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Smart Material Delivery Unit for the Production Supplying Logistics of Aircraft

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Abstract

Despite recent advantages, internal logistics for aircraft production is mainly performed manually. Missing or wrongfully loaded components can cause costly delays. Transforming delivery units into smart participants of a digitalized logistic chain has the potential to avoid such delays. In the scope of this work, we present a concept of a smart delivery unit for use in intralogistic processes on aircraft production sites. Its main functionality, the detection of loaded components and material, handles a high variety of identification principles that are defined by pre-existing processes. We therefore conceptualize smart sensor boards. Through a novel modularity structure, demand-driven equipment of these boards with different sensor types can be achieved. This includes AI-based, visual detection of components on delivery units. We display the versatility of our concept with a practical implementation based on low-cost sensors and demonstrate how our approach leads to demand-driven delivery units.

Keywords: Smart Delivery Unit; Production Supplying Logistics; Aircraft Production; Industry 4.0;

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1. Introduction

Characteristically, aircraft production processes are designed for lot-size one production and defined by the high numbers of different components, as single modern aircraft contain up to several million components. General transformation towards digitalized and automated processes in this domain is considered challenging due to the resulting need for high flexibility and versatility of digitalization solutions [2]. In the scope of this work, we consider the internal and production supplying logistics of a large European aircraft OEM. The transport of components with delivery units is an essential aspect of that logistic chain [15]. However, due to manual errors, wrongful loading of those delivery units occurs that can cause costly delays. With identification and tracking of loaded components throughout the internal logistics procedure, such errors may be avoided. In order to enable delivery units to gather this kind of process information and to integrate them into a global digitalization solution, they have been transformed into smart participants [17]. However, with the high variability of components and follow-up processes in aircraft production, existing concepts for smart delivery units [9] do not meet the special requirements of this application domain.

We therefore aim to introduce a different approach towards smart delivery units, that takes a broad range of applications into consideration. This in turn requires different sensor types that have to be integrated into a smart delivery unit concept. To obtain this variability, we develop a modular concept that allows demand-oriented equipment of smart elements into a single delivery unit. Although based on the demands for the production supplying logistics of aircrafts, we believe our smart concept to be transferable towards other domains, as this consideration of modularity allows for high integrability of the smart delivery unit in various digitalization strategies.

As OEM sites already contain up to several thousand delivery units, we consider the requirement of retrofittability for existing and standardized delivery units. Further, to minimize the costs for the smart equipment modules, we present a real integration with low-cost IoT components.

The work is structured as follows: We first conduct a process analysis of the aircraft production supplying logistics domain and derive potentials of smart delivery units. These potentials are then transformed into an integrative smart delivery unit concept for various identification processes, including AI-based

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object detection. Afterward, we present a real implementation of that concept.

2. Related Work

Due to their presence on production sites, delivery units have been the focus of various works aiming to digitize processes with delivery units. Similar to this work, designing such processes is often motivated by specific use-cases, such as white-goods [9] or automotive production [18, 7]. Although motivated by those use-cases, transferable benefits and concepts can be deducted. General use of smart and standardized containers and their benefit for efficient logistic procedures were discussed by [8]. The intelligent material shuttle as designed by [9] aims to integrate counting and automated registration of objects in a globalized MES. Four different identification concepts are developed, including technologies such as BLE, RFID, manual counters, and optical code readers. For automotive parts, [7] introduce and discuss an intelligent load carrier with various functionalities. Their concept includes identification of filling level, recording of environmental conditions as well as the detection of defects with the help of cameras or strain gauges. Apart from the delivery unit scale, smart intralogistics solutions exist for boxes. As such the *iBin*-concept [3] includes IR-cameras to monitor the filling level of small bulk-goods. A Similar concept, the *inBin* was discussed by [6].

Designing architectures and services for processes that resolve around smart delivery units, has been the focus of work from [11, 7, 18]. Based on functionalities of their developed intelligent load carrier, [7] developed a service system and workflow for process supervision as well as integration into a digitalized special load-carrier business model. Also addressing the challenge of smart special load carriers, [18] conceptualized an IoT-service architecture. This service architecture aims mainly to integrate Cyber-Physical-Systems (CPS) in the form of smart special load carriers, motivated by the use-case of automotive production. The developed services are transferable to different domains including aircraft production, as they represent approaches to integrate different Cyber-Physical Systems into logistic processes.

Designing modular load carriers with the specific need of the aircraft industry was addressed by [15]. They focused on transportation procedures with Euro containers. As they point out, they take up the bulk of internal transportation orders. Based on a process analysis, they derive a concept for connectable load-carriers, with which the packaging density of a single transportation movement can be increased significantly.

Addressing the problem statement of customized products in small batch sizes, [1] developed an intelligent material supply assistive system for manual working stations. They utilize intelligent systems to match identified material to manual assembly processes. Although this aims for a stationary system, concepts such as the event-based trigger of identification procedures can be incorporated for smart delivery units. Due to the high variability of transported components [2], the above concepts for smart delivery units are not directly applicable for the domain of aircraft production. As such, they often focus on marker or tag-based identification methods for components. However markerless identification of components through means of object detection has become increasingly popular in logistic environments [13]. We therefore aim to contribute a system, that includes functionalities of the above shown but is augmented with visual processing capabilities.

3. Process Analysis

Similar to [15] and without loss of generality, we base the following analysis on processes that were obtained with a large European aircraft OEM. We first describe typical use-cases for internal material flow. Afterward, transportation scenarios with delivery units are introduced. We then derive requirements and functionalities to enable the concept discussion about suitable identification technologies.

3.1. Intralogistic Material-Flow with Delivery Units

Aircraft are produced at low production rates. Due to the high number of components for a single aircraft and the need for flexibility, production supplying logistics is mainly done manually. Aircraft production is heavily supplier-based, with only few components manufactured by the OEM. Different material flow scenarios occur, the most important ones are indicated in figure 1. Suppliers usually deliver raw material, components, or entire modules to either an external warehouse or directly to the OEM production site. Before being routed into the final assembly line (FAL), some modules and components may be pre-assembled at a different station. This intralogistic production supplying transport between the warehouse, pre-assembly, and FAL is typically done with load carriers.

Among the different types of load carriers, standardized material delivery units as shown in figure take up the bulk of transport movements. The material is usually loaded in Euro containers. As shown by [15, 16], before reaching their final assembly station, those boxes are subjected to various re-loading processes throughout the entire transportation.

3.2. Potentials of Smart Delivery Units

The internal logistics chain is only very little digitalized and automated. Due to the low production rates and the need for flexibility, enabling digitalized processes is considered costly. With the generally low digitalization of the internal logistic procedure, potential benefits appear in abundance. We therefore strive to identify those potentials that can be achieved by means of low-cost technologies.

Four main groups and types of location-based services were identified that revolve around delivery units and that can be provided by a smart variant: (1) The **Detection and Identification of loading events** on a smart Delivery Unit can be formed into information for various process supervision tasks such as automated progress updates. Through identification of components, the correct loading of delivery units can be verified. With the

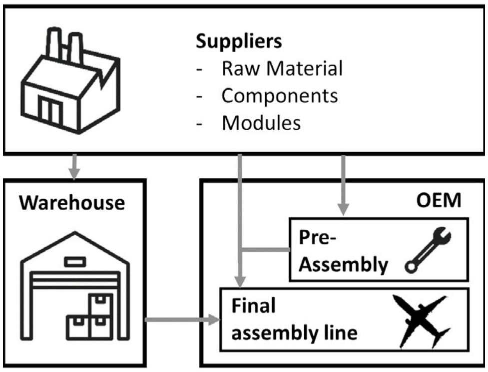

Fig. 1. Representation of material flow for aircraft production. Supplier provide various components and materials to either a warehouse or directly to the OEM site. As shown by [15], before being shipped to assembly sites, components are often re-packed and transported with delivey units.

high number of presented manual re-loading processes, avoidance of faulty loading condition, may prevent costly assembly delays; (2) Through a **localization** of the delivery unit [12] and knowledge about loaded components on that unit, in turn cascading localization information about the components can be derived. The exact position of delivery units on large production sites is often unknown. Providing this position enables selective and demand-driven locating of the units, e.g. for AGVs but also for human staff; (3) as material is mainly unloaded manually and unrestricted, faulty handling and unwanted withdrawal actions occur. With a digitalized authorization such process errors can be avoided and a correct **manual transfer** of material can be guaranteed. (4) through means of pose-estimation for loaded objects, **automated extraction** of material may be enabled.

To fully utilize a smart delivery unit, it has to be integrated into a globalized and digitalized process. As reviewed above, such appropriate service structures have been designed for other application domains. As our service system resembles the reviewed ones, we omit to detail its derivation. As shown in figure 2 we aim to utilize the identification potentials of the delivery unit, to detect loading events. Through identification of the components and comparison with the transport order, the correctness of the loaded unit is inferred. During consumption of the material, the personnel is expected to verify their authorization through appropriate human-machine interfaces.

In the following, we derive requirements and discuss technological concepts to realize a smart delivery unit.

3.3. Derivation of main requirements and functionalities

Out of the process analysis and presented use-case for a smart material delivery unit, we derive requirements and formulate the functionality scope of the delivery unit. Here, we present them grouped in four main requirements:

1. **variable identification procedures**: due to pre-existing concepts and solutions for material tracking, the smart delivery unit concept shall incorporate different identification principles. As such 1D/2D visual marker recognition and sensors for reading RFID/BLE tags are to be incorporated. Additionally, concepts for components that may not be tagged, are to be included.
2. **interfaces to humans**: to account for manual interaction and manual decommissioning processes, concepts for authorization of personnel are to be included. Additionally, a pick-by-light assistance system structure is to be included.
3. **independent operation**: the unit shall operate at least 10 hours independent from re-charging cycles. Through communication capabilities is each unit to be connected wirelessly with a globalized material handling system.
4. **cost-aware design**: as standardized units pre-exist on production sites, the concept is to be adaptable into a pure retrofittable solution. Low-Cost internet of things components are to be utilized, to minimalize hardware costs.

We now develop a concept for a smart delivery unit that meets these requirements.

4. Concept Development

To derive this concept, we first select suitable sensors that enable the above derived requirements. To gain this variability in tasks, various sensor solutions are needed. After the selection of those sensors, we present our novel concept for integration into the unit with a modular concept. To enable the AI vision processes, we briefly introduce a concept for synthetic training data. Afterward, we present the human-machine interface that enables manual interaction as well as the internal energy supply for the unit. Finally, we detail the retrofitability features for our concept.

4.1. Sensor selection for identification processes

Based on the requirements analysis, variable identification principles have to be met by the delivery unit: (1) marker based, (2) marker-less visual identification, (3) weight identification. To meet the requirement of cost-aware design, we aim to utilize low-cost sensors:

1. Material is tagged with either visual markers (1D/2D codes) or RFID/BLE tags. After reading the tag, components are identified through mapping of the marker ID and a manufacturer serial number. For 1D/2D codes we chose a *1D/2D Scanner module* from *Waveshare*. For RFID-tags the *M6E Nano* RFID-reader from *Sparkfun* is chosen. An *Espressig ESP 32* is used as BLE sensor.
2. for components that may not be tagged due to process demands, visual object identification can be used to identify the object types. As shown by [13], AI-based visual object detection of components in intralogistic environments, is a suitable identification method. For basic classification tasks, we chose an RGB ESP-32 cam. For pose-estimation tasks depth information is needed and we chose a *Intel L515* cam. As processing unit we chose a *Raspberry Pi 4*.

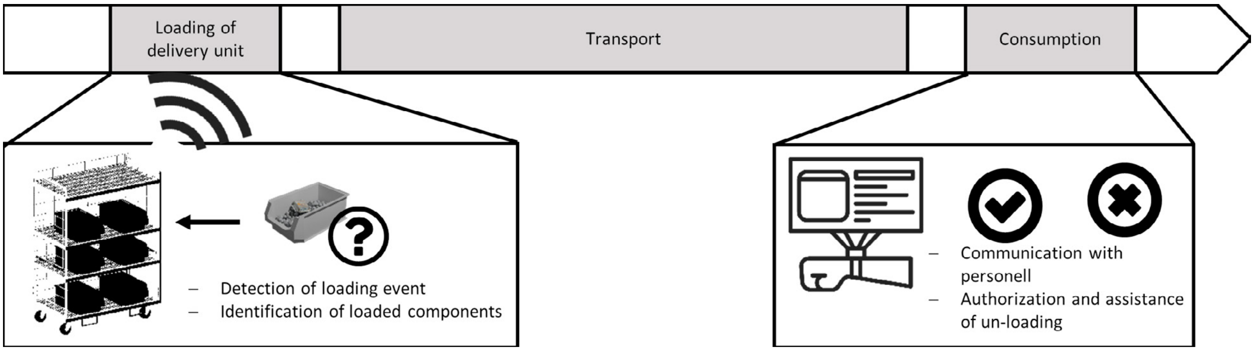

Fig. 2. Integration of smart delivery unit functionalities into a digitalized transportaion process. Main benefits can be drawn by applying automated detection and identification procedures, to verify correct loading of delivery units. Interfaces with the personnel, allow authorized consumption and to guidance for the un-loading process.

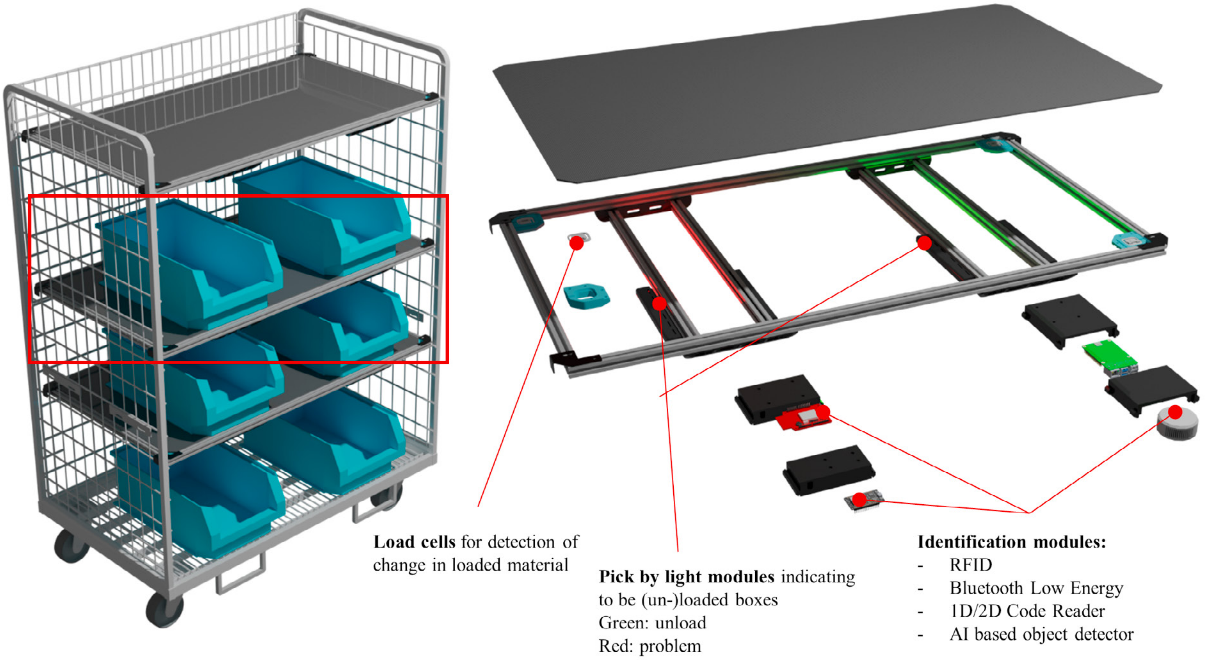

Fig. 3. Smart Delivery Unit concept with smart sensor boards. A delivery unit is set with multiple sensor boards. The shelf is mounted on load cells, detecting loading events. This may trigger further identification sensors. Each sensor board may be equipped demand driven with different sensor modules. We conceptualized an optical 1D/2D code reader module, an RFID- and BLE- tag reader module as well as an AI based visual processing module, trained with a synthetic data generator [13]

3. bulked goods, that are neither taggable nor identifiable through means of object identification, e.g. screws and rivets, are usually weighted to identify the correct amount of loaded objects. *Generic Load Sensors* are combined with *HX711 Amplifiers* from *Sparkfun* to create load cells with which weight information of loaded material can be derived.

Integrating these sensors on the delivery unit's frame, poses challenges like energy supply and internal communication. As we aim to develop a retrofittable solution, for existing delivery units, we omit the design of a new unit with integrated sensors. Instead, we introduce a novel approach for sensor integration.

4.2. Smart Sensor Boards

Visual sensors as the 1D/2D code reader or the camera have an optimal placement above the loaded material with downwards orientation and integration of those sensors has to occur in the delivery units tray. Therefore, we conceptualize smart sensor boards as depicted in figure 3. Those boards integrate all the above discussed sensor types. With that, each level of the smart delivery unit is covered with visual and BLE/RFID sensors from the top, and load cells from the bottom.

As depicted in figure 3, each board lays on four load cells. These load cells incorporate a double functionality. Besides providing weight data for bulked goods, they allow for an energy-efficient loading-event detector. Noticing change in the applied weight can trigger further functionalities on the smart Delivery Unit, especially sensory identification procedures.

Sensor boards can be equipped with modules as needed for a specific transportation procedure. We conceptualize four different modules

1. RFID Sensor Module
2. Bluetooth Low Energy (BLE) Sensor Module
3. Camera Module
4. Pick by light module

Each board is equipped with two slide-in trails that each can hold multiple modules.

4.3. Synthetic AI Training Data

As stated above, we aim to use AI based visual object detection. To enable this AI application, sufficient training data of the objects is needed. Due to the high variability of components, a high number of different training sets is needed. Further, with the low production rates, only a few occasions with the components can be captured, and acquiring the training data from the real process can be considered impracticable. On such occasions, synthetic data has grown in popularity. For the domain of intralogistic transportation with delivery units, [13] reported the successful use of synthetic data for this domain.

We propose the use of synthetic data with our smart delivery unit, to generate training data for the smart Sensor Boards AI-based object detection. Following the above derived process analysis, transported material that is to be identified with AI object identification appears mainly in Euro-containers. Applied packaging material is used to cushion the material and lesser wrapped around it. Those are scenarios for which synthetic data can be applied successfully. It is therefore possible to utilize the same system as in [13] to derive training data for these types of transportation scenarios. Examples of synthetic images are shown in figure 4.

4.4. Central CPU and Communication

Each smart sensor board is connected to a central CPU on each delivery unit. The boards and the central CPU are connected through a shared CAN-Bus, with each board serving as CAN-node. Sensor boards communicate via push-principle with the central CPU. As such, after a loading event is detected by or on a specific board, that board sends information about that event towards the central CPU. The central CPU itself maintains a WiFi connection towards a globalized fleet management or logistics control unit and reports to an MES or ERP system.

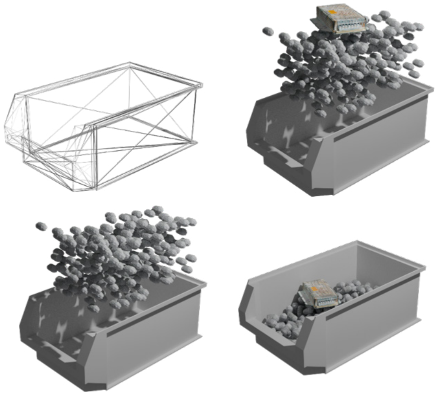

Fig. 4. Representation of synthetic AI training data for intralogistic scenarios as reported in [13]

4.5. Human-Machine Interaction

By upgrading the material delivery units with sensors, new types of information are generated that can be made available to the employee. At the same time, it is necessary to create the possibilities with which the employee can interact with the technical system in order to make the emerging potentials fully usable. Consequently, the development of systems for human-machine interaction is an important part of the overall concept. These systems can be differentiated based on the direction of information flow and the type of communication channel [5]. Information input is the transmission from human to machine, whereas information output is directed from machine to human. In principle, anything that can be interpreted by a machine can be used as a communication channel for information input, for example voice input, position tracking or manual input. All channels that can be perceived by humans - visual, acoustic, haptic - can be used for information output.

To enable the authorization process for the withdrawal of goods mentioned in chapter 3.2, a human-machine interface is implemented. This interface has the task of informing the delivery unit about the distance of an authorized employee. To realize this, the employee is equipped with a personalized smartwatch that contains a Bluetooth module.This module can be used to transmit the employee's authorizations and also to record the distance via the signal strength between him and the smartMDU. When the employee approaches close enough and has sufficient authorizations he receives a visual feedback through the Pick-By-Light modules. These in turn provide a machine-to-human interface and transmit information about the products to be picked. Another conceivable human-machine interface uses the information about the position of the material delivery unit within the factory building and passes it on to the employee. With the help of moving head spots, whose actual use is based in the event industry, large areas can be covered. The basic suitability for industrial applications and communication with CPS has already been shown [10]. A use-case for this would be to assist the employee in finding a required material delivery unit. Since these are basically the same design and therefore do not differ visually, finding them within a large production area can be time consuming. To improve the process at this point, the localization information of the smartMDU can be transmitted to the moving head spot. The moving head spot can then be used to illuminate the correct delivery unit and thus guide the employee to it.

4.6. *Energy management and Battery*

Due to the variability in processes and presently unstructured delivery unit management, the energy supply of a singular unit has to uphold longer than a typical transport procedure. We design the battery to last at least 24 hours. A power consumption profile is devised, considering three different energy usage modes: (1) **active**-, (2) **idle**- and (3) **sleep**-mode for sensors and controllers. Considering a smart delivery unit configuration as seen in figure 3 we derive the power consumption to 36 Watt for the active-, 14 W for the idle- and 3 W for the sleep-mode.

We base the derivation of the consumption profile on the above presented process analysis applied to a 10h transport procedure starting from the warehouse to a final assembly station. During a loading period of 16 minutes, the delivery unit is considered in active-mode. Eight loading events ar assummed, supervised by the highly power consuming AI based identification method in a span of up to 2 minutes each. Additionally eight unloading events with again 2 minutes each. In between the unloading events, the delivery unit falls in idle mode, estimated to 90mins. During the inter-site transportation and awaiting unloading, the smart delivery unit is in sleep mode for 8 hours. A visualization of the resulting power consumption profile is shown in figure 5. Out of that profile an energy demand of 150 Wh is calculated. Adding a security factor, results in a total energy requirement of 200 Wh.

We design a battery package to fit this requirement. As smart deliver units experience rough handling and shaking during pick-up and transportation with forklifts, explosive battery types, e.g. LiPo, are considered not viable. Although suitable for rough conditions, lead-based batteries of the necessary size result in heavy additional loading weights. Therefore, the non-explosive yet energy-dense battery-types LiFePo are chosen. We design a battery package consisting out of four serial wired 3,2 V cells that is converted into 5V voltage for the central CPU as well as the sensor boards.

Fig. 5. Distribution of power modes from the smart delivery units sensor modules and CPUs. Based on a 10h transportation procedure.

4.7. *Retrofittability*

The retrofitting of existing hardware in production is considered an economical alternative to the procurement of new systems. Therefore, we introduce a sensor board that is design to be integrated into existing material delivery units. Another aspect is the modularity of the sensor board, which allows changing the scope of the implemented sensor technology. This results in different advantages, firstly the material delivery unit can be equipped demand-driven, whereby only sensors that are needed have to be implemented and no unnecessary additional sensors are built in. This not only saves upgrade costs, but also keeps the complexity of the overall system to a necessary minimum. Another point is that retrofitting a unit is an evolutionary process in which individual functions are implemented and tested within an iteration loop [4]. Only after the completion and successful validation of a function, the system can be extended by further sensors and functions. With the modular sensor board presented here, this procedure can be applied and a step-by-step upgrade can be realized.

5. Demonstration

To validate the aimed for functionalities, we retrofit an existing delivery unit with two smart sensor boards. This retrofitted unit is shown in figure 6. The frame of the new sensor boards is constructed with aluminum profile bars. Sensor board modules are 3D printed. To replace the original trays, we attach the smart sensor boards on two hooks on each side. Those can be mounted on different levels of the delivery unit. We connect each slide-in trail of a sensor board with the central battery module, mounted in the bottom tray of the delivery unit. A configuration of the four modules as depicted in figure 3 is chosen. Finally, we connect the sensor boards with the central CPU through a local WiFi network.

Fig. 6. Retrofitted Delivery unit with a presented smart sensor board. The smart board is equipped with different sensor modules such as camera and BLE modules. Additionally, the slide-in trails are equipped with pick-by light modules that indicate to be loaded/unloaded areas. On the side of the delivery unit, the battery package is mounted.

5.1. Test scenario

To test the hardware and software implementation of the smart delivery unit, a test scenario is created that is based on a real transport procedure. In an application-oriented test environment, the scenario was tested with aircraft suppliers, an aircraft OEM, and an ERP provider. The test scenario contains a transport order from a supplier to an assembly site on the OEM premises and is modeled in a digital twin process. After specifying the component type a Bluetooth low energy beacon is attached to the real component and this component is placed in the box. The connection between beacon ID and transport order is noted in the ERP simulator. Afterward, the delivery unit is initialized with the transport order, containing the above information. Loading the box with the material into the delivery unit triggers the identification process. The delivery unit compares the initialized ID with the output from the sensor module and acknowledges the correct loading back to the ERP. After transporting the unit to the assembly line, a worker identifies himself to the unit through a handheld device. Afterwards the appropriate board of the unit indicates the to be picked element with green LEDs. Then, the smart delivery unit can be reinitialized with a new transport order.

5.2. Results and Evaluation of Requirements

Multiple runs of the above scenario were tested. For each scenario, the capability of the smart delivery unit to exchange status information with the global ERP process as well as the capability to detect the beacon is evaluated. Within the test scenario, the system does not fail to fulfill these principle functionalities and no errors were reported. After the initialization event for the smart delivery unit was emitted, the system responded in all cases in less than three seconds to the initialization and displayed the provided information on its own dashboard and interfaces. The time to detect loaded material and to report it back to the global system varies between 1 to 30 seconds, as the BLE module may be in a sleep mode and not in scan mode.

The requirements as they were defined in section 3.3 are revisited with respect to the developed concept and the test scenario:

1. **variable identification procedures**: with the concept of sensor modules, it is possible to meet the requirements of different identification processes. With respect to the reviewed systems for similar concepts, this is a novel approach for such delivery units. In the scope of the application test-scenario, the functionality of the BLE module was tested.
2. **interfaces to humans**: interaction with manual processes was successfully conceptualized, implemented and tested through the Pick-By-Light modules and visual interfaces.
3. **independent operation**: the implemented battery packages enable the smart delivery unit to be operated for at least 24h hours with the test-scenario equipment. Communication with the global ERP system was successfully tested and validated.
4. **cost-aware design**: use of low-cost components is encouraged through the modularized system. Using list prices for the suggested components, each sensor board equipped for the test scenario costs approximately 40€. The central CPU with an additional E-Ink display costs approximately 70€. The single biggest cost item is the central battery, which costs approximately 200€. Additional small material costs for casing and framing have to be considered but vary heavily for different qualities. With such low component costs, a suitable retrofitting of an existing delivery unit was achieved and the requirement is considered successfully met.

5.3. Outline for future processes

The main benefit of the new digitized process with the help of smart delivery units is the principle capability of reducing the need for manual touches in process supervision. Therefore, the smart delivery unit contributes to a general goal of optimizing logistic processes and further is an element of future intelligent and autonomous processes. As the smart delivery unit gathers primary information from the real process, disruptions in the process, e.g. due to a missing component, can be directly identified in various stages of the transport processes. Despite triggering direct actions to alleviate such problems, long term gathering of shop-floor information can enable identification of structural errors in the process. In addition to aiding pure data based processes, smart delivery units can enable real-world processes such as autonomous un-loading of elements from the load carrier [14]. For this the local cameras could provide pose information of the loaded elements and aid in the grasping process.

6. Summary

The presented concept for a smart delivery unit includes a broad range of sensor types for various identification scenarios. The sensor solutions are conceptualized based on a process analysis for production supplying logistics of aircrafts. The integration of an AI based visual object detection within a delivery unit itself, allows for markerless identification of objects and is to the authors knowledge unprecedented. As a novel approach for sensors-integration, we developed smart sensor boards that can be equipped with different sensor modules. Through this modularity a demand-driven configuration of smart delivery units can be achieved. Further, the smart sensor boards allow for retrofitting of existing delivery units.

CRediT author statement

Daniel Schoepflin: Conceptualization, Methodology, Software, Investigation, Writing - Original Draft, Writing - Review & Editing, Visualization, **Julian Koch:** Conceptualization, Methodology, Writing - Original Draft, Writing - Review & Editing **Martin Gomse:** Investigation, Resources, Writing -

Review & Editing, Supervision, **Thorsten Schüppstuhl:** Writing - Original Draft, Supervision, Resources, Funding acquisition, Project administration

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