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An intelligent bin system for decentrally controlled intralogistic systems in context of Industrie 4.0

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Abstract

Decreasing batch sizes in production in line with Industrie 4.0 will lead to tremendous changes of the control of logistic processes in future production systems. Intelligent bins are crucial enablers to establish decentrally controlled material flow systems in value chain networks as well as at the intralogistics level. These intelligent bins have to be integrated into an overall decentralized monitoring and control approach and have to interact with humans and other entities just like other cyber-physical systems (CPS) within the cyber-physical production system (CPPS). To realize a decentralized material supply following the overall aim of a decentralized control of all production and logistics processes, an intelligent bin system is currently developed at the ESB Logistics Learning Factory. This intelligent bin system will be integrated into the self-developed, cloud-based and event-oriented SES system (so-called "Self-Execution System") which goes beyond the common functionalities and capabilities of traditional Manufacturing Execution Systems (MES).
To ensure a holistic integration of the intelligent bin for different material types into the SES framework, the required hard- and software components for the decentrally controlled bin system will be split into a common and an adaptable component. The common component represents the localization and network layer which is common for every bin, whereas the flexible component will be customizable to different requirements, like to the specific characteristics of the parts.

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Keywords: Intelligent Bin; Logistics; Cyber-Physical Systems; Cyber-Physical Production Systems

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1. Introduction

The future global market and manufacturing environment of the Industrie 4.0 will require changeable production and logistics processes to deal with highly customized products leading to small batch sizes which will have to be produced under the cost and performance conditions of today's mass production. Particularly with regard to logistics, logistic networks have to keep pace with the emerging changeable production and value chain systems requiring autonomous and decentrally controlled networks of cyber-physical systems (CPS) which allow changeable logistical processes [1,2]. In line with this "fourth industrial revolution" logistics will further develop into a "cognitive logistics" which, based on the availability of a wide variety of information on all level of the logistic systems, is capable of adapting fast and flexible to volatile environments and can draw conclusions and optimize itself based on captured data. Also the tasks of logistics shift in times of decentralization and individualization of the production with the goal of low inventories more and more in the direction of a flexible and with respect to costs, time and use of resources optimized pathfinding. By doing this, logistics will also generate an added value in the future by providing customers the right products, at the right time, at the right location, in the right quantity and quality [3].

The cross-linking, automation and intelligent optimization of production and logistics processes will also lead to more efficient production of individualized products at economic reasonable conditions. Production and logistic equipment, raw materials, semi-finished and finished products will more and more communicate (semi-)autonomously with each other and independently optimize processes based on specific parameters of the respective partner, production and customer domain enabling tremendous efficiency gains. Also production and logistics networks can be adapted to the actual customer demands (instead of to the forecasted demands) in real-time. By a continuous optimization of the production program in combination with the use of additive manufacturing technologies, the production of customized products can be achieved under economically attractive conditions and at the same time logistics can be simplified e.g. by producing (spare) parts at the location where they are actually needed [4]. Intelligent bins are a major enabler to realize these autonomous and decentrally controlled value chains by transferring major decision and control functions of the material flow to the bins in transport.

2. Decentralized control of intralogistics systems

Following highly dynamic market conditions and an increasing complexity of logistic networks efficient logistical processes are becoming more and more difficult to achieve with conventional planning and control methods. To achieve future flexible, adaptive and proactive logistic processes a decentralization and autonomy of the logistic decision-making processes is required. Based on new information and communication technologies intelligent logistical objects which are able to take over planning and control processes can be realized and transferred to the level of the physical material flow [5,6]. Today's material flow systems in industry mainly rely on centralized material flow computers which are not capable of dealing with future challenges like individualized products, small batch sizes and volatile market conditions leading to the requirement of constant changes of the logistic system, like changing sources and sinks which have to be served. These centralized material flow systems are designed based on complex, centralized material flow controller architectures programmed based on predefined processes which would lead to a huge increase of complexity to transport these batch size 1 transport orders and a constant programming effort in changeable production systems [3,7,8]. The development and application of decentralized control methods for material flow systems combined with the approach of the Internet of Things bear a huge potential to solve the arising challenges within changeable production systems of Industrie 4.0 [3].

2.1. Structural elements and characteristics of decentralized logistics systems

Every automated material flow system can be structured with the basic units of the Internet of Things which are cooperating functional units (also called entities) of conveyor modules, transport units and (software) services [3,7]. So transport units respectively bins are becoming autonomous entities which guide themselves to their target destination, whereas intelligent conveyor systems are executing the actual transport of the transport units by communicating with other entities and by using the (software) services of the cyber-physical production system. All entities can interact with their environment and adapt to changing requirements by transferring more and more intelligence to the field level of the material flow system [9]. By replacing centrally controlled material flow systems by decentralized systems the complexity of the material flow system can be reduced while the versatility and responsiveness can be highly improved. Also the solution of arising interruptions and blockades as well as an automated replanning and rescheduling of transport processes and routes are becoming inherent functions of the material flow system [3,7]. Multi-agent systems, which consist of autonomous and cooperating software programs (agents) solving specific tasks based on defined behavior patterns, are the most common base technology besides other natural analog models for the realization of these decentralized material flow control systems. So each of the entities use one or more of these agents for a dynamic processing of various tasks like order management or route planning based on the current conditions of the production system [10]. These agents also have to conduct target management to deal with conflicting goals and should take previously made decisions and system behavior as well as the simulated or forecasted system behaviors into account to improve the quality of their behavior and their decisions continuously [11]. The continuous, proactive and iterative improvement and adaption of systems and structures combined with the capability of solving parallel problem domains are major characteristics of autonomous controlled systems [12,13]. By applying these capabilities the logistic objects perform information processing tasks, decision-making and the execution of the made decisions autonomously within the respective system environment [5]. Another major challenge is the structural merger of the approach of autonomous control systems and industry standard ERP, PPS and MES software systems to align central, decentral and autonomous controlled process structures [6].

2.2. Intelligent bin systems

Besides the conveyor systems also the logistical objects respectively transport units have to evolve to become part of the emerging Internet of Things. A major step for this is to transfer more intelligence regarding the control of logistics processes directly to the transport unit by adding computing capacities, identification capabilities, decision making capabilities/logics, sensors and capabilities for wireless communication to these logistical objects.

At the transcontinental level, smart standard ISO containers are used to track the position and condition of high value or sensitive goods, like electronics or perishable goods, by using build-in GPS modules for global tracking, various sensors (e.g. temperature, humidity, motion sensors) connected with a micro-controller for local sensor evaluation and decision making and a modem and SIM card combined with a satellite transmitter at the container vessel to not only provide real-time container information to the vessel but worldwide to companies or third party logistics providers to optimize global supply chains and to support the development and initiation of countermeasures to deal with unforeseen incidents regarding supply or product conditions [14,15].

Also at the small load carrier level, the first intelligent bins are under development or already available on the market, like the “inBin” prototype which was developed by the Fraunhofer-Institute for Material Flow and Logistics (IML). This bin system integrates innovative components like a “Energy-Harvester” to generate electrical energy using special solar cells or by using movements, vibrations or huge changes of temperature to gain energy to charge the energy storage of the bin, a micro-processor and adds a wireless communication module into the actual bin to serve as an energetic and control system independent bin system. This intelligent bin is also capable of communicating and interacting with humans and machines and to make decisions autonomously. To communicate with other transport units, conveyor systems, machines or software services wireless connection technologies are used, whereas the interaction with humans is supported by a graphical display e.g. to provide guidance for order picking tasks. Also this bin is able to locate itself and to capture ambient conditions like the temperature based on sensors, to simplify the location of the bin for the retrieval of goods and to prevent inappropriate storage conditions [3,16].

Another example for an intelligent small load carrier which also includes an industry service for C-parts is the “iBin” developed and distributed by the company Würth Industrie Service, which uses an integrated camera to generate filling level, counting and order information on bin level to place consumption-based replenishment orders automatically enabling a real-time C-part management covering the entire supply chain. Both small load carrier systems are capable of establishing an Internet of Things by interacting with autonomous conveyor systems and by requesting transport services from these conveyor systems to fulfill their mission (e.g. material supply for an assembly station) without a higher-level control instance [3].

Intelligent bins also allow a decentralization of data storage following the data-on-the-chip principle by storing all relevant information of the transport unit like a unique identification number, the source and sink information of the bin, content information and the dimensions or geometric shape of the bin directly on the microcontroller of the bin. This coupling of information and material flow also reduces the required communication of logistics related information and data redundancy within the system. Also tasks like routing, transport and avoidance of congestions are fulfilled decentrally and autonomously by the intelligent bins in cooperation with other logistic entities in the Internet of Things without a central control system [9]. Also transport units with common place of origin or destination can be combined to joint shipments or transport orders in an ad-hoc and decentralized manner to optimize logistical processes in real-time [17].

3. Intelligent bin system at ESB Logistics Learning Factory

Learning factories in its more narrow definition cover a real value chain and product which puts researchers, students and training participants in general in the position to perform, evaluate and reflect their own actions in a close-to-reality factory environment [18]. Learning factories are great testbeds for research projects also in cooperation with industry partners for complex research topics since state of the art industry infrastructure can be used and at the same time production downtimes do not lead to any financial losses. In addition trainings in various disciplines can be provided for professionals from industry and for students who benefit from the immersive, interdisciplinary and practice-oriented approach of learning factories.

3.1. Production system at ESB Logistics Learning Factory

The production system of the ESB Logistics Learning Factory (LLF) is focused on the assembly of a multi-variant city scooter including the application of innovative planning and control methods for production and intralogistics, technical assistance systems and additive manufacturing technologies. All workstations and logistics infrastructure are mobile to allow an easy change of the factory layout and all workstations are equipped with tablet-pcs using wireless communication technology for bidirectional information exchange between the shopfloor level and the digital planning environment as well as to access multimedia-based work instructions. The access and feedback of information can be designed manual as well as automated using different maturity levels of information technology, e.g. RFID-technology embedded on the product or microcontroller-based digital devices equipped with communication technology and sensors on the product or at the workstations, to gather and exchange data with other objects and to act as intelligent objects in the Internet of Things. The intelligent bin system, which is currently under development, will be integrated into the existing production system to support and optimize intralogistics as well as production processes at the LLF by acting as an intelligent object. These technologies also serve as major enablers for the development of a decentralized control system in which bins, products and other intelligent objects route themselves autonomously through the production system. Centrally and decentrally controlled objects will communicate with each other and with the workers by using a framework for decentralized control systems which is under continuous development with an industry partner.

3.2. Framework for decentralized control systems

The so-called “Self-Execution-System (SES)” architecture, which is based on an event-oriented concept enriched with a specific cloud data-storage structure for central and decentral system entities, serves as a framework for the development of decentralized control methods within the LLF. A simplified structure of the SES autonomous and decentralized control approach is shown in figure 1. In general the SES is composed of “system-related nodes and objects” and “scenario-specific nodes” which provide different services within the LLF production system to enable decentralized control and decision-making. The term “nodes” is standing for autonomous software agents providing specific services and interacting with other agents within the production system. Agents found in the level “system-related nodes and objects” cover amongst other things functionalities respectively services which usually also can be found in conventional Manufacturing Execution Systems, like order management, prioritization of production orders and specific production control functions as well as services to integrate different kind of conventional and cloud-based IT-systems, infrastructure and resources.

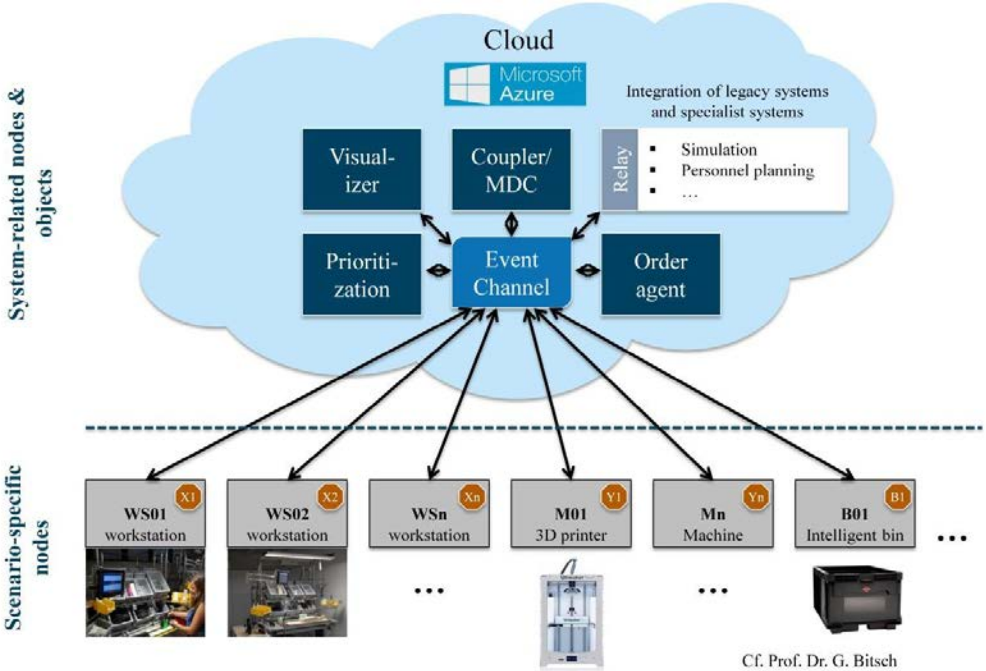

Fig. 1. Basic structure of SES

A major advantage of this approach compared to conventional (MES) system approaches, besides the ability to cope with the complexity resulting from the changeable production system of the LLF, is that the functional range of the SES can be extended easily and stepwise by modelling additional agents covering different functionalities and/or representing (cyber-physical) infrastructure elements due to its open architecture. Also scenario-specific nodes for additional resources like workers, collaborative robots, workstations or in this case intelligent bins offering specific assembly or logistics services can be modeled and integrated as well as conventional centralized systems or system functionalities can be transferred into the decentralized planning and control of the SES based on the developed framework. Various research, student and industry projects have shown the huge potential of this system approach in context with changeable production scenarios. But still the SES framework is in the proof of-concept phase and also is a major focus and enabler for further research topics in the field of decentralized control systems for production and intralogistics at the LLF. The intelligent bin system is the first intelligent object developed from scratch in the LLF and designed in line with the SES framework.

3.3. Technical setup

Since the potential fields of application of intelligent bins and their required functionalities can be very versatile, it was necessary to ensure that an overall technical design is used which can be applied uniformly for all applications and can be adapted to different purposes by specific (re-)configurations. For this purpose, the hard- and software components were split into a common and adaptable component. The common component takes over basic functionalities that are common for all intelligent bins and covers functions that correspond to the given spatial requirements, which are mostly independent of different application scenarios of the intelligent bin. The common component basically consists of the layers of communication, localization and battery monitoring. The communication layer takes over the direct connection to the SES via a specific network and network device. The localization layer enables a feedback to the SES to state location changes by identifying movements and position changes. Due to different limitations to determine the accurate location of the bin, the modules within the localization layer are also interchangeable and can be adapted to specific requirements such as accuracy, area or signal strength depending on the factory layout and intended use. Currently an ultrasonic based indoor location system is tested for bin location. The connection to the SES via the communication layer enables a bidirectional message exchange. In this way, queries (of sensors) or instructions (on actuators) can be transmitted directly from the SES to the bin. On the other hand, the SES can be addressed directly from the bins, in case of defined states, for example a low battery capacity. The logic for the states is set completely in the SES. The data processing of the states within a container type and an application category is represented in the SES as nodes, where the logic of the subsequent processes is mapped between the nodes via messages. The structure of the layers allows the application-specific implementation of the individual layers in the sense of Industrie 4.0 in order to be able to react quick and flexible to changing requirements.

The sensors and other components for the adaptable component were selected following the requirement to capture the content of the bin and to be able to fulfill changing requirements. Based on the number of sensors and actuators used per container, an ESP8266 microcontroller with integrated WLAN chip was selected, which allows a design with compact dimensions, low price and low energy consumption. The MQTT (Message Queue Telemetry Transport) communication protocol with a JSON data model was used for a flexible adaptation to the intended application. This forms the basis for the communication and the decentralized decision and control possibilities of the intelligent bin. Due to the flexible technical design of the individual layers, the concept can be used for different environments in which individual sensors and actuators have to be controlled. To determine the components for the adaptable component, experiments regarding the selection of appropriate sensor systems (such as weight measurement sensors, mechanical and optical switches and inductive sensors) were carried out to capture the bin content for A-, B- and C-parts made from metal and non-metal material and varying in weight. For example for C-parts which do not require an exact counting of the part quantity weight measurement sensors or level sensors are used depending on the respective part properties. For the interaction with humans different actuators and displays have been tested to assist the worker e.g. with picking the correct parts for order picking or to select the right parts for the assembly of non-standard products via picking instructions on the display and signal lights on the bin.

3.4. Fields of application

The intelligent bin system in general will be further developed to serve as an intelligent automation component and assistance system to improve assembly as well as logistics processes at the LLF. A central field of application in logistics will be the use of the intelligent bin system to establish a decentralized, autonomous and consumption-based material supply system in which the intelligent bins communicate and interact with other intelligent objects, like conveyor systems, or services, like nodes of the SES, to fulfill their material supply mission in the production system. The intelligent bin system should also be used to improve collaborative work between humans and robots by enabling a direct communication between the collaborative robot system, the intelligent bins and the worker for logistic tasks like order picking and collaborative assembly tasks where in both cases the human worker is guided by the intelligent bins and the robot can interact with the intelligent bins to receive and execute its robots commands to support the worker with his tasks. To enable intuitive human-machine collaboration a display in combination with different sensor systems will be used to give the worker instructions like at the assembly station as a decentralized pick-by-light system to assist the worker to pick and assemble the right parts and sensors to track the position and content (quantity) of the intelligent bin.

In addition to the use of the intelligent bins to monitor A-, B- and C-parts within the production system of the LLF, an approach has been investigated in order to cope with the problem of an efficient storage and capturing of several but unique objects needed for an customer specific assembly set, following the requirements of Industrie 4.0 and additive manufacturing technologies leading to small batch sizes and individualized part designs. For this purpose, the technical setup of the intelligent bin will serve as the basis for the development of an intelligent set creation box equipped with actuators, e.g. in terms of LEDs, and application-specific sensors to provide a decentralized assembly and logistics assistance system following the "pick-by-light"-principle and also giving a direct feedback of executed tasks to the SES. By interconnecting the intelligent bins and intelligent set creation boxes via the SES, location-specific and cross-functional processes based on the used sensors and actuators can be realized and executed. For example at the set creation workstation the intelligent set creation box can initiate the required picking operations triggered by its change of location via the SES and the respective intelligent bins receive the picking information from the SES, the bins are indicating the logistic workers which parts have to be picked based on LEDs at the intelligent bins and where to place it in the set creation box based on LEDs indicating the correct placing position in the set creation box. This new “pick-and-place-by-light” approach will be tested in the production system of the LLF to prove the potential of the described intelligent bin system in combination with the SES.

4. Conclusion

The cross-linking and emergence of physical and digital entities in global production systems in combination with decentralized control systems bears a great potential to cope with future challenges like small lot sizes, individualized products and volatile market conditions. In the field of logistics intelligent conveyor modules, transport units respective intelligent bins and (software) services will be crucial enablers to support changeable production scenarios.

The intelligent bin system which is currently under development at LLF will strongly support the development of decentralized production scenarios also involving decentralized material supply strategies combining various conveyor systems and services to provide a real-time optimized material flow within the production system. Also the development of the intelligent bin system will be interlinked with a current research project dealing with the development of a collaborative tugger train using collaborative robot systems for an autonomous material supply in changeable assembly and logistics systems by also integrating the potentials of intelligent bins, e.g. to identify transportation orders without a centralized control instance, into this project.

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