



Artificial Intelligence in Manufacturing leading to Sustainability and Industry5.0

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AIMS5.0

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Publishable Executive Summary

The deliverable D1.1 of the AIMS5.0 project describes the planned AI-enabled electronic components and systems for sustainable production tools that are planned to be developed and/or used in the AIMS5.0 project, as it is envisaged at the first internal technical milestone. The objective is to share the knowledge that can be useful for general industry and academia to address their own related challenges. Keeping in mind the sensitive nature of the methods used by some of the AIMS5.0 industrial partners, it omits the details about the particular configuration and fine-tuning that gives the authors their competitive advantage on the market. Instead, it provides a description of the hardware tools, methods and algorithms in isolation, but with sufficient detail to allow application in similar use cases.

The objective of this document is to summarize the challenges to be addressed in AIMS use cases and corresponding hardware solutions under consideration. This is a preliminary report based on the initial analysis done by partners and solution designs are still being established.

The main objectives of Work Package 1 (Exploration of HW components for the edge processing platform) are threefold: First, to provide hardware exploration taking the industrial needs and practices of the other technology WPs in AIMS5.0. Second, to present use-case specific integration methods that lead to actual, working prototypes in use-case WPs and based on that the creation of integration guidelines is also a result of this endeavour to improve the time-to-market.

In Chapter 1 of this deliverable, we present an overview of WP1 and its associated aims and objectives. In Chapter 2, each partner or use-case grouping provide a description of their requirements and mission statement. Chapter 3 reviews a corresponding questionnaire and summarizes the responses provided by each partner to the respective questions. Finally, Chapter 4 is a summary of the in-progress use case works and conclusion about the deliverable.

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1. Introduction

AIMS5.0 will contribute to the European digital sovereignty in comprehensively sustainable production. This involves the strategic adoption, extension, and implementation of artificial intelligence (AI) tools and methods throughout the entirety of the industrial value chain. To achieve this, the project will collectively achieve a set of concretely defined objectives. The primary outcomes sought through these endeavours include a significant enhancement in overall production efficiency, concomitant with a dedicated focus on advancing sustainability development. The following subsections present the objectives to be achieved, along with a set of corresponding success metrics to validate their achievement.

1.1 Objective of WP1

The objectives of WP1 are the following:

- AI-READY EDGE HARDWARE: creation of necessary components to run the AI-enabled edge hardware of the AIMS5.0 systems.
- EFFICIENT SYSTEM INTEGRATION AND COMMUNICATION: co-design of the edge and cloud hardware of use-case demonstrators.
- TEST AND VALIDATION ENVIRONMENT: a powerful test and validation environment in order to assess a planned system environment before performing costly installation procedures of AI-enabled edge hardware; improved predictive maintenance.

1.2 Means of Achievement

This entails hardware, firmware, and AI-enabled software components that are being optimized for embedded hardware. Analysis and provision of AI-enabled hardware components for assembling, testing, and validating the next-generation industrial systems against a set of predefined criteria related to sustainability.

In the context of the co-design efforts, interfaces, and interactions will be specified, and the parts of the network edge will be implemented. Furthermore, the communication approaches for data transfer between edge devices and the cloud will be explored and implemented. The required tools, interfaces and other components for this environment will be developed, resulting in AI-supported human assistance in production.

1.3 Success Metrics

- Metrics on improved quality & reliability of hardware components; improvement by 15%
- Improved Low-Latency Communication in IIoT applications by 10% (speed) and 20% (efficiency)
- Metrics on Quality and Productivity; overall improvement by 10% productivity
    - Provision for improved silicon Lifecycle Management
    - Predictive maintenance improvement

1.4 Relationships with other WP

AIMS is organized into work packages (WPs), each involving a specific number of partners. These partners engage in clear and defined communication and interaction facilitated by task structures and management processes. Figure 1 illustrates the interconnections and information exchange among the WPs. In a simplified overview, WP1, WP2, and WP3 contribute to WP4, which constitutes the four purely technical WPs within the project. WP4, in turn, supports WP5 and WP6, housing the 20 project use cases. Additionally, WP7 and WP8 encompass activities that span from WP1 to WP6, while WP9 coordinates the efforts of WP1 to WP8.

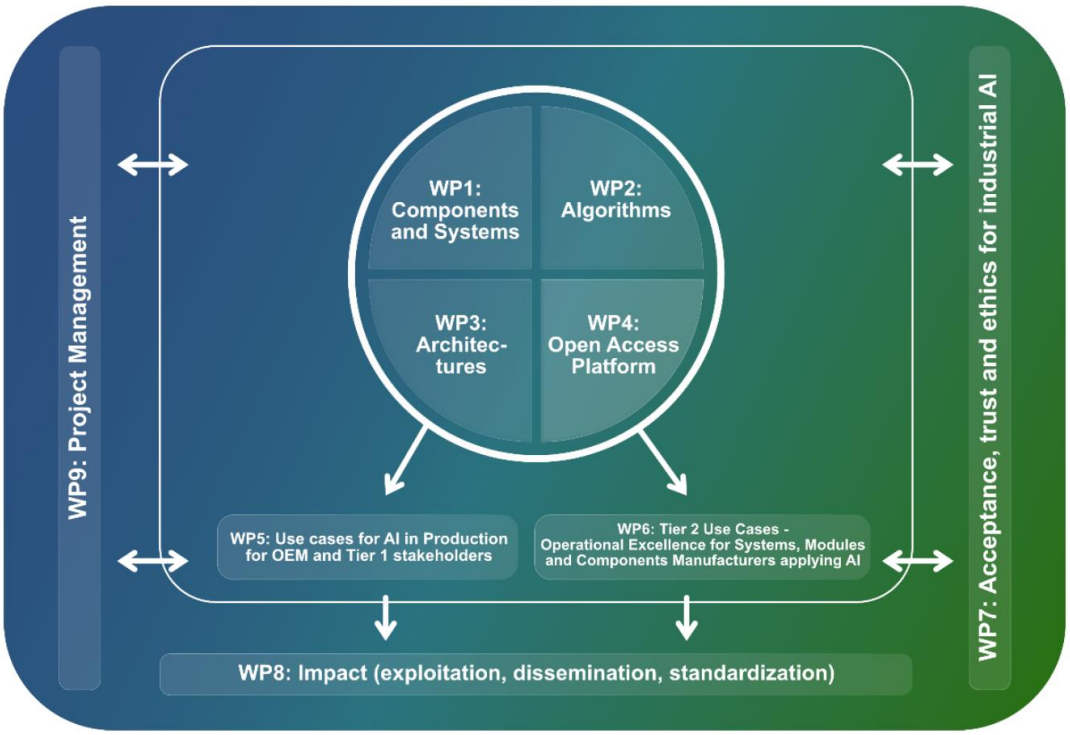

Figure 1:PERT diagram for the major relationships and information flow between work packages

WP1 will elaborate on intelligent components and systems for the edge, which is the bottom level of the future AIMS5.0 systems. WP2 will develop new algorithms as well as refine and integrate already available AI-related algorithms for sustainable industrial processes. WP3's focus is on elaborating on new cyber architectures for an AI-supported intelligent production environment. Besides, this WP will give new approaches to the information, material, and energy flows of AIMS5.0.

WP4 targets the AIMS5.0 open-access platform, an intelligent open-access platform, consolidated, matured, and advanced. Partners will present applicable market orders. WP5 will provide Use Cases for AI in production from OEMs and Tier 1 for validating and application of the project findings. WP6 will provide Use Cases from Tier 2 with a focus on artificial intelligence for operational excellence in the ECS, for cross-validation and application of the project findings.

WP7 will work on human acceptance of trustable AI from the social and ethical side of AI technology development. WP8 will drive standardization efforts and will address dissemination and support exploitation, including collection of training kits produced by the technology and use case WPs. WP9 is dedicated to the coordination and management of the project.

2. Partner and use case plans for individual and collaborative contributions in WP1

This section briefly summarizes the planned individual and collaborative contributions of partners and use case providing groups.

2.1 Contribution of IFAG

In this work, the IFAG FE Regensburg (AUT ASO) is working on the further development of customary sensor system solutions in order to operate a wide variety of semiconductor transport components safely and as error-free as possible with regard to their contamination class, allocation and condition. The main challenge is to ensure that the sensor technology used is suitable and stable for use in new high-automation processes. Furthermore, the existing transport components are not allowed to be changed for manufacturing process reasons and existing local requirements.

Initial performance analyses showed that a widespread introduction of new automation components in the semiconductor production environment requires further development of sensor systems to achieve a stable production and logistics process. In order to identify the potential weak points, the first step was to define requirement and collect the data to determine the current situation.

The first sensor development is to further improve the RIFD read quality of the current installed base of almost 600 RFID readers all over the frontend production site. Over the last few months there were approx. 150.000 readings per day, which have been recorded. First results have shown that supposedly the same hardware and software of RFID Reader systems achieve different values in there reading quality. In isolated places, only 98% of successful readings were achieved and this is far below 99,5% what is necessary to avoid material re-routing or logistic errors. The data recording is currently recorded. In a next step an analysis will be executed to identify failure mechanisms and patterned peculiarities. After this, an accompanying market analysis will be started for solution comparison.

The second sensor development belongs to a highly automated ceiling transport/storage system which is designed with a novel bearing system in a clean room environment. After a certain period of productive use, a high wear on the rolling bearings in the linear-axis guide was suddenly observed. The exchange is rather time consuming and needs expertise. The aim of this sensor development is to detect rolling bearing damage at an early stage with the help of permanent acoustic measurements in order to establish the preventive maintenance approach.

Due to the mechanical design of the bearing system, the sonic sensor must very compact and therefore a feasibility study and technical market analysis has been started. The requirement engineering revealed that a measurement setup has to be made which allows stable measurement data. A microphone calibration procedure must be worked out so that sound pressure levels are recorded correctly. Therefore, an AI driven solution is planned to find a correlation between existing peaks and the expected peaks of the rollover frequencies of the bearings for different types of damage vs. the "rolling bearing physics" (Collaboration to WP6 Subtask 6.3.4).

Additional work by IFAG focuses on sensors to be investigated in WP6 use cases, such as radar, pressure or gas sensors for equipment matching/harmonization, assembly and packaging and supply chain operations. In supply chain operations, particular efforts include the development of a biometric identification solution by PPG (Photoplethysmography) enabled by a PALS (Proximity and Ambient Light Sensor). Here, the following tasks were performed:

- Refinement of machine/deep learning models for accurate biometric identification
- Hardware set-up (shielding, e.g.) and assessment of reliability
- Field study for further evaluation of results

2.2 Contribution of SU

2.2.1 WP1 Activity Status of SU (SMARTUNIVERSAL) for the first 6 months

Objective

TUBITAK and SmartUniversal (SU) will develop an AI supported AMR Task and Traffic Management System that enables the safe and energy efficient intralogistics inside any factory floor. Additionally, SU will develop an AMR sensor fusion, perception, obstacle detection and classification, as well as AMR human-like reaction with visual/sound communication between AMR and human obstacle detected.

Activity Status for the first 6 months

In the scope of the AIMS5.0 project, SU is working on an AMR platform together with TUBITAK in UC8 (AI supporting and strengthening human and manufacturing cycles). The very first efforts regarding the project scope elaboration was the meetings on the key achievements of the project. The related KPI is “Acceptance, trust and ethics for explainable industrial AI leading to human-centered sustainable manufacturing”. The use case is reviewed based on the project goals (acceptance, trust and explainable AI).

Saying that, the core technologies/innovations are identified as:

1) Human Identification/Classification
2) Explainable AI
3) Hand Gesture Recognition
4) Human-Like Interaction



Figure 2:Workstation Scenario

Requirements for the use case are studied. Originating from the main goals of the project, high-level requirements are classified as follows:

- Human Classification
- Hand Gesture Recognition
- Human-like Interaction based on Explainable AI

The required sensor set for this task is identified as:

- Lidar (Navigation, Obstacle Detection)
- Camera (Classification, Gesture Recognition)
- Radar (possibly from Infineon, Obstacle Detection)

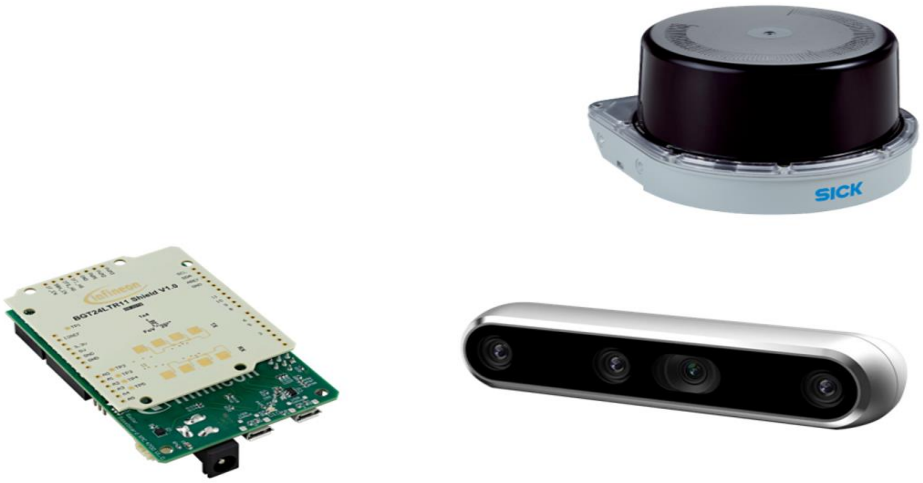

Figure 3:Sensors Set

Planning for the next 6 month

During the next 6 months Q1/Q2 2024, the planned activities are given as:

- Finalization of UC requirements
- Sensor set acquisition
- "Human-like Interaction" workshop with TUBİTAK

Changes requested in amendment 1

SU requested the following changes in the first amendment due to a typing error occurred in the Technical Document (Part B), and tasks of TUBITAK are mistaken with tasks of SU. In the following Table 1, the current text in the Technical Annex is given in the left column and requested text is given in the right column:

Table 1: Technical Annex

Section and page	Current description	Requested description
Section 3.1.3.5 (T5.3 AI techniques applied to Industrial	SU will be responsible for the development of EEG Brain signals supported exoskeleton using AI (at manufacturing for human workers with disabilities). Furthermore, SU will take care for AMRs for in-factory logistics with	TUBITAK will be responsible for the development of EEG Brain signals supported exoskeleton using AI (at manufacturing for human workers with disabilities). Furthermore, SU will take care for AMRs for in-factory logistics with

Domains) Page 196	AI supported Task and Traffic Management System focusing on Explainable AI. As a complement, TUBITAK will contribute with AMR sensor fusion, perception, obstacle detection and classification. In addition, TUBITAK will focus on AMR human-like reaction and visual/sound communication with human obstacle for higher acceptability and safety using AI.	AI supported Task and Traffic Management System focusing on Explainable AI. As a complement, SU will contribute with AMR sensor fusion, perception, obstacle detection and classification. In addition, SU will focus on AMR human-like reaction and visual/sound communication with human obstacle for higher acceptability and safety using AI.
Section 3.2.1 (Table 19) Page 253	SU (RES): * Development of EEG Brain signals supported exoskeleton using AI (at manufacturing for human workers with disabilities) * AMRs for in-factory logistics with AI supported Task and Traffic Management System focusing on Explainable AI TUBITAK (SME): * AMR sensor fusion, perception, obstacle detection and classification. * AMR human-like reaction and visual/sound communication with human obstacle for higher acceptability and safety using AI	SU (SME): * AMR sensor fusion, perception, obstacle detection and classification. * AMR human-like reaction and visual/sound communication with human obstacle for higher acceptability and safety using AI TUBITAK (RES): * Development of EEG Brain signals supported exoskeleton using AI (at manufacturing for human workers with disabilities) * AMRs for in-factory logistics with AI supported Task & Traffic Management System focusing on Explainable AI

Table 2: Status

No.	Activities	Running /Delayed/Finalized	Status
1	Definition of requirements and specifications	Running	Initial definition of goals and UC is performed.
2	Review of components and implementation	Running	Required sensor set is determined.
3	System development and integration	Running	Prerequisite: Sensor acquisition, platform availability
4	Final demonstration	Running	To start in Q1/2026

2.3 Contribution of TUBITAK

2.3.1 **Analysis of Use Case-8 Requirements**

TUBITAK is responsible for development of the AI-supported Task and Traffic Management System focusing on Explainable AI with AMRs for in-factory logistics. Furthermore, TUBITAK will study physiological signals to be applied for estimating the user motion intention in skeletons by using AI techniques. For this purpose, a draft scenario has been created to help analysing system requirements. As a result of these studies, the necessary hardware requirements were determined and are explained in the following section.

2.3.2 Autonomous Mobile Robot (AMR)

In order to enable safe and energy-efficient intra-logistics in any factory, it is necessary to establish an autonomous working environment. AMRs constitute the basic agent of this working environment. It was decided to use the OMRON brand LD-90 model which is shown in Figure 4: OMRON LD-90 AMR as AMR in the scenarios. This model is designed to automate material transport tasks in factories and indoor facilities.



Figure 4: OMRON LD-90 AMR

This model is designed to automate material transport tasks in factories and indoor facilities. Some of the specifications of this model are described in Table 3: AMR Specifications.

Table 3: AMR Specifications

Item		Specification	Note
Materials		Polycarbonate	
Dimension (L x W x H)		699 x 500 x 383 mm	
Weight (with Battery)		62 kg	
Environment	**Ambient Temperature**	5 to 40°C	
	Ambient Humidity	5 to 95% (non-condensing)	
	Operating Environment	Indoor usage only, no excessive dust, no corrosive gas	Direct sunlight may cause safety laser false positive
Navigation	**Routing**	Autonomous routing by localizing with safety scanning laser based on environment mapping	
	Environmental map making method	Scan by walking the mobile robot through the environment, and upload the scan data in the MobilePlanner	
Payload	Max. Weight	90 kg	* Excluding cart weight
Mobility	Max. Speed	1350 mm/s	
	Max. Rotation Speed	180/s	
Power	Run Time	15 hours (continuous) approx..	With no payload condition

	Recharge Time	4 hours (5:1 ratio) approx.	
	Charging Method	Automatic / manual	
Speaker		3.5 in., 80 W max	
Indicator		Light disc in each side	
Operation Interface	Screen / Touch Pane	3.5 in. TFT 320x240 pixels, color screen	
	Button	On button: green Off button: red Brake-release button: orange Key switch (disabled off button)*	* Key switch can be used to disable the off button to avoid accidental shutdown or tampering.

2.3.3 Sensors on the AMRs

TUBITAK and SU will also work on sensor fusion (with LIDAR, radar, stereo camera) for AMR operating in a metallic environment with distractions in WP5. Object detection and classification will be developed for defined human-like reactions against the obstacles on the path inside the factory environment. The sensors, which are to be used in this process and during demonstration of UC-8, are also shown in Table 4 with their specifications.

Table 4: Sensor Specifications

Item	Spesification	Note
Safety Scanning Laser	1 at front Class 1 PLd safety per ISO13849-1 15 m maximum range 240° field of view	Included in OMRON LD-90
Rear Sonar	2 at rear, 2 m range	Included in OMRON LD-90 Each pair includes one emitter and one receiver working together
Low Front Laser	1 at front of platform Class 1 4 m maximum range 126° field of view	Included in OMRON LD-90
Side Laser	Option*	* 2 on sides of payload structure, user-mounted
Radar - SP005728718	60 GHz	From IFAG

2.3.4 Task And Traffic Management Station (TTMS)

Another component required within the scope of UC-8 is a platform on which to run the TTMS software. The system requirements that will be sufficient for TTMS, which consists of three modules, i.e., task planning, traffic management and user interface. HP Omen 7H8Z4EA was deemed appropriate to meet these requirements.

- **Processor:** Intel Core i7-12700H
- **Memory:** 32 Gb Ram

- **Graphics:** NVIDIA GeForce RTX 3070 Ti
- **Storage:** 1 Tb SSD

Lastly, in order to demonstrate the smart-factory environment, the mobile robots and other components such as the central coordinator workstation should be able to communicate seamlessly. The WiFi IEEE 802.11 protocol is preferred due to its ease of installation and use. The WiFi router ASUS DLS-AX82U modem is selected for this use case.

- **Network Standard:** 802.11ax (WiFi 6)
- **Operating Frequency:** Dual Band (2.4 Ghz & 5 GHz)

2.3.5 Exoskeleton

Exoskeleton robotic devices have been developed as a practical auxiliary system for therapists to handle impaired joints or limbs. In recent years, robotic technologies have been applied in motion rehabilitation to provide training assistance and quantitative assessments of recovery for the patients. Exoskeletons, shown in Figure 5, can be defined as a wearable device designed to perform body parts like ankle joints. Moreover, the torque produced by the actuators is transferred to the body when this wearable device is worn. Later, these devices have been developed into full-limb exoskeletons to support shoulders, elbows, wrists, and ankle joints in the body.

Since it is aimed to control a device using physiological signals, a selection of proper exoskeletons will be realized. It should be an active exoskeleton so that it could be possible to transmit command signals to control its actuators.



Figure 5: Exoskeleton

Actuators should be designed so that power consumption can be minimized, with less weight of the motors and battery. Basic technical specifications of the exoskeleton is given in Table 5.

Table 5: Exoskeleton basic specifications

Specification Parameter	
Gait Velocity	> 0.2 m/s
Joint torque	40 N·m|-(nominal)
Input Impedance	>100 Mohms
Accuracy	+/- 1.5%
Noise	‹ 5μV

2.3.6 EEG Headset

To obtain one type of physiological signals, EEG signals, an EEG headset will be required. Among different brands and models, Emotiv Flex Gel headset, shown in Figure 6, has been selected due to its common usage and for satisfying our requirements. EEG data will be collected by using this 32-channel headset.



Figure 6: Emotiv Flex Gel headset

While collecting data, proper data acquisition software to transfer data from EEG headset to computer will be needed. EEG data will be transferred from the headset to the computer will be transferred via Bluetooth and will be saved on the computer. Moreover, this software will have the ability to run with some other programs to be used under experimental paradigm in the context of UC-8. Technical specifications of the Emotiv Epoc Flex Gel headset are given in Table 6.

Table 6: Emotiv Flex specifications

No. of Channels	32 (plus CMS/DRL references)
Channel names	Configurable on standard 72 channel international 10-20 locations.
Sampling method	Sequential sampling. Single ADC
Sampling rate	128 SPS (1024 Hz internal)
EEG Resolution	14 bits 1 LSB = 0.51μV (16 bit ADC, 2 bits instrumental noise floor discarded)
Max Slew Rate	32.64uV/sample (Compression required for BLE data transmission)
Bandwidth	0.2 - 45Hz, high attenuation at 50Hz and 60Hz
Filtering	Built in digital 5th order Sinc filter
Dynamic range (input referred)	+/- 4.12 mV
Coupling mode	AC coupled
Connectivity	Proprietary 2.4GHz wireless, BLE(coming soon)
Battery Capacity.	LiPo battery 595mAh
Battery life (typical)	6-9 hours
Impedance Measurement	Real-time contact quality using patented system
IMU Part	ICM-20948 3-axis Accelerometer, 3-axis Gyroscope, 3-axis Magnetometer. Data Output 10 channels Quaternions, (Q0, Q1, Q2, Q3), Acceleration (X,Y,Z) and Magnetometer (X,Y,Z)
Motion Sampling	16 Hz
Motion Resolution	8-bit Output
Sensor Material	Sintered Ag/AgCl (EPOC Flex Gel model) can be used with any EEG gel Electroplated Ag/AgCl (EPOC Flex Saline models) with replaceable polyester felt pads that can be sterilised and re-used (bulk pack available for separate purchase)

2.3.7 EMG Sensors

Another possible sensor to be used in UC-8 are EMG sensors. EMG sensors can be used to collect signals transmitted over muscles. EMG signals will be analyzed together with EEG signals to investigate data in the data fusion context. This physiological signal will also be applied via UC-8 requirements. Possible EMG sensors and amplifiers and its requirements are given in Table 7.

Table 7: EMG sensors / amplifiers specifications

Specification	Wireless / Wired EMG Amplifier
Bandwidth	10 – 250, 470, 950, 5000Hz
CMRR @ 60 Hz (dB)	> 96 dB (typically 110 dB)
Input Impedance	>100 MOhm
Accuracy	+/- 1.5%
Noise	‹ 5μV

2.4 Contribution of THALES and FORTH

2.4.1 UC16: AI enhanced production and performance of RF transceivers for civilian SATCOM and radar applications (THALES, FORTH)

The activities regarding Use Case (UC)-16 are performed by the close collaboration between THALES and FORTH. The major focus in UC-16 is to properly apply AI techniques in a way that will offer an overall improvement in the manufacturing throughput and sustainability of RF components and system utilized in avionic radars and related high-power communication applications. Regarding the activities related to WP1, the two teams are focusing on developing sensors that could be co-integrated with the transmitting/receiving (TRX) modules. For these modules there exist two aspects that should be considered during their operation. The one is related to the thermal effects stemming from the high RF power levels generated by the High-Power Amplifier (HPA) and the other one is the potential RF leakages that could damage the devices (e.g. the Low Noise Amplifier, LNA) that are not designed to or are not expected to deal with these high power levels. For continues monitoring of the temperature in the vicinity of the high-power devices, surface acoustic waves (SAW) type temperature sensors are considered whilst the so-called mini-MEMS will be developed and utilized for detecting potential RF leakages. Once these devices will be fabricated, datasets that will be generated by the corresponding signals will be considered for developing machine learning based methodologies that could be useful for improving the performance and/or the reliability aspects of the TRX modules.

The mini-MEMS based RF leakage sensors activity is mainly performed by the THALES team. The RF-sensing capability of the mini-MEMS is relying on the self-actuation phenomenon. This refers to the condition where the equivalent attractive force induced by the RF signal itself is sufficient to actuate the MEMS switch without the application of a DC voltage. Self-actuation typically occurs during the high-power operation of RF MEMS and is considered as an undesirable effect and overall constitutes a reliability issue that should be carefully considered during fabrication. This is because the self-actuation limit defines the maximum power level that can be effectively handled by the switch. For a typical configuration of a shunt capacitive switch the self-actuation occurs when the equivalent bias induced by the RF signal and is $V_{eq} = \sqrt{PZ_o}$, (where P is the power level and Z_0 the characteristic impedance) becomes greater than the pull-in voltage. This relation between the power level and the equivalent induced bias may depend on various parameters for the different types of RF MEMS switches.

In contrary to this approach, within the UC-16 and for sensing potential RF leakages, the self-actuation phenomenon should be considered not as undesirable but rather as the favorable one that will be utilized in the design of the mini-MEMS sensors. More specifically the mini-MEMS should be self-actuated and to isolate in this way from any RF signal that exceeds beyond the expected power level at the specific point of interest of the TRX module where the sensor will be placed. To effectively achieve this a sophisticated configuration in conjunction to careful design of both the mechanical and the microwave response of the mini-MEMS is required. This is the major activity that is presently in progress with regards to the mini-MEMS development. Once the design tasks will reveal the appropriate device configuration and details the suitable mini-MEMS will be fabricated and characterized. The latter is the activity to follow up after the present reporting period.

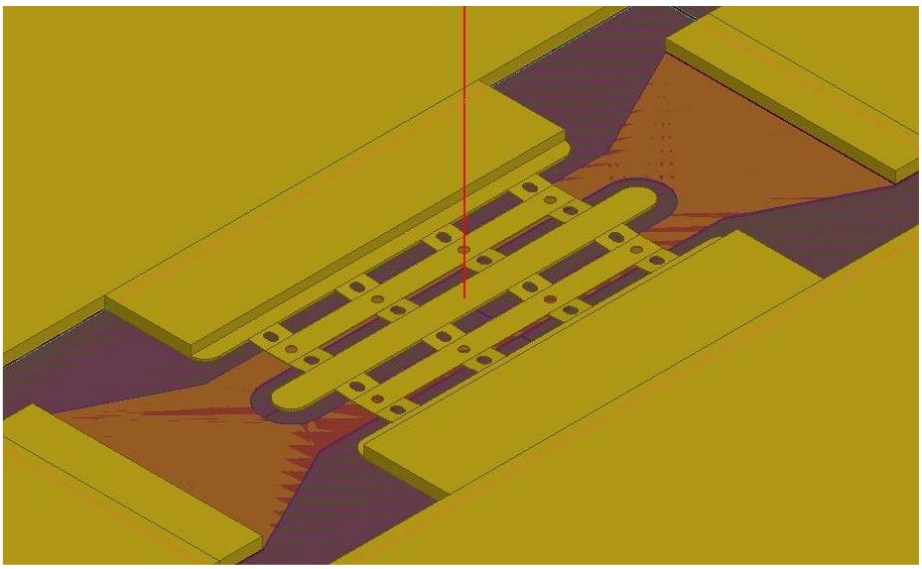

Figure 7: An example of the mini-MEMS design tasks considered for the UC-16

With respect to the thermal effects, always having an important role on the proper operation of high-power RF electronics, an activity related with SAW type temperature sensors has been considered for the UC-16 and is mainly performed by the FORTH team. The main idea about the temperature monitoring need stems from the fact that during the operation of the TRX modules, the HEMTs that are utilized for the HPA are inducing important heating effects as result of their high-current operation conditions. These thermal effects could be responsible for several undesirable phenomena not only for the active devices but due to dissipation even for the passive ones affecting the response at the output of the circuits as well as of the RF MEMS. Overall, due to these high-power conditions it is anticipated to induce an increase in the temperature of the TRX module chip. Therefore, the integration of sensors for the monitoring of the temperature on chip level is very important for understanding the impact of the thermal effects but also for designing if required proper mitigation actions.

The FORTH team has a good know how on developing SAW type temperature sensors and for this specific application, bearing in mind the various details of the UC-16, single resonator SAW structures has been selected. This type of SAW sensors is found to offer increased sensitivity for temperature monitoring over similar counterparts. The devices will be developed on the same substrate and in the vicinity of the heat-generating components but potentially also elsewhere. The temperature monitoring is relying on the monitoring of the shift of the resonant frequency obtained in the reflection coefficient (S_{11}) for an incident signal in the microwave frequencies. In brief this could be expressed by the following equation

$$TCF = \frac{1}{f}\frac{df}{dT} = \frac{1}{v}\frac{dv}{dT} - \frac{1}{L}\frac{dL}{dT} = \frac{1}{v}\frac{dv}{dT} - \alpha$$

where TCF is the temperature coefficient for frequency, f is the frequency, v is the sound velocity, T the temperature, α the expansion coefficient of GaN and L is the distance between IDTs (Interdigitated Transducers).

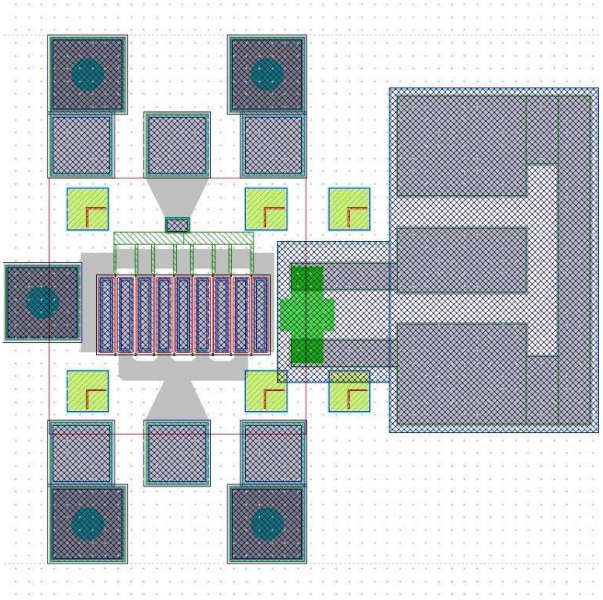

Figure 8: An example of the SAW type temperature sensors configuration and topology considered for the UC-16

During this reporting period, the FORTH team is focusing on designing and choosing the appropriate configuration for the SAW type temperature sensors (e.g. the IDTs details) as well as effort is placed for preliminary mask design with an example presented in the figure above. Soon the FORTH team will commence with the fabrication of SAW devices on the same substrates with the active components.

2.5 Contribution of AIDI and Cetto

During the months of the project, the primary focus has been on Work Package 1. This work package centers around the development of use cases for specific requirements. Specifically, the project has concentrated on formulating requirements for the AIMS 5.0 approach, which involves visualizing the digital twin in the context of simulation and virtualization. To achieve this, relevant content from the domains of production and logistics, as well as existing manufacturing systems employed by Company Cetto.

The process began with a thorough analysis of injection molding machines, emphasizing their properties and efficiency. This analysis was conducted using the Papyrus tool to create block diagrams. Subsequently, the initial step of the approach, comprising six distinct stages, was embarked upon. In the upcoming phases of the project, both Cetto and AIDIGI will collaboratively focus on defining functions, architecture, validation, testing, and usage phases of the MAGIC approach. The objective is to utilize the MAGIC Tool to systematically implement the generated data and information in a holistic manner.

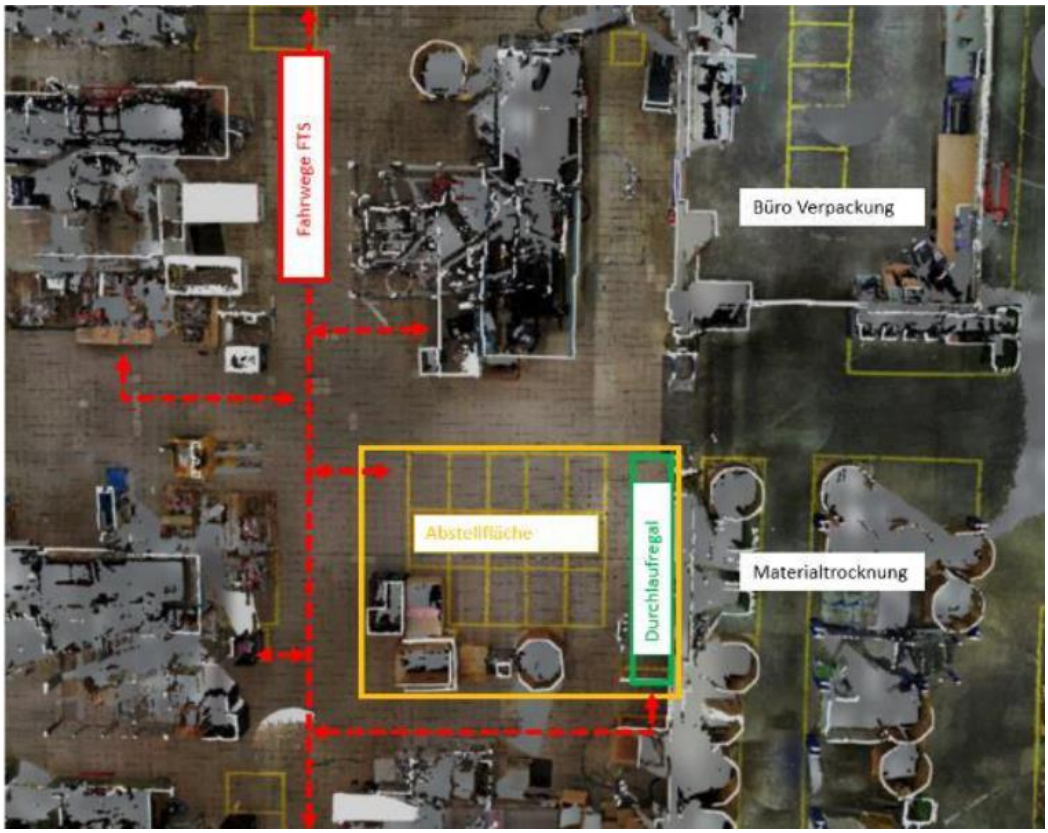

Figure 9: Robot Transportation and route optimization.

2.5.1 Requirement detection and definition

In this section, the different requirements which are relevant for AIMS 5.0 have been defined based on a SysML Model created with the tool papyrus. Papyrus is an open-source UML2 tool based on Eclipse and licensed under the EPL. It has been developed by the Laboratory of Model Driven Engineering for Embedded Systems (LISE) which is a part of the French Alternative Energies and Atomic Energy Commission (CEA-List).

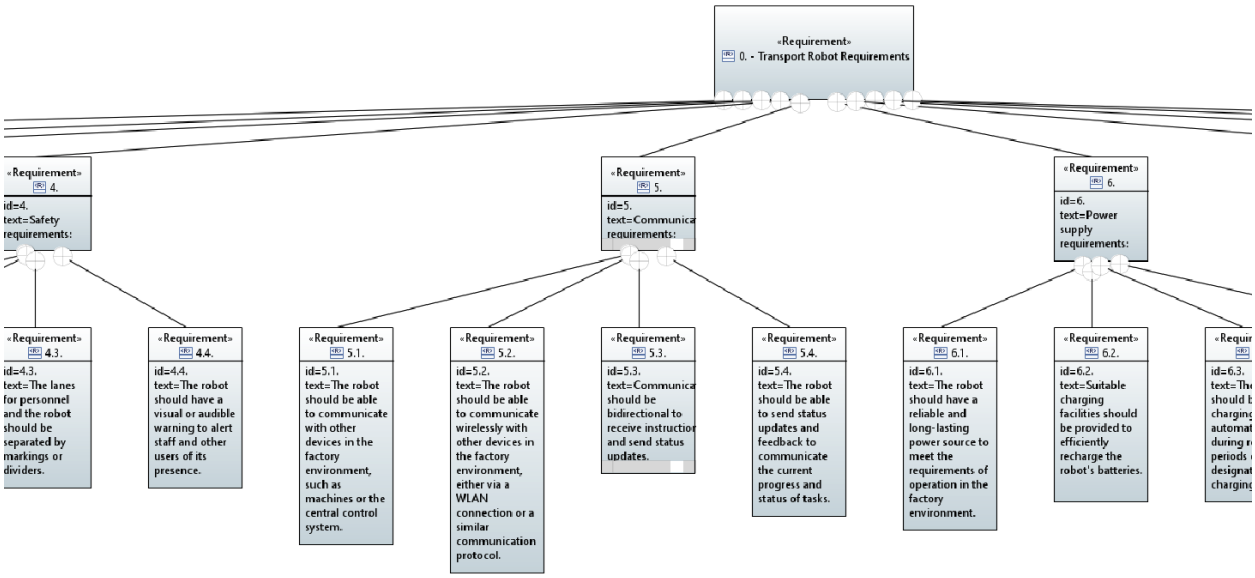

Figure 10: SysML Model for the requirements based on Papyrus

Papyrus can either be used as a standalone tool or as an Eclipse plugin. It provides support for Domain Specific Languages and SysML. Papyrus is designed to be easily extensible as it is based on the principle of UML Profiles.

2.5.2 Definition of the Requirement List

Table 8: Requirements list

1.		**Navigability requirements:**	
	1.1.		The robot should be able to safely navigate the factory environment and avoid obstacles.
	1.2.		The robot should be equipped with sensors to recognize position markers and direction markers.
	1.3.		The robot should be programmed with the possible routes.
	1.4.		There should be a precise location function to reliably position the robot.
	1.5.		The robot should be able to operate autonomous in the factory environment.
	1.6.		The robot should be able to operate even on humid and oily surfaces.
	1.7.		The robot should be able to operate in bright sunlight.
2.		**Size and load capacity requirements:**	
	2.1.		The dimensions of the robot should be such that it can easily navigate through the work areas of the factory environment.
	2.2.		The robot should be able to transport the desired materials and products and have sufficient load capacity for the specific requirements of the factory environment.
	2.3.		The robot should have adaptable gripping or holding mechanisms to transport and hold the objects safely.
3.		**Flexibility requirements:**	
	3.1.		The robot should be able to transport different types of objects, including different sizes and shapes.
	3.2.		It should be possible to programme and adapt the robot for different transport tasks.
4.		**Safety requirements:**	
	4.1.		The robot should be equipped with sensors to avoid collisions and protect workers from injuries.
	4.2.		There should be an emergency stop function to allow immediate shutdown of the robot in emergencies.
	4.3.		The lanes for personnel and the robot should be separated by markings or dividers.
	4.4.		The robot should have a visual or audible warning to alert staff and other users of its presence.
	4.5.		The robot should be impervious to humidity and water.
5.		**Communication requirements:**	
	5.1.		The robot should be able to send status updates and feedback to communicate the current progress and status of tasks.

	5.2.		The robot should be able to communicate wirelessly with other devices in the factory environment, either via a WLAN connection or a similar communication protocol.
	5.3.		The robot should be able to communicate with other devices in the factory environment, such as machines or the central control system.
	5.4.		Communication should be bidirectional to receive instructions and send status updates.
6.		**Power supply requirements:**	
	6.1.		The robot should have a reliable and long-lasting power source to meet the requirements of operation in the factory environment.
	6.2.		Suitable charging facilities should be provided to efficiently recharge the robot's batteries.
	6.3.		The robot should be charging automatically during rest periods or at designated charging points.
	6.4.		The robot should be run energy-efficient, during rest periods there should be a special energy saving program.
7.		**Requirements for the Integration with existing infrastructure:**	
	7.1.		It should be possible to integrate the robot into the existing factory environment, including communication with the existing control system.
	7.2.		It should be possible to synchronise the robot with the existing plant and machinery.
	7.3.		There should be clear documentation of interface requirements and communication protocols to ensure smooth integration.
8.		**Maintenance and support requirements:**	
	8.1.		The robot manufacturer should provide support for installation, maintenance and troubleshooting.
	8.2.		Spare parts should be readily available, and the manufacturer should provide effective technical support to resolve any problems quickly.
	8.3.		If necessary, training should be provided for operators and maintenance technicians to ensure that staff can use and maintain the robot effectively.
9.		**Cost requirements:**	
	9.1.		The cost of purchasing, implementing and maintaining the robot should be within the given budget.
	9.2.		A cost-benefit analysis should be carried out to assess the added value of the robot to the factory environment.
10.		**User requirements**	
	10.1.		The robot should be user-controllable via a wireless control panel.
	10.2.		Tasks that the robot has been assigned should only be able to be cancelled by users with a higher level.
	10.3.		Only trained staff should be able to assign tasks to the robot.
	10.4.		It should be possible to assign different user levels to the users who can interact with the robot.

2.5.3 The Robot platform used by Cetto

The MiR100™ [1] is an autonomous mobile robot for transportation applications within manufacturing plants, hospitals, warehouses and many other commercial and industrial environments. The user sets the destination for the goods to be transported via a web-based user interface. The MiR100™ can be programmed with a fixed route, be available on call or carry out special tasks (missions). It can also act as part of a MiR robot fleet that is centrally controlled by a single web-based user interface. MiRFleet should always be used when two or more robots are operating at the same site. The MiR100™ operates from a map that can be programmed when the robot is first used can be programmed. During operation, safety scanners ensure that the robot avoids robot avoids obstacles (people, furniture) that are not shown on the map. In The internal map shows specific locations (office, product delivery, factory floor, etc.) that can be used for logistical planning can be used for logistical planning. When using a MiRCharge™ charging station, the robot searches for the charging station independently. All you need to do is create a charging mission and specify a charging point on the map be specified on the map.

2.6 Contribution of GUT

GUT will prepare a dedicated gateway for wireless communications, aimed to maximize the connectivity with wireless sensors and actuators. This will be done by integrating selected edge device with smart antenna which radiation patterns can be externally controlled. The control will be performed within the edge device, which needs to be equipped with sufficient computational power to perform analysis of received signal and control the beam accordingly. For the edge device, an industrial-graded edge computer provided by TTTech will be used.

For the antenna, the Electronically Steerable Parasitic Array Radiator (ESPAR) antenna will be chosen. It is a structure consisting of 12 passive elements and the one active monopole in the center of the ground plane being the top layer of the printed circuit board (PCB) base. In the design shown in Figure 11, the described topology is shown along with numerated passive elements.

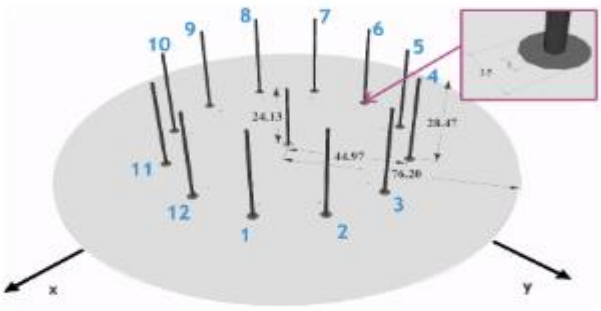

Figure 11: Topology with Numerated Passive Elements

The active element (the central one) is fed by an SMA connector, while the parasitic components can be connected to the ground or opened by the single-pole, single-throw (SPST) switches connected to the end of each of them at the bottom layer of the structure. The reflectors are the parasitic elements and are responsible for reflecting energy, while the opened elements are named directors, so that the electromagnetic wave can pass through. Considering that functionality, the overall possible configurations of ESPAR antenna are 4096, what enables versatile, fast beamforming properties.

All of the smart antenna's switches are controlled by gold pin connectors (Figure 12), allowing independent opening, and short-circuiting of steering components, which can be denoted as steering vectors $V_{steering} = [V_1, .., V_{12}]$.

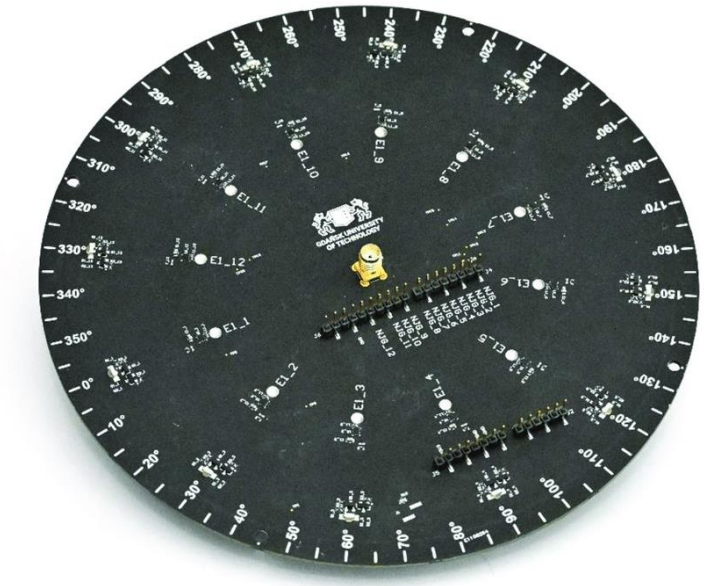

Figure 12: Smart Antenna's Switches

Such a design extends the possibilities of controlling the device using a relatively simple microcontroller (e.g., Raspberry Pi, Arduino, Particle) equipped with GPIO pins and UFL/SMA ports for connecting the RF. In addition, the design improvement process led to the introduction of I²C interface control capabilities.

The example radiation pattern gain for steering vector $V_1 = [111110000000]$, which result in maximum power propagation for $90^{\circ}$is shown in Figure 13.

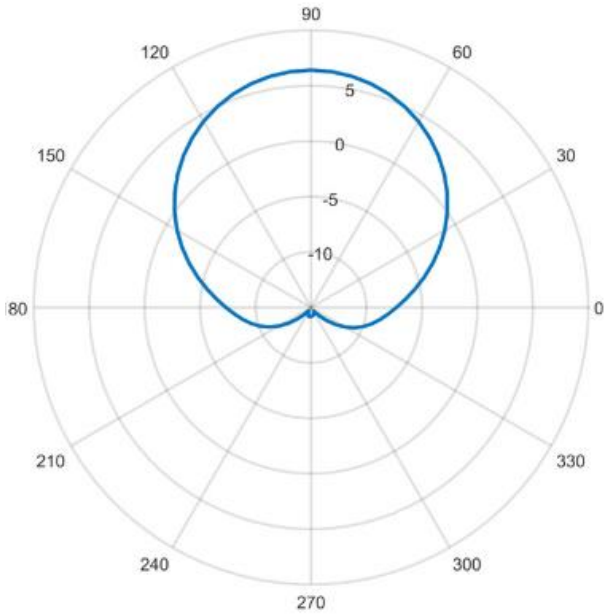

Figure 13: Radiation Pattern

By choosing the optimal radiation pattern, it is possible to increase the connectivity with one or more devices by selecting the pattern of the maximum gain towards those receivers. At the same time, the pattern for minimizing the sources of noise can be selected. Thus, the aim is

to maximize the Signal-to-Noise ratio in a situation where the positions of other communication devices are unknown. This needs to be done as effectively as possible.

In terms of ESPAR antenna capabilities and versatile behaviour, together with the adjacent edge device, it is a powerful instrument for wireless communication that increase the efficiency of data transfer, especially in changing, difficult propagation conditions, such as factories or farms.

2.7 Contribution of Signify

Signify works on End-to-End digitalization of its manufacturing workflows, aiming at optimizing Operational Excellence and people welfare.

AI based anticipation of anomalies in the E2E manufacturing flow is the selected use case for advanced sensing and data analysis. We focus on (still mainly manual) assembly processes, for the fabrication of luminaires.

Based on earlier findings we believe that the 'best' solution for monitoring process execution, parts and assets (BOM and equipment) and human (activities) is camera vision (ground truth sensing). The camera vision is supported by Computer Vision algorithms (ML and AI) for deducing deviations/deltas versus the ideal situation. This might be used for quantification of, e.g., TAKT times for processes, detection of mistakes (e.g., using wrong parts or incorrectly execution of process steps, etc.).

By tracking the process execution in real-time we can provide guidance to the operators, such that deviations (mistakes) can be observed immediately, and information can be given to the operator for an instantaneous correction. So, not only yield loss is prevented but also human satisfaction is achieved.

Our baseline technology choice are ceiling- or tripod-mounted cameras. The set-up for data capturing and data processing requires the following specification for the camera: at least 2MP, 25-30 fps, with C-mount lens to adjust the field of view and focus. The resolution depends on the field of view of the camera and the camera mounting height. Pixel size should be about 0.266 x 0.266 mm. Data processing is with a PC- Lenovo workstation P520c, 8 core, 32 RAM or equivalent Nvidia graphics card, 12 GB onboard memory (GeForce RTX 4070, RTX 3060 etc.)

Having remote cameras is a preferred unobtrusive method, as compared to alternatives like camera-goggles or body-worn cameras. We realize that visual data of people can lead to privacy objections, so we have already introduced and tested methods to convert images into hand features (skeleton) information, using integrated AI algorithms. This function can later be integrated in the camera electronics for edge processing. An example of such conversion is shown in Figure 14 that shows the conversion for a hand tracking function interacting with a product part:

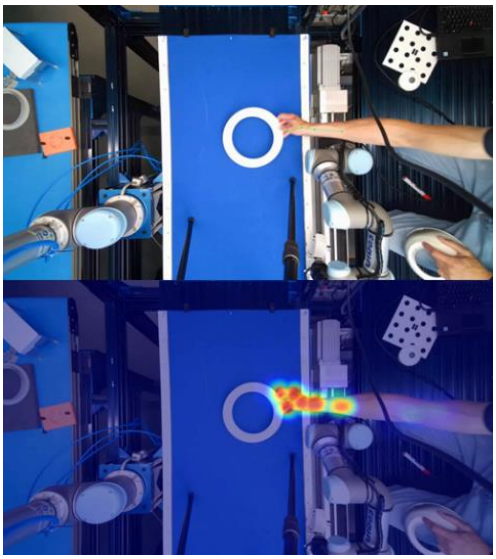

Figure 14: Conversion for a hand-tracking function

Worktable and hand actions are preselected by cropping of the images and videos, for further reducing privacy issues.

We also need tracking of the parts that are assembled along a process flow. Part tracking is for now done locally but could be migrated to the cloud on Microsoft Azure or Amazon Sagemaker.

At this time, we still have sequential capturing and processing (in our lab studies), but in a later stage before we deploy the technology to a (pilot) factory we will explore how to replace the workstation PC by an edge- and cloud-based solution. This should then also provide the required privacy measures.

Also, to be studied are solutions to 'match' the tracking tools for parts, assets and human actions into one integrated tool. And find out whether we need multiple cameras on a workplace to capture all required visual data (as sometimes line-of-sight might be blocked, the use of algorithms for sparse/missing data processing might be required).

As a fallback scenario, if it would turn out that either the use of computer vision is too computational-extensive or if technical feasibility is not reached, we would like to study other sensing modalities as well, either single-modality or mixed-modality (sensor fusion). Candidate sensing technologies are, e.g., RADAR, thermal cameras, pixelated thermopile. Preferably drop-in sensor modules for industrial monitoring are considered: small/unobtrusive, wireless (WiFi, Zigbee), autonomous, with easy commissioning, connected to an IoT platform (Signify's Interact platform). For this we reach out to AIMS5.0 partners in the consortium.

Algorithms for the vision-based data processing (and possibly data from the optional other modalities) are co-developed in WP2. That work is reported in WP2.

2.8 Contribution of UzL

Neural networks, particularly Deep Neural Networks (DNNs), have gained significant popularity during the last decade. They do not need feature extraction expertise and deliver better accuracy than classical Machine Learning (ML) methods.

Field Programmable Gate Arrays (FPGA) are well known for their flexibility and ability to deliver high performance with lower energy consumption. Therefore, exploring FPGA architectures and their building blocks for DNN acceleration provides valuable insights for researchers and industry specialists designing FPGA-based deep learning accelerators. However, the increasing size and complexity of DNN architectures have led to higher computation and memory requirements, making it challenging to deploy them efficiently on resource-constrained devices such as FPGAs.

Almost 120 FPGA-based deep learning accelerators have been collected and investigated based on the state of the art of the past five years as shown in Figure 15. The aim is to gain deep knowledge about building an FPGA-based accelerator and the most prominent techniques to deliver the highest performance. Consequently, this knowledge should assist researchers and specialists in making informed decisions when selecting appropriate accelerators or techniques for accelerating their DNNs. Nearly 63% of the surveyed accelerators utilize integer datatypes for representing weights and activations. Specifically, INT-16 and INT-8 are favoured due to their excellent trade-off between accuracy, energy efficiency, and computational density, as illustrated in Figure 15.

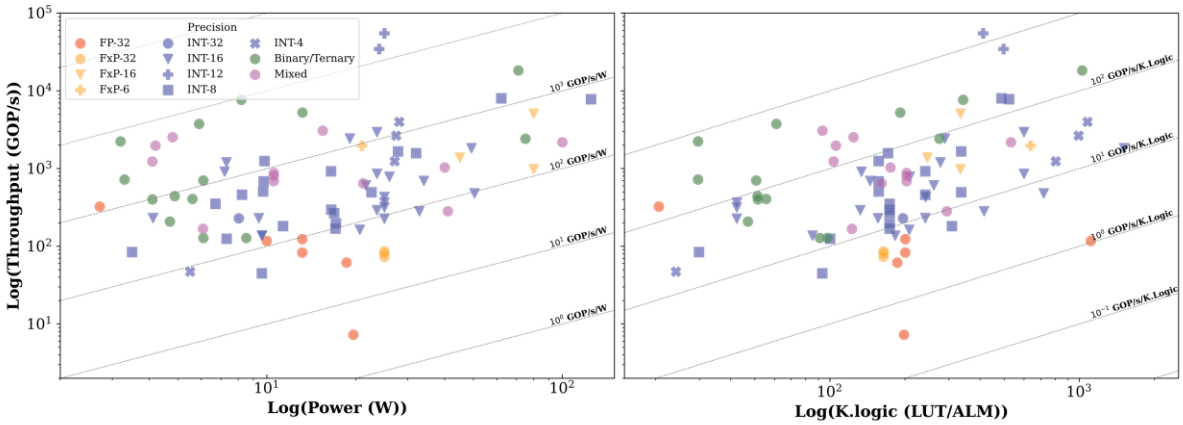

Figure 15: Energy efficiency (left side) and logic density (right side) plots of FPGA-based DL inference accelerators [2].

Specific acceleration criteria are crucial in designing an FPGA-based DNN inference accelerator. Standard criteria that exist for acceleration are inference throughput and energy efficiency. These criteria facilitate the comparison of hardware designs across different FPGA technologies.

Inference throughput is one of the primary acceleration criteria for FPGA-based DNN inference accelerators. Model-simplification techniques such as quantization and pruning, as well as parallelization, are commonly used to increase the peak performance of DNN inferences. Through experiments, it has been shown that increasing the reuse factor (reuse factor is referred to as parallelization. The lower it is, the better.) leads to a decrease in throughput, while increasing the pruning ratio improves the inference speed. Quantization affects the inference throughput in that it decreases with the increased bit-width representation of both model parameters. Figure 16 shows the pruning, quantization, and reuse factor effects on the throughput of proposed ResNet- and LSTM-based accelerators.

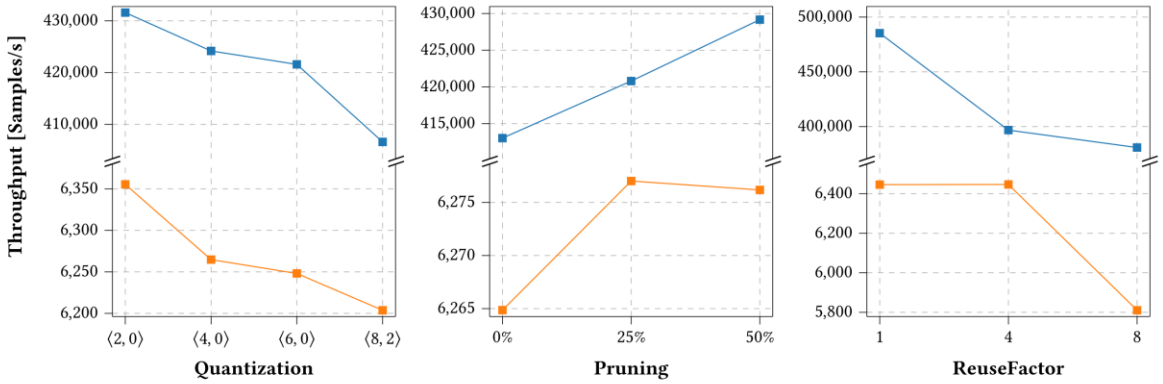

Figure 16: Quantization, pruning, and parallelization effects on inference throughput for LSTM(Blue Line) and ResNet- 2 (Orange Line) [2]

Energy efficiency is another crucial criterion for FPGA-based DNN inference accelerators. Quantization has been shown to improve energy efficiency by reducing the storage size of model parameters. Furthermore, binarized and ternarized models suffer from notable accuracy loss and hardware underutilization, prompting further research into harnessing BNN capabilities for FPGA-tailored DNN architectures. Figure 17 shows the effect of such techniques on energy efficiency.

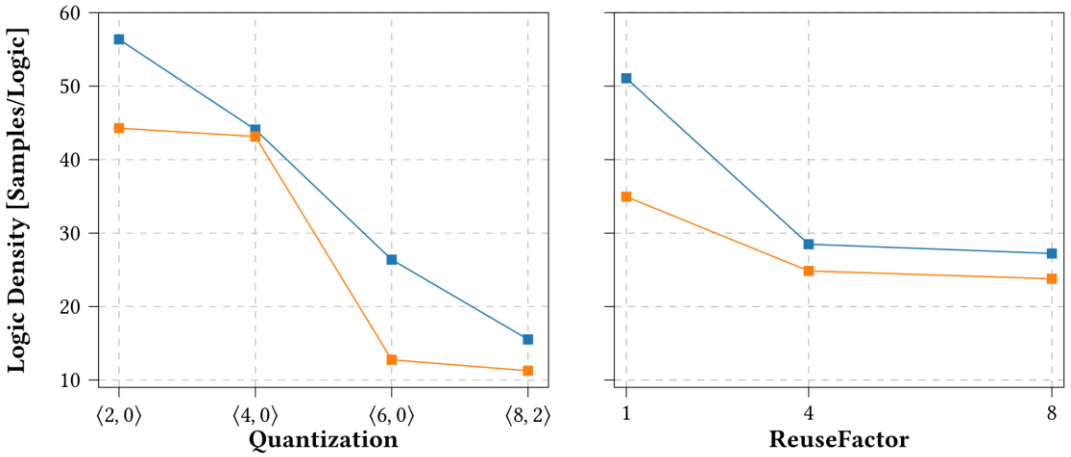

Figure 17: Quantization, Pruning, and Parallelization effects on energy efficiency for LSTM (Blue line) and ResNet-2 (Orange line) [2].

Computational density is a critical metric in FPGA design, representing the ratio of computations performed by a design over the number of resources utilized. It indicates whether the hardware design suffers from resource underutilization. The use of reduced bit-width representations increases the logic density, and highly parallel designs are characterized by higher logic density. Additionally, the impact of quantization and parallelization on logic density is discussed, with the reuse factor affecting logic density and potentially leading to resource underutilization. Figure 18 demonstrates the effect of quantization and parallelization on the logic density.

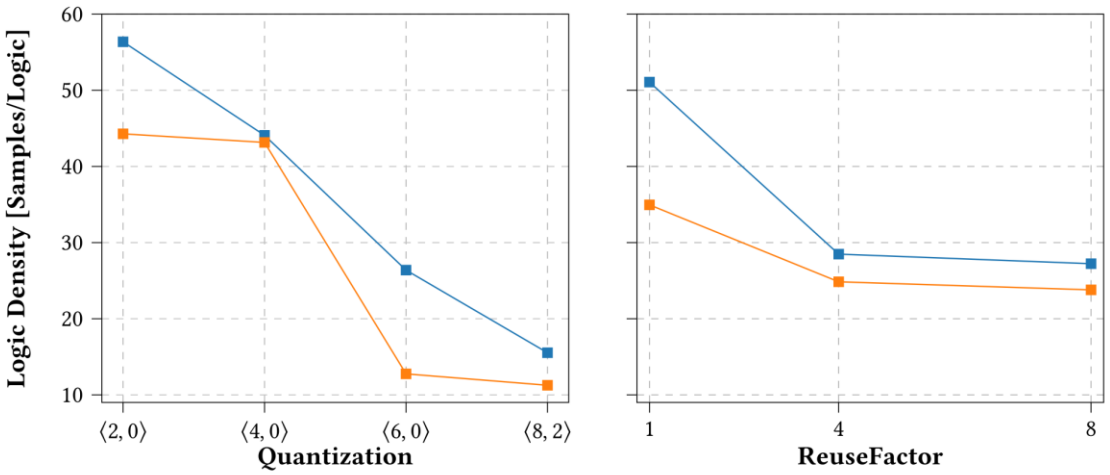

Figure 18: Quantization and Parallelization effects on computational density for LSTM (Blue line) and ResNet-2 (Orange line) [2].

Our analysis work was published as a peer-reviewed survey in the prestigious Journal ACM Transactions on Reconfigurable Technology and Systems [2], serving as valuable input to our WP1-related work.

3. WP1 Questionnaire

3.1 Questionnaire Summary

In WP1, aligning with your mission and goals, we've designed a questionnaire comprising six questions in order to determine general requirements. Eleven partners, including TTTech, IFAG, AIDI, Ideko, SU, NXP, and Signify, TUD, Gdansk, Stream Analyze Sweden AB, TÜBİTAK, GOIMEK, SORALUCE, SAVVY, and HOST have shared their responses. A summary of these answers is provided below.

1. What are your requirements and limitations for selecting hardware?

Edge Computing Platform Requirements:
The selected hardware for the edge computing platform must fulfill specified criteria set by partner GUT for their smart antenna, encompassing aspects like performance, interfaces, operating system, and ease of integration.

Computational Power and Interfacing:
The hardware should possess ample computational power for quick data analysis and action execution. Additionally, it must meet smart antenna requirements for interfaces such as Ethernet, GPIO, I2C, and RS422.

Semiconductor Components Demands:
IFAG FE Regensburg is actively involved in advancing sensor system solutions to ensure safe and error-free operation of various semiconductor transport components. The focus includes contamination class, allocation, condition, reliability, security, energy efficiency, and interfaces for edge or cloud deployment.

Functional Support and Integration:
The hardware is expected to support functions like Human Classification, Hand Gesture Recognition, and Human-like Interaction based on Explainable AI. Robust integration and compatibility with a 2.4GHz quad-core 64-bit Arm Cortex-A76 CPU are essential.

SWAP-C for AGVs:
The hardware is primarily associated with computer vision (cameras), but there is openness to incorporating other sensing functions capable of tracking parts, products, activities, and people.

2. Describe the challenges/issues/problems to be solved in a few sentences.

Interfaces and Performance Discussions:
Current interfaces are satisfactory, but discussions regarding performance, hosting AI applications, and related matters are ongoing.

Computational Power and Wireless Communication:
Computational power may pose a challenge, though the risk is low. Selection of a wireless communication protocol is pending.

Sensor Technology Challenge:
The primary challenge is ensuring the suitability and stability of sensor technology for high-automation processes. Existing transport components must remain unchanged for manufacturing and local requirements.

Challenges in AI System Development:
Developing complex AI systems presents challenges, including inefficient hardware setups and potential misalignment between edge and cloud components.

Human-like Interaction and Multi-Domain Integration:
Defining human-like interaction is subjective and application-dependent. The focus is on multi-domain integration solutions, expanding from the machine tool industry to electrical equipment.

Localization Challenges and Sensor Fusion:
Indoor localization with limited GNSS access is required. Lighting conditions can affect perception sensors, and sensor fusion methods will be adapted to address these challenges.

Human/Machine Interface Preference:
Non-obtrusive technologies are preferred, particularly for remote technologies like camera vision, to avoid disrupting operators on an assembly line.

3. Which hardware will pass all requirements?

Various components, including the Programmable Array Logic (PAL) chips and potentially other sensors, XMC2GO evaluation board with XMC1100 and XMC2400 microcontrollers, are under consideration for Sensor, Processing, Control, and AudioVisual subsystems.

Also, the compatibility of Raspberry 5 with IoT system firmware and software is under evaluation.

4. How many hardware platforms can you choose based on your limitations and requirements? And which ones are they?

- Jetson Nano (T1.2)
- Coral TPU (T1.2)
- BRAINE’s Edge Micro Data Centers (EMDCs)

5. Do you need further collaboration for your use cases, and if so in which ones and to what extent?

IFAG is in the process of aligning with WP2 and WP3, specifying interactions and interfaces between WP1 components, AI algorithms from WP2, and the cloud infrastructure developed in WP3 (T1.1). Also, they are currently developing an AI-driven solution to analyze rollover

frequencies of bearings and detect different types of damage. This initiative is part of WP6 Subtask 6.3.4 and UC13/14.

In SU, collaboration with WP5 and WP6 is centered around defining hardware and software requirements for WP1 components based on use case specifications. Adjustments and optimizations will be made based on evaluations from WP5 and WP6 (T1.1). Also, they are considering a collaboration with partner TUBITAK.

NXP plans to collaborate with WP2 for algorithm integration in the use case and with WP4 to utilize the open access platform within the use case.

Signify is actively looking for additional partners in computer vision, particularly those involved in hardware and AI tools.

4. Conclusions

Moving forward, the trajectory of our efforts in D1.1 will be concentrated on the development of AI-enabled electronic components and systems tailored for sustainable production.

This deliverable centres on compiling and analysing the reports provided by our partners, detailing their research into HW, and sharing updates on their progress. Notably, these reports have catalysed collaborative initiatives among certain partners to jointly develop sensors and hardware solutions.

Over the past nine months, all partners have collaborated extensively to identify their needs and constraints, conducting surveys on hardware options and selecting appropriate sensors and devices accordingly. With this groundwork laid, partners have proceeded to test their hardware and finalize their processes.

Reviewing the reports received from all 10 partners indicates positive progress in their assigned tasks. Also, it's important to note that NXP and TIAG partners did not have any HW exploration essential for assembling their reports for the first delivery.

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[2] Nechi, A., Groth, L., Mulhem, S., Merchant, F., Buchty, R. and Berekovic, M., "FPGA-based Deep Learning Inference Accelerators: Where Are We Standing?," *ACM Transactions on Reconfigurable Technology and Systems,* vol. 16, pp. 1-32, 2023.

6. Appendices

6.1 Appendix A - Abbreviations

Table 9: Abbreviations

Abbreviation	Meaning
AIMS5.0	Artificial Intelligence in Manufacturing leading to Sustainability and Industry5.0
AI	Artificial Intelligence
AMR	Autonomous Mobile Robot
DL	Deep Learning
DNN	Deep Neural Network
EEG	Electroencephalogram
EMG	Electromyography
ESPAR	Electronically Steerable Parasitic Array Radiator
FPGA	Field Programmable Gate Array
HW	Hardware
ML	Machine Learning
PCB	Printed Circuit Board
RF	Radio-Frequency
RF MEMS	Radio-Frequency Microelectromechanical System
TTMS	Task And Traffic Management Station
UC	Use Case
WP	Work Package