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Development of a descriptive model for intralogistics as a foundation for an autonomous control method for intralogistics systems

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Abstract

Future intralogistics systems need to adapt flexibly to changing material flow requirements in line with future versatile factory environments, producing personalized products under the performance and cost conditions of today's mass production. Small batch sizes down to a batch size of "1" lead to a high complexity in the design and economical manufacturing of these customized products. Intralogistics system are integrated into higher-level areas (segment level) as well as into upstream and downstream performance units (system-wide areas). This includes the logistic activities relevant for the system (organized according to storage, picking, transport) such as transportation or storage tasks of tools, semi-finished products, components, assemblies and containers, and waste. Today's centralized material flow control systems, which work based on predefined processes, are not capable and more specifically not suitable to deal with the arising complexity of changeable intralogistics systems. Autonomous, decentralized material flow control systems distribute the required decision-making and control processes on intelligent logistic entities. A major step for the development of an autonomous control method for hybrid intralogistics systems (manual, semi-automated and automated) is the development of a generic archetype for intralogistics systems regarding the system boundaries, elements and relations resulting in a descriptive model taking into account amongst others the time of demand, availability of resources, economic efficiency and technical performance parameters. The ESB Logistics Learning Factory at ESB Business School (Reutlingen University) serves for this as a close-to-reality development and validation environment.

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Keywords: Intralogistics; Autonomous control; Decentralized control; Descriptive Model

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1. Introduction

In times of decentralization and individualization of production, the tasks of logistics is going to shift from aiming on low stock keeping more and more in the direction to achieve a flexible and with respect to costs, time and resource deployment optimized logistic function. Therefore, logistic systems have to evolve to be still able to provide the right product, at the right time, at the right location, in the right quantity and quality even in dynamic logistics systems. Besides production equipment, also logistical objects have to be capable to interconnect and exchange information with other intelligent objects autonomously to control themselves through material flow systems. The result of these networked intelligent logistics objects are changeable logistics systems with a high robustness regarding errors and unexpected process changes, which are essential capabilities for modern value creation networks facing an increasing dynamic and complexity [1]. Nopper [2] describes the changeability of intralogistics systems as the "capability of a material flow system […] to adapt to the requirements of the environment beyond the limits of the system's design. In order to do so, the system must be expandable or adaptable. The requirements of the environment can be described for material flow systems completely along the dimensions of conveyed goods, layout and throughput."

Future-oriented, changeable intralogistics systems, conveyor systems as well as all other logistical resources and entities have to be capable to adapt to changing requirements (conveyed goods, layout and throughput) aiming on a continuous optimization of the entire intralogistics system. A major enabler for this is the development of decentralized, autonomous control methods, which are transferring the required control and decision-making processes to intelligent logistical objects on the level of the physical material flow [3].

Since the development of a descriptive model for intralogistics covered in this paper is still work in progress, this paper focuses on the state of the art concerning the autonomous control for intralogistics systems. In addition, the research gap and how the research in this field is fostered by using learning factory concept is going to be investigated.

2. Control of future-oriented intralogistics systems

Most material flow control systems currently used in industry rely on centralized material flow computers. These centralized material flow systems have complex, centralized and hierarchically structured control architectures that are programmed based on predefined material flow processes. In changeable intralogistics systems, the logistical processes have to adapt dynamically to changing production system requirements, e.g. with respect to changing source-sink relationships and the used conveyor systems, to ensure an efficient material supply for individualized production. For centralized material flow control architectures these changes would lead to a huge increase of complexity to fulfill these batch size 1 transport orders and a constant programming effort [1, 4]. The development and application of autonomous, decentralized control methods for intralogistical 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 [1, 5, 6]. Every decentralized material flow system can be structured according to the basic units of the Internet of Things of intralogistics which are the cooperating functional units (also called entities) of conveyor modules, transport units and (software) services [1, 6]. Formerly passive transport units (like bins) are becoming a crucial system component of the emerging decentralized material flow control systems by communicating with intelligent conveyor systems, more precisely software services, to route themselves to their target destination by using the services provided by the intralogistics system. By transferring more and more intelligence and autonomy to the field level of the material flow, the complexity of changes of the material flow can be reduced whereas the changeability and responsiveness can be significantly improved. An (semi-)automated replanning, rescheduling and optimization of the intralogistics processes as well as providing a solution of potential interruptions or blockades of the material flow are becoming system inherent functions of the material flow system [1, 6]. The constant, proactive and iterative enhancement and adjustment of systems behavior and structure in combination with the ability to solve parallel problem domains are the characteristic features of autonomous controlled systems [7, 8]. By applying this decentralized approach, intelligent logistical entities are performing information gathering and processing tasks, decision-making as well as the execution of the made decision without predefined solutions for the intralogistics system.

However, the logistic infrastructure within companies and entire value stream networks is not becoming intelligent all of a sudden and also standardization is lacking. Therefore, a crucial first step is to develop a generic archetype for intralogistics systems regarding the system boundaries, elements and relations Based on this archetype, a universal descriptive model taking into account amongst others the time of demand, availability of resources, economic efficiency and technical performance parameters has to be developed with close ties to existing reference architectures and models to order to reduce the implementation effort.

3. Modelling of autonomous controlled intralogistics systems

Existing intralogistics models, architectures and research projects are usually limited to individual aspects and system components of intralogistics systems (e.g. order picking systems [9, 10], meta model architecture for automated material flow systems[11]) and do not take into consideration the required interconnections with other logistic objects and changed requirements of autonomous controlled logistic systems (e.g. Dortmund process chain model in intralogistics [12], flexible control of tugger trains [13]).

In order to make sustainable use of the opportunities of distributed, centralized control systems in the context with Industrie 4.0, reference architectures must be created to avoid time-consuming interface programming both within single companies and entire value creation chains including logistics processes. Furthermore, service-oriented, standardized software solutions are required, since proprietary solutions do not go along with flexible and connected value adding networks. Based on common system architectures also new entities can be integrated quickly and cost-effectively into the existing production systems and easily adapted to changing requirements due to quick reconfiguration of the system [14]. The Reference Architecture Model Industrie 4.0 (RAMI4.0) [15] consists of a three-dimensional coordinate system that incorporates the essential aspects of Industrie 4.0 and enables breaking down complex relationships into smaller, manageable parts and should also foster standardization by making overlaps and gaps in standardization visible.

3.1. Reference Architecture Model Industrie 4.0 (RAMI4.0)

RAMI4.0 is a reference model for the reference architecture of Industrie 4.0 systems and facilitates a structured description of solutions [15]. The major aim of RAMI4.0 is to provide a sufficiently precise description of an asset or an asset combination based on the three axes “Layers”, “Life Cycle & Value Stream” and “Hierarchy” (see Figure 1 (a)).

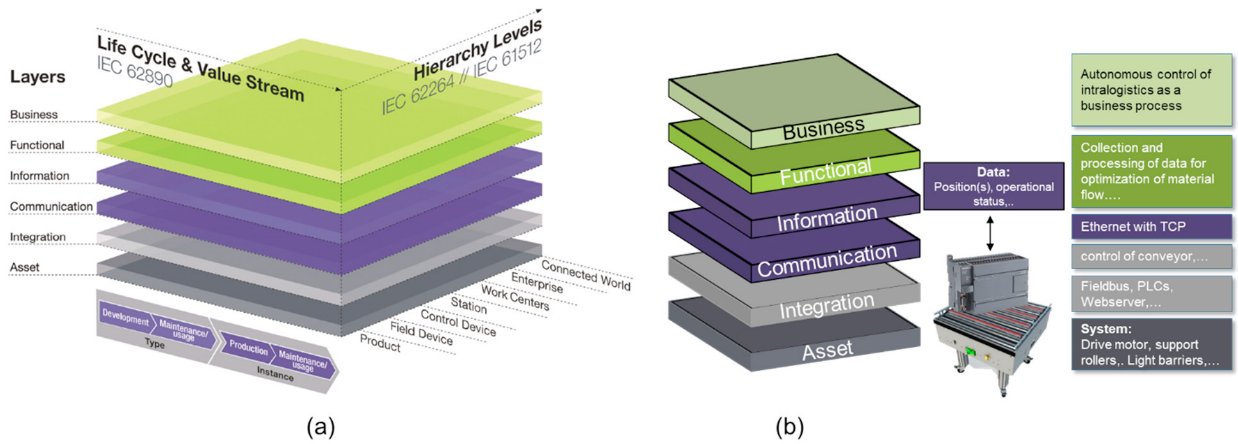

Fig. 1. (a) Reference Architecture Model Industrie 4.0 (RAMI4.0) [15]; (b) Intelligent conveyor module in RAMI4.0.

The “Layers”-axis describes the systems architecture regarding their functions and domain specific data based on layers. The “Business”-layer describes the business perspective (e.g. organizational constraints, business models and the orchestration of services of the “Functional”-layer), the “Functional”-layer outlines (logically) the functionality of an asset concerning its role in the system (e.g. runtime and modeling environment for services and business processes) whereas the “Information”-Layer describes the data used, generated or modified by the asset executing its function (e.g. Reception of events and their transformation according to the data available for the “Functional”-layer). The “Communication”-Layer defines the Industrie 4.0-compliant access to information and functions of a connected asset from other assets (e.g. unified communication using a uniform data format). The “Integration”-layer serves as the transition layer between the physical world and informational world and contains the properties and process-related functions of the asset to fulfill its role and the “Asset”-layer represents the real asset in the physical work (e.g. machines, machine components, software services, but also the human interface to the information world). The “Life Cycle & Value Stream”-axis enables the description of an asset with respect to its lifecycle phase starting from its creation, the value creating usage phase until its disposal. The “Hierarchy”-axis represents the hierarchy levels starting from the (intelligent) product to be manufactured, intelligent field devices (e.g. smart sensor), control devices, stations, work centres, enterprise up to the “Connected World” describing the relationship between an asset or a combination of assets (e. g. machine, company) and another asset or combination of assets (other machine, other company), e.g. in a value chain network [15].

To illustrate single assets, their compositions and interconnections the principle of a recursive asset description is applied. Modules as well as entire machines, conveyor systems and stations consisting of multiple assets can be described in an aggregated or a detailed form depending on the required level of observation. Also, the functional and organizational integration of intelligent objects or entire autonomous conveyor systems into the respective hierarchy levels can be described and modelled. Figure 1 (b) illustrates exemplarily the structured description of an intelligent conveyor system module following the RAMI4.0.

3.2. Industrie 4.0 component

The “Industrie 4.0 component (I4.0 component)” is the first model based on the reference architecture model RAMI 4.0. The I4.0 component is a model that describes the properties of cyber-physical systems, which are real objects that are networked with virtual objects and processes, in more detailed way [16]. The I4.0 component can represent a single component within a machine or an entire production system, but it is important to consider it as a unit and with respect to the role (domain specific functionality) that it has to fulfill within a system. I4.0 components have to fulfill certain requirements, which have to be clearly identifiable (as an entity), they need an I4.0-compliant communication ability (active/passive), they have a status in asset history (life cycle) and they are a representation of an asset by information and, if necessary, they have a domain specific functionality. For the representation of asset through information including its domain specific functionality, an administration shell is required which turns an asset into an I4.0 component and serves as the virtual digital and active representation of an asset in an I4.0 system. The administrative shell contains of characteristics and functions from different domains in separate partial models that are maintained independently of each other following RAMI 4.0. The administration shell may contain of any number of I4.0-compliant partial models and each partial model has hierarchically organized characteristics that refer to individual data, functions and views as defined in RAMI 4.0 [15].

The RAMI4.0 as well as the Industrie 4.0 component have so far only been investigated from a production-, service- and supply chain perspective, although the intralogistics processes and objects are of vital importance for the success of future-oriented supply chains. By using the RAMI4.0 a standardized, seamless and recursive modelling covering entire value chains, intralogistics systems as well as single assets can be achieved as described above. Consequently, the RAMI4.0 will be investigated as a foundation for the application-oriented modelling of a descriptive model for autonomous, decentralized intralogistics systems at ESB Logistics Learning Factory.

4. Production system of ESB Logistics Learning factory

ESB Logistics Learning Factory (LLF) is a close-to-reality research, education and training environment at ESB Business School (Reutlingen University). Learning factories, such as the LLF, covering a real value chain and product have proven to be an ideal environment for the development and demonstration of future production scenarios [17]. These holistic learning factories, like the LLF, are especially suitable for complex research topics like the industry-oriented development of autonomous control methods since state-of-the-art industry infrastructure is available and at the same time, production downtimes within the learning factories do not lead to any financial losses.

4.1. Digital and physical factory environment of ESB Logistics Learning Factory

Major components of the digital factory environment are a cloud-based Manufacturing (Self) Execution System (MSES) which is under development with a local IT-partner as well as the cloud-based Dassault Systèms digital and virtual factory environment solution “3DExperience”. By using the open architecture of the MSES, a decentralized controlled factory environment will be established over the next years in accordance with the RAMI 4.0. The physical factory environment of the LLF consists of manual workstations as well as workstations with collaborative robot systems and collaborative robots on automated guided vehicles which are able to drive autonomously to different locations of the LLF to automate processes or for situative support of workers. Manual and automated transport systems, like roller conveyor systems or automated guided vehicles, are used for internal transport. Also augmented reality glasses, tablet pcs and large screens are used for a decentralized provision of information and visualization on specific workstations as a worker assistance system for assembly or logistics processes. To achieve a close to real-time feedback from the physical factory environment into the digital factory environment, an indoor localization system is used to track workers and objects like bins, workstations and conveyor systems. In addition, a photorealistic 3D laser scanner is used to capture changes of the factory layout and structural infrastructure changes. A motion capturing system is applied to assess manual or collaborative workstations within the 3DExperience system world. For the production of prototypes, jigs and fixtures as well as of individualized products various 3D printers using different technologies and material are in use. Within this production system a decentralized control of all factory processes should be established within the next years. Starting point is going to be the control of the intralogistics system of the LLF with close ties to the research project “Collaborative tugger train 4.0 (KollRo 4.0)” funded by the Federal Ministry of Education and Research.

4.2. Development of a descriptive model for autonomous controlled intralogistics systems

The aim of the research project “Collaborative tugger train 4.0” is to develop a tugger train system which is capable to deal with the intralogistics material supply for changeable production systems manufacturing highly individualized products. The tugger train will be able to drive autonomously from the material source (e.g. material supermarket) to the material sink (e.g. assembly workstation) and also to manipulate the bins which have to be transported and handled in a (semi-)automated or collaborative manner. Therefore, the trailers of the tugger train are towed by a robot platform on which a collaborative robot system is installed to manipulate the bins. The tugger train system in combination with the digital and physical infrastructure of the LLF will be used to develop an autonomous, decentralized material flow control system within the LLF which distributes the required decision-making and control processes on various intelligent entities in the LLF.

Based on a descriptive model, a method for decentralized control of intralogistics systems will be developed to achieve an efficient intralogistical material supply. The method will be based on a target-oriented, dynamic transport order allocation to make transport systems available, while taking in consideration manual systems (like hand trolleys), semi-automated systems (like forklift trucks), automated systems (automated guided vehicles) or collaborative systems (like the collaborative tugger train system). The modelling of the method will be done following the RAMI4.0 or rather I4.0 component model to foster a structured description. Besides the transport, also the intralogistic activities of storage and picking should be included in a similar manner into the decentralized control method. Based on the descriptive model for intralogistics and a given system demand, e.g. a scheduled material demand of an assembly workstation, the intralogistics system should orchestrate itself to decide on the suitable resources (e.g. manual/semi-automated/automated/collaborative storage, picking or transport system components) to fulfill the intralogistics function autonomously in a decentralized manner.

5. Conclusion

For a successful and economically feasible implementation of distributed production systems manufacturing individualized products, decentralized control systems and common architectures like the RAMI4.0 are a crucial requirement. Logistics as the connecting function between external and intracompany places of supply and demand is of central importance for future value creation networks. But the control of these decentralized systems is still a major challenge. Learning factories, like ESB Logistics Learning Factory (LLF), with industry-oriented infrastructure and processes can serve as a close-to-reality and risk-free research environment for the development of innovative solutions in this field of research. Within the next years, the LLF will be stepwise transferred into centrally controlled production system involving all planning, control and execution tasks. The first steps are currently done in the field of a decentralized decision making and control of intralogistics processes by starting with the development of a descriptive model for intralogistics systems which will be applied in a first prototype version within a current research project with the aim to develop a collaborative, autonomous tugger train system in the LLF.

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