the other deliverables can reference the defined requirement IDs within the IMOCO4.E project.

The requirements are prioritised through the MoSCoW method.

- M: must have (necessary requirements for the IMOCO4.E project)
- S: should have (additional desired requirements with high priority)
- C: could have (additional requirements with low priority)
- W: would have (future requirements, ideally after the completion of the IMOCO4.E project)

We consider the following requirement verification methods

- I: inspection (observation using basic senses)
- D: demonstration (use the system as it is intended)
- T: test (more precise and controlled demonstration using scientific principles and procedures)
- A: analysis (validation of the system by scientific methods)

The expected technical maturity will be quantified using the technology readiness level (TRL) criteria.

Table 1 - Requirements on layer 1 – sensors, actuators and interfaces coding scheme

	TRL	Description
Research	1	Basic principles observed
	2	Technology concept formulated
	3	Experimental proof of concept
Development	4	Technology validated in lab
	5	Technology validated in (industrially) relevant environment
	6	Technology demonstrated in (industrially) relevant environment
Deployment	7	System prototype demonstration in operational environment
	8	System complete and qualified
	9	Actual system proven in operational environment

4. System-level requirements

As indicated in the introduction, there are several tasks within WP3 which all need their own specifications and requirements at the layer 1: Hardware level. All effort w.r.t. the layers above rely on the backbone.

The main requirement will be that the essential data needs to be available, present and represented correctly in time (time-stamped) with the right accuracy to enable control of the actions required. To enable data transfer through a limited bandwidth system with latency, the amount of crucial data needs to be extracted from the raw data gathered. As such, its needs to be exactly specified what is needed from the raw data to enable the extraction of the crucial data.

Raw data might also be confounded with other influences: vibration, height, speed, acceleration, temperature, light, moisture, humidity, supply voltage, interference, etc. which all need to be taken into consideration with the extraction of the crucial data from the raw data. As already indicated with the specifications and requirements, some physical parameters do change slowly and allow slow collection whereas others are extremely fast.

E.g., with high-speed vision, the synchronisation of the light (exposure) as well as the framing of the picture need to be aligned. Additionally, the direction of the light exposure towards the object is crucial too. When a picture is taken e.g., with megapixel resolution, all stationary information in the picture is worthless and can be skipped. When it concerns the geometrical alignment of a component, all info is useless except for the contour of the component is only of interest and not even its colour. As such, only kilobytes of binary contour data may be left over for transfer from a high-speed high-resolution picture.

It is up to the system level definition whether the data reduction can an/or needs to be done in the smart sensor or whether DMA video data links are needed towards the central processor which needs to do the data crunching (image processing algorithms) in parallel to the process control.

Furthermore, it will be up to the instant availability, cost, software development and other constraints whether COTS parts; sensors, processors, modules, are taken together or that dedicated smart parts will be needed to enable further developments towards AI. When developed as a dedicated part/module, it can be easily integrated into the digital twin concept as an unambiguously defined part (of which the embedded software can still be adapted for the purpose of application e.g., human face or number plate recognition).

What is known is that the earlier the 'sensor' data is processed and digitalized, the less vulnerable it will be for interference. Here, on the other hand, when interference is mainly suppressed due to noise cancellation techniques, these requirements may become less critical.

Hard-wired and/or wireless communication of data, both have their application constraints with their suitability in its application. With wireless, line-of-sight is preferred with narrow beamwidth but has the advantage of no-strings-attached (at the cost of local power provision: batteries (= weight, volume), contactless by induction, energy scavenging or still hard-wired).

As a recall, the main areas of developments considered in the WP3 tasks are:

1. Analysis of interaction/ interferences with other mature facilities and equipment (i.e., re-used existing modules: proudly-found-elsewhere) and no part of a present WP3 task but can be considered by the Pilots, Demo's and Use Cases.
2. Requirements and specifications for signal and image processing algorithms based on relevant pilots, further linked to Task 3.3 (UWB, EDI, TUE, TNL, ITML, CNET, GEF, IKE, TNI)
3. Requirements and specifications for sensors (e.g., velocity, acceleration, acoustic, cameras, etc.) and actuators (e.g., piezo movers, reluctance actuators, etc.), further linked to Task 3.2 (INL, EMC, ECS, SIE, TNO, OE)
4. Wireless requirements analysis and technology evaluation, specification for robust and reliable WSN, further linked to Task 3.4 (UWB, EDI, TNL, INL, OE, ECS, UMO, IKE, COR, TNI, VIS)
5. Requirements and specifications for high-speed vision sub-components, further linked to Task 3.5 (TNO, SCC, UWB, INL, NXP, UMO)
6. Requirements and specification for smart servo drive ECUs, further linked to Task 3.6 (SCC, ING, TNL, EMC)
7. Requirements and specification for multi-many-core embedded control HW, further linked to Task 3.7 (SCC, TUE, ING, TNL, FAG, NXP, SIE, IMA, UMO, EVI).

4.1 Architecture layer requirements

From the overall IMOCO framework, only a few tasks from the Pilots, Demo's and Use Cases, see paragraph 2, rely on the output of the tasks carried out in WP3. As such, these 'other' teams for these tasks do not have specific requirements w.r.t. layer 1 developments. As such, they have not contributed to the specifications and requirements of this deliverable.

4.1.1 Requirements on layer 1

Not all Building Blocks, Pilots, Demo's and Use Cases have to rely on hardware as specified for Layer 1 as COTS available parts, modules, systems are taken. For the higher layers in the IMOCO framework, see Figure 1, no relation with the physical hardware (Layer 1) exists and all is related with data.

4.1.2 Sensors, Actuators and Network

Table 2 - Requirements on layer 1 – sensors, actuators, and interfaces

ID	Requirement	Priority	Verify	Comments	Tasks
Interfaces and connectivity					
Req-D3.1-L1-hw	Used vision sensors are easy to connect to a PC-based processing unit (USB2, USB3)	S	I	EDI	5
Req-D3.1-L1-hw	Sensors must have a reader/ controller connected to upper layers (through BB1 or BB4) by USB or Ethernet	S	I	INL/ECS	4
Performance					
Req-D3.1-D3-hw	Antenna parameters for the new front-end: elevation angle, MIMO configuration. 10 dB angle limit for the field of view.	M	T	IMST	4
Req-D3.1-L1-hw	Robotic gripper and motors able to hold weight at least 0,2 kg	M	D	EDI	
Req-D3.1-D2	Sensors must be able to read temperature within the range -40 to 85 ºC with at least ±0.5 ºC accuracy and in the range 0 ºC to 45 ºC with at least 0.3 ºC accuracy.	M	T	INL/ECS	T3.2
Req-D3.1-D2	Sensors must be able to read variations of pressure and temperature, at least 10 Hz.	M	T	INL/ECS	T3.2
Req-D3.1-D2	Pressure and temperature measurement data must be communicated, at least 1 Hz.	M	T	INL/ECS	T3.2
Req-D3.1-D2	Sensors must stand the injection molding pressure and temperature.	M	T	INL/ECS	T3.2, T7.2.2
Usability (operability)					
Req-D3.1-D2	Sensors must be fitted on the tool molding area.	M	I	INL/ECS	T3.2, T7.2.2

4.2 Connectivity requirements

System-to-system connectivity specifications and requirements between layers and systems and connectivity to machines is split in two application areas: hard-wired and wireless.

Hard-wired and/or wireless communication of data, both have their application constraints with their suitability in its application. With wireless, line-of-sight is preferred with narrow beamwidth but has the advantage of no-strings-attached (at the cost of local power provision: batteries (= weight, volume), contactless by induction, energy scavenging or still hard-wired).

With some of the WP3 applications, wireless power transfer is considered to be used for which external (outside) the machine RF emission requirements have been set or are under development. For now, no counterpart has been defined as an RF immunity standard. I.e., compatibility within the machine/ motion system may be at stake.

W.r.t. the reliability and availability of data, it must be ensured that whatever interface is chosen that data (streams) come in time, is not lost, robust i.e., redundant, retrievable (when necessary) and needs to be cybersecure.

4.3 Digital twining

To enable digital twining of the parts developed in WP3.x it is the intend that all sensors, subsystems, controllers, and actuators (have to) come with a behaviour model which describes the relation between the physical parameter being affected and the signal i.e., data applied and/or obtained. These behaviour models are necessary to allow a total projection of the full operation of the system including the contribution of these parts.

5. Building block requirements

5.1. BB1

ID	Requirement	Priority	Verify	Comments	Tasks
Performance					
R077-D2.3	The interface to/from BB1 shall support update rates of at least 20 kHz to layer 2 and/or BBs	M	D		BB1
Usability (operability)					
R02-D3.1-B1-sw/fw	TSN Centralized Network Configuration to facilitate the network configuration and monitoring	S	T	OROLIA Network adaptation attending to application requirements and network telemetry (latency, congestion, failures). Control and telemetry features exposed through a standard API between TSN bridges and CNC	T3.4
Reliability (fault tolerance, availability)					

R03-D3.1-B1-sw/fw	Frame Replication and Elimination Reliability (IEEE 802.1CB) available for user designated data streams.	S	I	OROLIA	T3.3

5.2. BB3

ID	Requirement	Priority	Verify	Comments	Tasks
Interfaces and connectivity					
Req-D3.1-D2	Controller must provide communication and power supply, both wireless.	M	D	INL/ECS	T3.3
Performance					
Req-D3.1-D3-hw	Antenna parameters for the new front end: elevation angle, MIMO configuration. 10 dB angle limit for the field of view.	M	T	IMST	
Req-D3.1-D2	Sensors must be able to read temperature within the range -40 to 85 ºC with at least ± 0.5 ºC accuracy and in the range 0 ºC to 45 ºC with at least 0.3 ºC accuracy.	M	T	INL/ECS	T3.2
Req-D3.1-D2	Sensors must be able to read variations of pressure and temperature, at least 10 Hz.	M	T	INL/ECS	T3.2
Req-D3.1-D2	Pressure and temperature measurement data must be communicated, at least 1 Hz.	M	T	INL/ECS	T3.2
Req-D3.1-D2	Sensors must stand the injection molding pressure and temperature.	M	T	INL/ECS	T3.2, T7.2.2
Usability (operability)					
Req-D3.1-D2	Sensors must be fitted on the tool molding area.	M	I	INL/ECS	T3.2, T7.2.2

5.3. BB8

ID	Requirement	Priority	Verify	Comments	Tasks
Performance					
R185-D2.3-B8-D4	Sim2Real transfer provides synthetically trained object detection algorithms that detect objects of interest in 80% of images with said objects	S	D	EDI	

5.4. BB9

ID	Requirement	Priority	Verify	Comments	Tasks
R198-D2.3-B9-com-DAT	Support real-time information exchange with a protocol based on message set abstraction (publish/subscribe model) that can handle parallel data streams between multiple endpoints	M	D		T3.7
R199-D2.3-B9-com-DAT	BB9 will be able to aggregate, transform and fuse incoming text-based data from multiple sources and of multiple data types (e.g., time-series and cross-sectional data, real and simulated data, raw sensor data, inference result data from AI components).	M	D		T3.7
R200-D2.3-B9-com-DAT	BB9 will provide persistent storage for the aggregated and fused data (see R199-D2.3-B9-com-DAT) in the cloud infrastructure (historical data).	M	D		T3.7
R201-D2.3-B9-com-DAT	BB9 will allow all authorised components to access incoming data streams collected from multiple sources (see R199-D2.3-B9-com-DAT) in real-time via a dedicated API.	M	D		T3.7
R202-D2.3-B9-com-DAT	BB9 will allow all authorised components to access historical data stored in the cloud infrastructure (see R200-D2.3-B9-com-DAT) via a dedicated API.	M	D		T3.7
R203-D2.3-B9-sw	BB9 architecture to be based on microservices to be delivered in containerised form and deployed on the edge/cloud (e.g., using Docker/Kubernetes cluster)	S	D		T3.7
R204-D2.3-B9-com-DAT	BB9 will be able to handle time-sensitive data streams between multiple endpoints in real-time while conforming to the bandwidth and latency requirements of connected IMOCO4.E components.	S	T		T3.4 T3.7

R205-D2.3-B9-SEC	BB9 must be able to generate alerts in real-time (e.g., related to supported cyber-security threat detection, see R215-D2.3-B9-SEC).	M	D		T3.7
R206-D2.3-B9	BB9 will be designed to support and be operational in multiple Pilots/Demonstrators/Use Cases	S	D		T3.7
R207-D2.3-B9	A GUI will be provided for configuration purposes of BB9.	C	D		T3.7
R208-D2.3-B9	BB9 will provide an appropriate dashboard for visualising data and providing insight related to the operation of BB9 (e.g., system health status, data traffic, performance metrics, alerts)	C	D		T3.7
R209-D2.3-B9-DAT	Data safety will be ensured through Data Replication support over secure channels between the infrastructure cluster nodes.	S	D		T3.7
R210-D2.3-B9	BB9 will be able to continue operating despite receiving and processing invalid or wrong data.	S	D		T3.7
R211-D2.3-B9	BB9 will provide high computing availability, having a continuous, uninterrupted, fault-tolerant operation.	S	D		T3.7
R212-D2.3-B9-SEC	Only authorised users will be allowed to access the system.	S	D		T3.7
R213-D2.3-B9-SEC	Access to the system's data and services will be granted only to authenticated users and components that have been granted the necessary privileges.	S	D		T3.7
R214-D2.3-B9-SEC	Data security will be ensured at rest and in flight.	S	D		T3.7
R215-D2.3-B9-SEC	BB9 will support the automated detection of cyber-security threats and vulnerabilities that can be inferred from applying anomaly	S	D		T3.7

	detection techniques to the BB9 data streams.				
R216-D2.3-B9-SEC	The system will alert the user if any supported cyber-security threat and vulnerability is detected and present an assessment (see R215-D2.3-B9-SEC).	S	D		T3.7
R217-D2.3-B9	BB9 will be fully scalable so that it can easily be adapted to new integration needs or changes in performance, reliability, and data volume requirements.	S	D		T3.7
R218-D2.3-B9	All used libraries/frameworks/components must not have known security vulnerabilities nor infringement of (open source) license conditions.	S	D		T3.7

6. Pilot requirements

6.1 Pilot 2

ID	Requirement	Priority	Verify	Comments	Tasks
Req-D3.1-P2	Operating temperature (in degree Celsius): +20 - +24	M	D	Typical working temperature for semiconductor equipment.	
Req-D3.1-P2	**Control sample rate** Min – 8 kHz Max – 20 kHz	M	T		
Req-D3.1-P2	**Machine throughput** Min – 60 kUPH Max – 100 kUPH (36 ms per unit)	M C	T		
Req-D3.1-P2	Machine assembly precision <6 µm 1 sigma <3 µm 1 sigma	M C	T		

7. Demonstrator requirements

7.1. Demonstrator 2

ID	Requirement	Priority	Verify	Comments	Tasks
Interfaces and connectivity					
Req-D3.1-D2	Controller must provide communication and power supply, both wireless.	M	D	INL/ECS	T3.3
Performance					
Req-D3.1-D2	Sensors must be able to read temperature within the range -40 to 85 ºC with at least ±0.5 ºC accuracy and in the range 0 ºC to 45 ºC with at least 0.3 ºC accuracy.	M	T	INL/ECS	T3.2
Req-D3.1-D2	Sensors must be able to read variations of pressure and temperature, at least 10 Hz.	M	T	INL/ECS	T3.2
Req-D3.1-D2	Pressure and temperature measurement data must be communicated, at least 1 Hz.	M	T	INL/ECS	T3.2
Req-D3.1-D2	Sensors must stand the injection molding pressure and temperature.	M	T	INL/ECS	T3.2, T7.2.2
Usability (operability)					
Req-D3.1-D2	Sensors must be fitted on the tool molding area.	M	I	INL/ECS	T3.2, T7.2.2

7.2. Demonstrator 3

Following requirements for the radar system have been chosen by IMST in the first measurements. They are based on the discussion results with project partners. Further specifications can be done as soon as specific measurement scenarios are clear.

The ones to be clarified are:

- MIMO configuration for angular resolution in azimuth
- Opening angle in azimuth (10 dB)
- Height detection in elevation (for passage under a subway)
- Opening angle in elevation (10 dB)
- Radiated power (EIRP)

The radar should be able to face following scenarios at maximum given distance of 10 meters: Travel path limited by fixed/static equipment such as shelves, high storage, columns, etc.

- Obstacles in the travel path: people (moving, standing), people crossing the travel path, goods from the storage area, size, and min./max. distance.
- Lateral paths and obstacles: Detection to be determined experimentally.

ID	Requirement	Priority	Verify	Comments	Tasks
Performance					
Req-D3.1-D3-sw	Use of the 77-81 GHz band: 2 GHz bandwidth in the first measurements.	S	D	IMST	
Usability (operability)					
Req-D3.1-D3	Definition of Measurement scenarios.	M	I	IMST	

7.3. Demonstrator 4

Vision-based (AI) pick & place robotics for randomly arranged and differently shaped bottles

ID	Requirement	Priority	Verify	Comments	Tasks
Interfaces and connectivity					
Req-D3.1-D4	Screen and input HW for inspection and correction of perception and control modules	M	I		
Req-D3.1-D4	Internet connection for possibility to remotely inspect behaviour of perception and control modules	S	I		
Maintainability (modularity, analysability, testability)					
	Demonstrator should be easily maintained by basic operators				
Performance					
Req-D3.1-D4	Number of successful picks from a random pile in a minute up to 70	M	D		
Req-D3.1-D4	95% successful placement of the bottle into a socket on first try	M	D		
Compatibility (interoperability, co-existence)					
Req-D3.1-D4	Demonstrator should be compatible with an existing production line	M	D		
Req-D3.1-D4	Demonstrator should be compact size	M	D		
Cost					
Req-D3.1-D4	Overall cost of deploying the demonstrator (without R&D) < 200,000 EUR	S	I		
Scalability					
	Demonstrator can be adjusted to several conveyors/production lines	S	I		

8. Use Case requirements

8.1. Use Case 3 - Tactile Robot Teleoperation

The Tactile Robot constitutes the next generation of soft collaborative robots, equipped with sensing capabilities to process humanlike tactile sensation. Human safety and labor/skill shortages in industry will be improved dramatically, as potentially dangerous, or complex operations involving inspection, repair, or even decommissioning, will be performed by a remotely controlled Tactile Robot.

The Use Case will implement safe remote teleoperation via a tactile robot. Human in the loop will be considered through complex HMI coupled with a digital twin representation of the process implemented in virtual reality. The application will be enabled with high performance AI embedded close to the edge, mitigating motion control errors introduced because of sensor and user input (and feedback) limitations.

ID	Requirement	Priority	Verify	Comments	Tasks
Interfaces and connectivity					
Req-D3.1-U3-com	Successful interfacing and connectivity between the PolarFire SoC-FPGA (MPFS250T-FCVG484EES) placed at the local user-end and the PolarFire SoC-FPGA (MPFS250T-FCVG484EES) placed at the remote CoBot-end.	M	I-D	This connects the local user end to the remote tele-operated CoBot using two edge devices.	3.3
Req-D3.1-U3-com	Create connectivity between both PolarFire edge devices using the PROFINET - Isochronous Real-Time (IRT) industrial Ethernet protocol as the initial communications infrastructure.	M	I-D	This provides industry grade Ethernet connectivity protocol.	3.3
Req-D3.1-U3-com	Use of the interface module: RapID-NI-V2007 to connect the PolarFire SoC-FPGA (MPFS250T-FCVG484EES) to the PROFINET-IRT.	M	I-D	This connects the edge devices to the PROFINET-IRT.	3.3
Req-D3.1-U3-com	Use of PLC: SIEMENS S7-1500 CPU as the network management component of the PROFINET-IRT industrial Ethernet protocol.	M	I-D	Network management between local and remote edge devices.	3.3
Req-D3.1-U3-com	Research and investigation into TSN advancements for PROFINET-IRT that may be suitably and technically incorporated into the Use Case communications infrastructure.	M	I-D	This is for future research as TSN becomes an accepted, quality assured standard.	3.3

Performance					
Req-D3.1-U3-hw-sw	The local (user-end) PolarFire device to be programmed to perform HMI-IMU and ToF vision processing to create CoBot commands communicated using PROFINET-IRT to the second remote PolarFire device to perform the physical CoBot movements.	M	I-D	On-board edge device sensor processing at the local end for communicating CoBot commands to the remote physical CoBot end.	3.3/5.7
Req-D3.1-U3-hw-sw	Ongoing investigation, research and development into opportunities to improve performance, energy efficiencies and latency reduction between the local and remote PolarFire edge devices across the PROFINET-IRT industrial Ethernet protocol.	M	I	This research involves continual improvements work in edge-based AI processing and Use Case related processing services.	3.3/5.7
Compatibility (interoperability, co-existence)					
Req-D3.1-U3-hw-sw	Co-existence of Information Technology (IT) and Operation Technology (OT) on the same network infrastructure.	M	I	This technology will significantly decrease the network wiring that results in lower cost of implementing industrial network.	3.3/3.4
Tools/toolchains					
Req-D3.1-U3-hw-sw-com	Edge focused research and development will be conducted using the PolarFire SoC-FPGA (MPFS250T-FCVG484EES). This work will use the VectorBlox SDK and will involve research and deployment of CNNs at the local end in the mapping of HMI-IMU and ToF sensor data streams to CoBot activations at the remote end.	M	I-D	This is ML related research and engineering into the use and deployment of CNNs on the PolarFire edge devices.	3.2
Req-D3.1-U3-sw-com	Generally available APIs and related SDKs (C/C++, Python) to interface the remote PolarFire SoC-FPGA (MPFS250T-FCVG484EES) edge device with	M	I-D	Interface the edge device with the CoBot and finger gripper. Also process received	3.2

	the UR16e CoBot and the UR16e finger gripper device.			CoBot commands from the local end.	
Req-D3.1-U3-sw	Produce a number of Use Case related data sets, incorporating HMI-IMU (tactile glove) and ToF (depth camera) sensor data streams to be used in both cloud and PolarFire edge device related AI/ ML research and development.	M	I-D	ML related research and development in relation to tactile tele-operated robotics.	3.4
Req-D3.1-U3-hw	Several Use Case related data sets from latest generation ToF vision data processing in order to assess suitability for real-time human arm/hand movement recognition.	S	I-D	Specialised ML research and development using latest ToF vision related technologies.	3.4
Safety					
Req-D3.1-U3-hw-sw	Continually addressing the health and safety aspects of the functionality to be implemented at both the user local end and the remote CoBot end of the tele-operation platform.	M	I-D	User safety as a critical, mandatory and core aspect of the Use Case research into tele-operated robotics.	

9. Operability requirements

The systems have to be able to operate in various environments e.g. semiconductor, physical and chemical (cleanroom) laboratory environments as well as automotive production areas with welding equipment. As such, there will not be a one size fits all boundary constraint.

The main differences will be in:

- Measurement ranges of the physical quantities and their tolerances w.r.t. to their electrical representation
- Temperature, pressure, humidity range
- Pollution degree
- Power quality
- EM environment, including EM-fields from nearby wireless connectivity, motion control and wireless power transfer (WPT)

9.1 Safety

The term safety applies in the IMOCO4.E methodology to the human environment w.r.t. generated noise, pollution, radiation as well as dangerous (unintended) motion from autonomous robots and production machinery

9.1.1 Motion safety

As torque and force are the paramount parameters with the autonomous robots and production machinery, they need to be well guarded to ensure human safety of the operators as well as a limitation on foreseeable machine damage.

Though the main focus in IMOCO4.E will be on electrical autonomous robots and production machinery, also hydraulic and pneumatic sources for motions have to be taken into account (when used).

The two "sister standards" IEC/EN 60204 series (Machine Directive) and ISO 12100 (Risk Assessment and Risk Reduction) are closely related to regulatory aspects. Both standards are transposed as national / regional standards across the world, including in Europe, US, China, Japan and many other countries and their closely related regulatory activities.

Further examples of horizontal safety standards include:

IEC 61140 (Protection against electric shock)

IEC 60529 (Protection by enclosures)

IEC 60664 (Insulation coordination for equipment within low-voltage systems)

In the area of group safety and product standards, the following could be regarded as highly "regulatory relevant":

IEC 60335 series (Household appliances)

IEC 61010 series (Industrial equipment)

IEC 62368-1 series (Safety of multi-media equipment)

IEC 60598 Luminaries

IEC 60601-1 (series) Medical electrical equipment

The EN versions of these standards, for example, are listed in the Official Journal of the European Commission to support the respective European Directives. The application of these standards also leads to acceptance of products by the authorities in countries such as the United States and China.

9.1.2 Electrical safety

All electric and electronic autonomous robots and production machinery needs to be electrical safe according to the international requirements (and their national deviations). Typically, these requirements are part of the Machine Directive as well as the Low Voltage Directive.

9.1.3 Electromagnetic compatibility: emission and immunity requirements

All electric and electronic equipment has to satisfy the EMC directives, as applicable to the products considered.

9.1.4 Radio equipment

All products which incorporate wireless and/or radio related functions have to satisfy the Radio Equipment Directive (RED), for which the EMC requirements are superseded i.e., extended by the ETS 301-489-1. Additionally, the wireless and/or radio related functions have to satisfy the ETS related requirements for the products used. Pre-qualified modules may be used to circumvent testing against the specific ETS. The use of short-range-devices (SRD) are recommended to avoid formal type testing.

10. Conclusion

As can be seen from the collected specifications and requirements there is the match between those collected from the WP3 members compared to those responsible for the Pilots, Demos and Use Cases. On the other hand, this is likely to happen as some of the WP3 members are directly involved with those Pilots, Demos and Use Cases.

With some of the applications, wireless power transfer is considered to be used for which external (outside) the machine requirements have been set or are under development. For now, no counterpart has been defined as an immunity standard. I.e., Compatibility within the machine/ motion system may be at stake.

11. References

[1] IEC/EN 60204 (Machine Directive)
[2] ISO 12100 (Risk assessment)
[3] IEC 61140 (Protection against electric shock)
[4] IEC 60529 (Protection by enclosures)
[5] IEC 60664 (Insulation coordination for equipment within low-voltage systems)
[6] IEC 60335 series (Household appliances)
[7] IEC 61010 series (Industrial equipment)
[8] IEC 62368-1 series (Safety of multi-media equipment)
[9] IEC 60598 Luminaries
[10] IEC 60601-1 (series) Medical electrical equipment