Bringing Agents into Application: Intelligent Products in Autonomous Logistics

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Abstract. Autonomous logistics is a new research domain that works on the decentralization of decision-making processes. To reach the research objectives of this domain, intelligent products are becoming the focal point. The implementation of autonomous systems leads to the deployment of Multi-Agent-Systems which manage the complex decision making processes. A key finding of the autonomous logistics research is the demand for positive emergence that should arise out of the global system when applying decentralized intelligent products. This paper concentrates on the first integration attempts of intelligent products in the context of autonomous logistics processes and presents a demonstration platform which assembles automotive tail-lights with autonomous logistics methods.

1 INTRODUCTION

Reaching the well-known requirements for logistics - having the right product at the right time at the right place - is becoming more and more difficult with traditional planning and control methods. The current research considers, therefore, the concepts of decentralization and autonomy on the logistics decision-making processes and reflects aspects such as flexibility, proactivity and adaptability. The idea of autonomous cooperating logistic processes is characterized by shifting decision competencies to autonomous logistics objects for decentralized and heterarchical planning and control. This is deemed to be an answer to the mentioned demands. Applying this concept new properties of a larger system may emerge by local interaction of subsystems. This key characteristic is called emergence whose effects are hard to anticipate due to complexity, resulting from subsystem interaction. Emergence may concern organizational structures or even problem solutions. Emergent organizations are evolving and thus able to adapt themselves to modifications in the environment and their members' goals. Positive emergence means that subsystem interaction leads to a better achievement of objectives of the total system than it is explicable by considering the behavior of every single system element. In the context of autonomous logistics, these effects are incorporated by implementing logistic objects (e.g., means of transport, freight, parts) as decentralized subsystems that dynamically coordinate with other subsystems to manage logistic processes and reach their respective goals (e.g., on-time delivery or minimization of delivery times).

This paper reflects an ongoing work on implementing autonomous control methods on logistics systems, specifically in production logistics, where the *Intelligent Product* plays a central role. This work is being performed in a technical subproject which develops also an application and demonstration platform within the Collaborative Research Centre 637 "Autonomous Cooperating Logistic Processes-A Paradigm Shift and its Limitations" (CRC 637). Through the course of the paper a production scenario will be presented designed to investigate the applicability in the domain of production logistics. The scenario illustrates an autonomous assembly system for an automotive tail-light.

The assembly scenario is taken from a flow shop system that does not allow any flexibility within the sequence of processes. Today automotive tail-lights are manufactured with variant types in order to meet the customer demands. Thus variant flow shop systems evolved from the inflexible systems. Since these systems are still controlled centrally with a limited and predefined space of variants that are determined and scheduled beforehand, this realistic scenario was taken as a starting point to derive the introduced scenario with Autonomous Control by implementing variant types of the finished product which have to be chosen by the product itself.

2 RELATED WORK

2.1 Internet of Things

The concept of "Internet of Things"(IoT) is mainly driven by technologies and concepts like pervasive and ubiquitous computing. The vision of IoT describes the strongly growing interconnectivity not only between people, but also between "things" and has become a new paradigm in the recent years [10]. Today several research institutions and universities are working on this topic and even authorities are funding this research topic. There are also associations like EPC-Global[2] that work on industry driven standards on electronic product code with the perspective on implementing RFID[3] in the supply chain. IoT can be understood as an enabling framework for the interaction between a bundle of heterogeneous objects and also as a convergence of technologies. There are some required key functionalities to enable the interaction between "things" [3, 1]:

- Identification: Objects in the IoT are precisely identifiable by a defined scheme.
- Communication and Cooperation: Objects are capable to interact with each other or with resources in the net.
- Sensor: Objects can collect information about their environment.
- Storage: The object has an information storage that stores information about the object's history or/and its future.

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[2] EPC-Global: Electronic Product Code, http://www.epcglobalinc.org/home/
[3] RFID: Radio Frequency Identification

- Actuating elements: IoT Objects are capable to act on their own without having a superordinate entity.

- User Interface: Adapted metaphors of usage have to be made available by the object.

2.2 Intelligent Products

An *Intelligent Product* can be understood as today's products enriched with competencies and abilities for decision-making and interaction with its environment. High level requirements of intelligent products are mentioned by several authors who reflect the demand on autonomous products. McFarlane [11] and Wong [20] describe the *Intelligent Product* as a physical and information based representation of an item which:

- possesses a unique identification.

- is capable of communication effectively with its environment.

- can retain or store data about itself.

- deploys a language to display its features, production, requirements, etc.

- is capable of participating in or making decisions relevant to its own destiny.

There are also very similar definitions of the properties of an Intelligent product from Kärkkäinen [9] and Ventä [17] but different in the perspective from which they look on the *Intelligent Product*. The focus of Kärkkäinen's description of *Intelligent Product* are logistics aspects in a supply chain.

2.3 Autonomous Logistics

In the field of *Autonomous Logistics*, cooperation and interaction are general requirements for complex systems where a high number of logistics objects are supposed to interact. Windt and Hülsmann [6] define autonomous cooperation and control as follows:

Autonomous Control describes processes of decentralized decision-making in heterarchical structures. It presumes interacting elements in non-deterministic systems, which possess the capability and possibility to render decisions.

The objective of Autonomous Control is the achievement of increased robustness and positive emergence of the total system due to distributed and flexible coping with dynamics and complexity.

One of the key elements of this definition is derived from the concept of positive emergence [8]. Emergence can be understood as the development of new structures or characteristics by the concurrence of simple elements in a complex system. As a consequence, positive emergence means that the concurrence of single elements leads to a better achievement of objectives of the total system than it is explicable by considering the behaviour of every single system element [8], [16]. Positive is meant to be an emergence that acts positive in the sense of the logistics system.

2.4 Multi-Agent-Systems

Intelligent autonomous objects require the integration of software agents and multi-agent-systems (MAS) which are a state-of-the-art approach in implementing autonomous and interacting software systems. The autonomous decision maker are implemented and situated as software programs in a multi-agent environment and act on behalf of the real-word entities. The deployments of MAS imply capable agents as well as simple agents for distributed control in logistics systems and are one of the basic principles of our research. The ability of agents in MAS to communicate and coordinate with other agents enables them to solve complex tasks in cooperation (or competition) depending on their respective goals and abilities in distributed way. The decisions of an intelligent agent depend on its internal or "mental" state [14]. The presence of the current state and the knowledge on the current state of the world is a minimal requirement for the goal-oriented behaviour of an agent. Furthermore, the intelligent agent should be able to infer new knowledge from present knowledge by logical reasoning. Agents in a multi-agent environment interact in a standard way defined by FIPA[4][4] which is a subsection of IEEE since 2005. In particular, the format and semantics of messages (Agent Communication language, ACL) sent between agents are defined by the FIPA standards [4]. Also the protocols for certain interaction processes based on speech act theory [15] are standardized by FIPA. In production logistics agents may be representatives of different logistic entities, e.g., products, assembly machines or hardware control items.

3 BUILDING BLOCKS

We present an ongoing implementation of a bundle of methods which are reflected in a material flow system with an applied production scenario. The material flow system is also being introduced into the research to ensure industrial conditions.

3.1 Hardware Abstraction Layer

The most relevant requirement of autonomous control is the ability of individual logistics entities to access context and environment data. Thus the ability to understand and process the data from data sources is the condition to build local decision-making systems [5]. For this purpose we used a "Hardware Abstraction Layer", which was developed for having a structured access to nearly any hardware of the system. The Hardware Abstraction Layer considered the findings from the point of view of data integration. Hans et al. [5] and also Hribernik [7] examined which aspects have to be considered from the point of view of data-integration in autonomous logistics networks. This gives freedom in terms of future extensions of the system.

3.2 Metal Cast RFID

One of the important steps towards autonomous parts is the unique identification possibility of autonomous objects. This can be attained by tagging or embedding auto-ID[5] technologies such as RFID. There are first prototypical integration of RFID tags at 125 kHz in the metal parts [2]. The implementation-scenario uses an automotive tail-light as Intelligent Product. The RFID tag was inserted while casting the tail light. This approach has the focus on enabling the products to be exactly identifiable and also autonomous from begin of their birth. Pille describes how to solve related challenges of this engineering process [12].

[4] FIPA: Foundation for Intelligent Physical Agents
[5] auto-ID: Automatic Identification

3.3 Decision Algorithms

To act autonomously, software agents are used as representatives of intelligent logistic objects, thus decision-making algorithms have to be implemented within the agents. For operating intelligent products in the mentioned assembly system, an algorithm basing on the "Product Type Corridor" is used. This algorithm is developed for assembly systems which produce more than one variant of products. The product moves along the product type corridor during the manufacturing and assembly process [19]. This means that there are variants to choose along the assembly process that allow the product to re-decide which product variant to target. This concept describes the available type variants that are currently possible considering the progress of production. The product is using the introduced method of autonomous product construction cycle for assembly systems. By deciding for a final type variant, the next possible production steps are identified. Therefore it is necessary to analyze the all-up situation, which calls for evaluation of every operation alternative [18]. This concept is a prerequisite for going into decision-making that is done with a model, which is capable to evaluate multicriterial status. This approach makes a multicriterial mathematical evaluation possible and is based on the fuzzy hierarchical aggregation [13]. The algorithm calculates one from several alternatives considering given criteria. Criteria are for instance waiting time at potential assembly stations, material in stocks of the stations and current customer orders.

3.4 Hardware

For setting up a scenario that is comparable to real life machinery, a monorail conveying system is being introduced that works with self-propelling shuttles with a work piece holder capable to carry loads of up to 12kg (Figure 2). It is a modular system and gives the freedom of future extensions. The actual set-up of the monorail conveying system at the shop-floor of the BIBA [6] Institute allows the products to act flexible and to change the planned route by using the system integrated monorail-switches that offer multiple paths (Figure 1).

For the product it is then possible to remain on the main line or to deviate to a bypass. The implemented 125 kHz RFID technology was customized for our purposes to work with the casted RFID tags. RFID technology that is used in metals or even nearby is characterized by a low performance. The oscillating circuits of RFID tags detune in these environments, which has to be considered when tuning an antenna to work with metals.

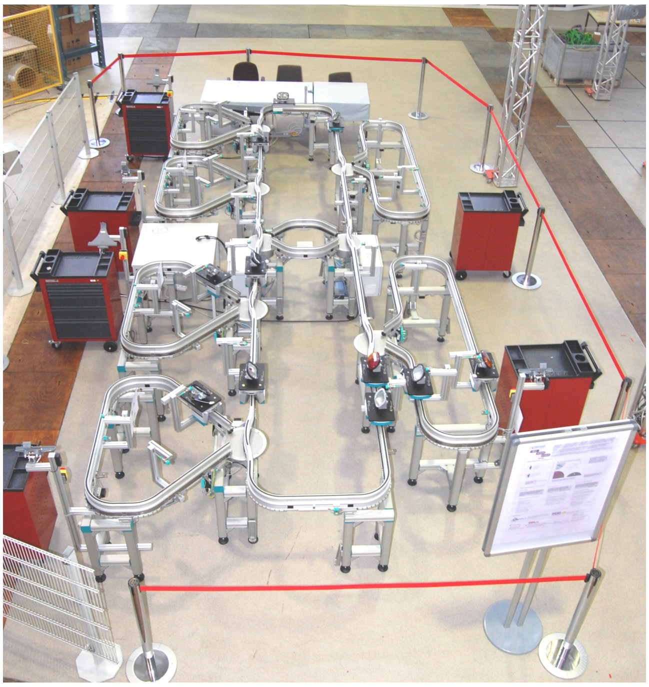

Figure 1. Mono-rail System

Figure 2. Shuttles with Intelligent products

4 FIRST IMPLEMENTATION

Induced by the amount of results coming out of the CRC 637 and the necessity to evaluate them, it was required to develop a platform that incorporates hardware such as RFID readers, a material flow system and on the top a software framework in order to integrate different methods and research results in a flexible manner. In this paper we describe the implementation of an autonomous control for manufacturing systems with the help of this developed framework. It is designed to have a user friendly interface. Different scenarios can be defined and edited by using the operator interface which is finally stored in a XML based configuration file. Editing a scenario includes the definition of final products to be manufactured, the manufacturing steps to be processed respectively the corresponding assembly

[6] BIBA: Bremer Institut für Produktion und Logistik GmbH

stations, needed parts, type of hardware (e.g. auto-ID Systems) and finally the material flow layout.

4.1 System Architecture

The described platform consists of different software packages that can be started in a distributed way on different machines. A scenario can be designed and started by using the operator interface. This action affects the starting of the multi-agent platform and creates the workshop agent that is equipped with the context information. The challenge of this agent is to create other relevant agents such as station agents depending on the available information. Furthermore the unique product agents will be created by the workshop agent at the first identification on the material flow system. Figure 3 shows the design of the system.

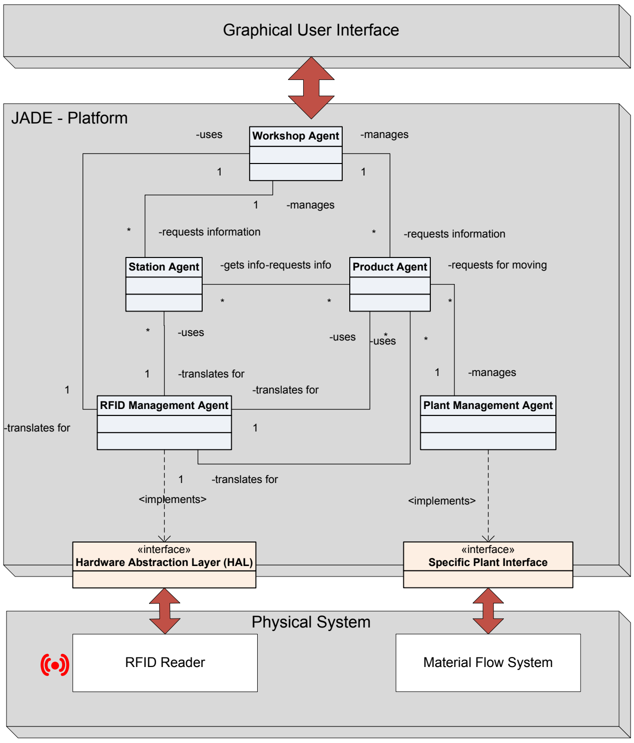

Figure 3. System Design

Based on MAS it seems to be appropriate to implement also the control software for hardware in form of software agents that pick up the signals, process them and communicate the information to other relevant agents. Up to now there are two hardware manager agents created, firstly for the RFID-Reader and secondly for the material flow system. These agents will be created automatically by starting the scenario. For supplying all created agents with context information, the configuration data is being send to all agents. The Hardware agents are triggered by real world signals (e.g. sensor signals) which induce them to broadcast information to the according product agents or station agents. As depicted in figure 3 product agents send requests to station agents as well as to workshop agent in order to gather necessary information for decision-making. The product agents also request the plant manager agent for any moving in the material flow system. The RFID management agent holds the connection to the RFID Hardware over the Hardware Abstraction Layer (HAL) and delivers important information to other agents. This information contains the ID of the product as well as the the geographical position of the product.

4.2 The Scenario

By using the developed framework we implemented a production scenario for investigating the applicability in the domain of production logistics. The scenario illustrates an autonomous assembly system for an automotive tail-light whereby the assembly itself is still designed to be a manual task. The autonomy refers to the decision-making of the specific products. The scenario has six stations; the starting station is implemented as the input/output for the material flow system where the the semi-finished parts (metal cast part with integrated RFID) enter the assembly system. It is also used to take out the assembled/finished products. The other five stations are designed as assembly stations. The implemented assembly stations correspond to the assembly process and are designed to assemble bulbs (coloured and clear), seals and three types of diffusers.

The assembly process consists of five stages which are depicted in figure 4. The process starts with inserting the semi-finished metal-cast part into the material-flow system. The products, represented by software agents, are targeting a type variant (colored, clear or dark diffuser), which they choose on their own by considering customer orders. Orders can be edited in a separate user interface at any time, which affects then the behaviour of the products. All related processes of transport of the work piece and decisions are made by the products respectively their corresponding agents. The three variants require specific parts during the production process, which are then scheduled and chosen by the products as well.

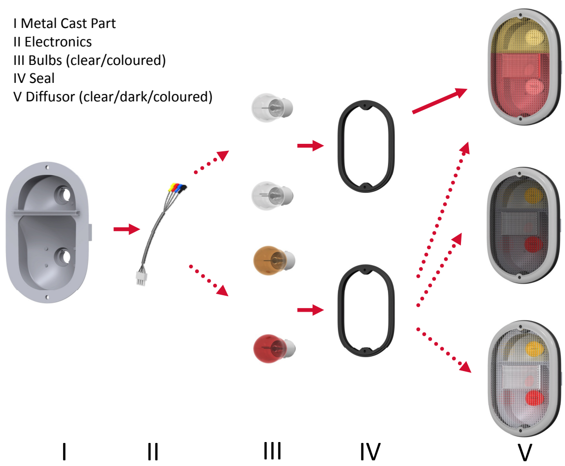

Figure 4. Assembly scenario

There are several possibilities to exert influence on the behaviour of the assembly scenario. Applying intended malfunctions or failures to the system or changing the costumer orders force products to react autonomously to the new situation and make a new decision.

4.3 The intelligent product software agent

This implemented scenario is completely based on the multi-agent structure of Java Agent Development Toolkit JADE which is considered as the leading open-source agent platform in academia. So every real object such as casting parts or assembly stations are represented by distributed software agents which interact with each other. In general the product agent is mainly dedicated to decision-making and uses autonomous methods to route its real-world part through the assembly process using recent information. Depending on its current state it requests other agents for required information and thereupon makes new decision that may change its state. There are also other agents implemented to represent hardware which have a quite simple design and act without active decision making algorithms. The implementation of the product agents is based on the described method of the autonomous product construction cycle for assembly systems [19]. The agents have the challenge to decide for the optimal product type considering different context factors.

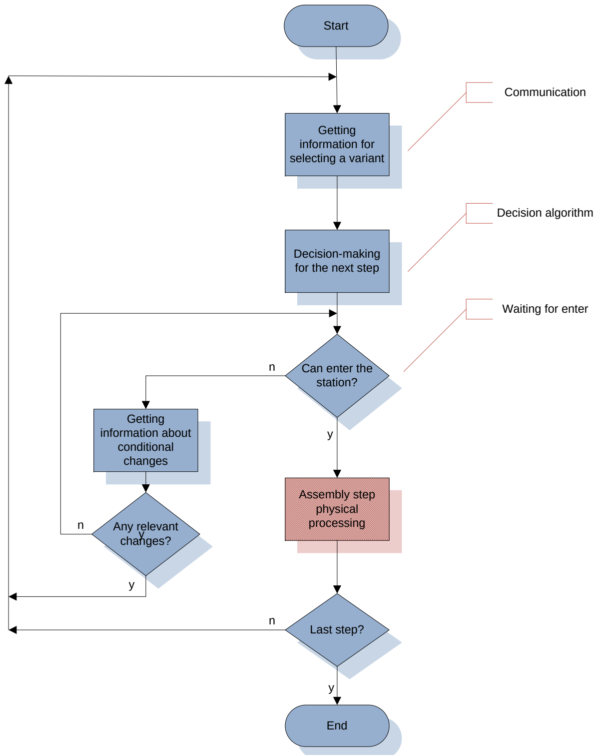

Figure 5. Scenario processing

The decision-making is in fact focused on choosing between the three product variants, which directly affects the next targeted production step respectively assembly station. These agents have to rerun the decision making process after each manufacturing step.

The product agents need important information for the decision-making such as current customer orders, waiting time at a potential assembly station and material in stocks of the stations. The needed information is gathered by communicating to other relevant agents such as the station agents, workshop agents and all other existing product agents. After having collected relevant data the product agent starts the decision-making process. There do exist logical (and physical) constraints that forbid products to choose the next production processes randomly. The currently possible variant (constraint) and the scheduling to the next production step is determined by the implemented decision methods. The used decision-making algorithm is described in an own section. Figure 5 shows the process flow within the product agent.

5 CONCLUSIONS

In this paper we presented the first implementation of a decentralized control of an industrial material flow system with autonomous control methods through a multi-agent-system. The intelligent product agent becomes the centre of attraction and is enabled to make own decisions. The implementation in this demonstration platform shows that when having a product centric approach and not only having the control over the product, positive effects can be observed. It becomes obvious that the basic technology fundamentals for intelligent products do already exist. We believe that an emergence arises out of the decentralized approach. This becomes evident when applying intended malfunctions to the system or when conditions (e.g. customer orders) change. The products are able to react to the new situation without a central re-planning. We can state qualitatively that an increased robustness can be observed. Future will show more quantitative results, when metrics and operating figures, such as cycle times, will be elicited with the system.

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