Agent-based Control for Material Handling Systems in In-House Logistics

Towards Cyber-Physical Systems in In-House-Logistics Utilizing Realsize Evaluation of Agent-based Material Handling Technology

Marco Lewandowski
LogDynamics Lab
University of Bremen
Bremen, Germany
lew@biba.uni-bremen.de

Max Gath
Institute for Artificial Intelligence
Technologie-Zentrum Informatik und Informationstechnik
Bremen, Germany
mgath@tzi.de

Dirk Werthmann
Intelligent Production and Logistics Systems
BIBA – Bremer Institut für Produktion und Logistik GmbH
Bremen, Germany
wdi@biba.uni-bremen.de

Michael Lawo
Institute for Artificial Intelligence
Technologie-Zentrum Informatik und Informationstechnik
Bremen, Germany
mlawo@tzi.de

***Abstract*—Automation and material handling technologies for in-house logistics tasks are widely applied. Generally, modules of the automation systems are planned, programmed, and commissioned according to specific requirements. Constantly changing conditions and flexible demands of production processes pose new challenges for the dynamic composition of various system components. Cyber-physical systems (CSP) propose an approach for storing and processing additional data of a physical system in a virtual representation. The paper illustrates an agent-based architecture for dynamic and modular control of single material handling equipment within a logistics system. Specifically, the paper addresses the issue of modeling and operating physical interfaces based on multi-agent communication and points out the benefits of this approach. The evaluation of the approach is done by implementing it into real industrial material handling equipment and gives a valuable insight into the prospects and challenges of cyber-physical concepts.**

Keywords—multi-agent systems; cyber-physical systems; automation technology; material handling technology; in-house logistics

I. Introduction

Logistics is often considered as the backbone of modern economy. This essentially includes in-house logistics which nowadays is important for an efficient production process for having competitive products on sale. In general, the term in-house logistics describes the flow of materials within the borders of a company. Within complex production networks these tasks are increasingly operated by 3rd party service providers on contract basis [1].

The changing attitude of in-house logistics operations, e.g., the division of work utilizing 3rd party service providers, led to increasing investments in automation technologies. In-house logistics is strongly related to storage systems, conveyor belts, sorting and handling systems for packed goods, as well as corresponding information flows. As these systems getting even more complex, it is harder to meet the requirements of dynamic changes in the in-house logistics environment, for instance, the type and amount of packaged goods, its size and weight, as well as corresponding picking and further value-adding services. Moreover, changing IT requirements influence and increase the complexity of in-house logistics systems. An example is the requirement to have transparent and ubiquitous information about all objects within the supply chain by tracking and tracing them via radiofrequency identification devices (RFID) and to share this information along the supply chain.

The modularization of system components in material handling systems minimizes the challenge of operating them in dynamic and complex environments. Consequently, the design of efficient physical interfaces and information flows between several modules becomes essential. A suitable modularization in the fields of logistics is the decomposition into the basic functions of automated handling of goods. These are, e.g., unloading pallets or cases, hauling, storing, passing switch points, removing from the transport stream, and finally loading palettes or cases [2].

In general, cyber-physical systems propose an approach for storing and processing data generated in a physical system in a virtual representation. Accordingly, the main topic of the paper is the conception of an agent-based architecture for dynamic and modular control of automation modules within an in-house logistics system. It addresses essentially the issue of modeling and operating physical interfaces based on agent communication and interaction.

For addressing the mentioned topics the paper is organized as follows. The previous paragraphs illustrated some key elements of today's challenges on industrial automation technology in the field of in-house logistics. This will be explained in more detail by presenting an overview of the state of the art in multi-agent systems and cyber-physical systems related to the topic of automation control. The second chapter illustrates the proposed methodology and architecture for modular automation equipment in logistics. Chapter 3 evaluates the proposed approach based on real automation equipment and ends up in first results in chapter 4. At least, the findings are summarized in chapter 5 in order to start further discussions on cyber-physical systems in in-house logistics scenarios.

A. *Multi-Agent Systems*

An intelligent agent is an entity that is "able to act without the intervention of humans or other systems: that agents have control both over their own internal state and over their behavior" [3]. Therefore, each agent is self-content and acts autonomously. To enable autonomous decision making, agents observe their environment with sensors, act upon it, and communicate and negotiate with other agents. Consequently, agents react on changing environmental influences by continuously sensing their environment [4]. In addition, they have proactive behaviors to reach their long term goals [5].

In multi-agent systems the planning and control is shifted from a central system with hierarchical structures to decentralized autonomously acting agents. The general problem is split into smaller problems that agents solve locally. In cooperating systems the agent's goal is to pursue a globally optimized behavior and achieve common goals whereas in competitive systems each agent acts selfish to reach its own objectives. Therefore, multi-agent systems show parallels to social structures, even to the human society.

The advantages of applying multi-agent systems are high flexibility, adaptability, scalability, and robustness of decentralized systems. As a result, the potentials of MAS are even higher in dynamic, distributed, and complex environments. Complex systems are modeled by the intelligent behavior and goals of its contained components, which is relatively simple compared to modeling the whole system behavior [6]; [7]. Furthermore, the modularization enables the dynamic reuse of agents and the ongoing assimilation of further components. Individual behavior of agents could also be changed while other parts of the holistic systems remain untouched. Numerous ranges of applications have been provided for industrial logistic processes [8]; [9]; [10].

B. *Cyber-Physical Systems (CPS)*

Information and communication technologies (ICT) facilitated an enormous change in the way humans, devices or machines interact with each other during the past decades. The ongoing development of embedded ICT solutions in diverse devices offers the possibility, that the interaction between humans and things as well as things between things will be ubiquitous in the future. [11]

By embedding ICT seamlessly into devices which, for instance, interact with the physical environment, a further dimension of interaction becomes reality. Embedded systems become cyber-physical systems (CPS), which means integration or interaction between the computational cyber world and the physical environment will be possible [11]; [12]. Comparable to the previous described agents, communication, and networking between CPS and further entities like human beings is also expressly stated. This leads to a CPS landscape of multiple entities. Accordingly, [12] concludes that CPS integrates computation with physical processes, in order to monitor and control physical processes. At the same time, computation is affected by the physical level.

C. *Prospects and Challenges for Multi-Agent Systems and Cyber-Physical Concepts in Automation Technology*

Both trends in the field of ICT, namely multi-agent systems and cyber-physical systems, affect the ability to operate and control traditional automation technology in general and also in-house logistics equipment. This addresses prospects expected in modern in-house logistics equipment, which are about reducing complexity, handling dynamics, and integrating further systems or manual work.

As a result, advantages of multi-agent systems in in-house logistics equipment have already been tested in an assembly scenario, e.g., by [13]; [14]. This scenario demonstrates how workstations in a production line can be modeled as agents behaving based on information about waiting queues, uncertain lead times, and failures. The scenario is based on real world industrial automation technology for the flow of goods between work stations. In conclusion, the case is also dedicated to cyber-physical systems as computational results from the multi-agent systems are used to control the material handling equipment and failures in the physical system influence the computational part. Other examples even allow further concepts for flexible material handling modules [15].

II. Methodology and Architecture

The proposed system for control the automation technology in in-house logistics scenarios is based on the Java Agent DEvelopment Framework (JADE) [16]. JADE complies with widely spread software standards from the Foundation for Intelligent Physical Agents (FIPA) [17]. The goal of FIPA is to promote standards for the interoperability of heterogeneous agents and their services.

Our multi-agent system is clustered into five core components. Each of them can be a service provider and a service consumer simultaneously. The following list shows the available core components, being explained in the subsequent sections and illustrated in Fig. 1.

- User-Interaction-Layer
- Transport-Agent-Layer
- Hardware-Agent-Layer

- Log-Agent
- Localization-Agent

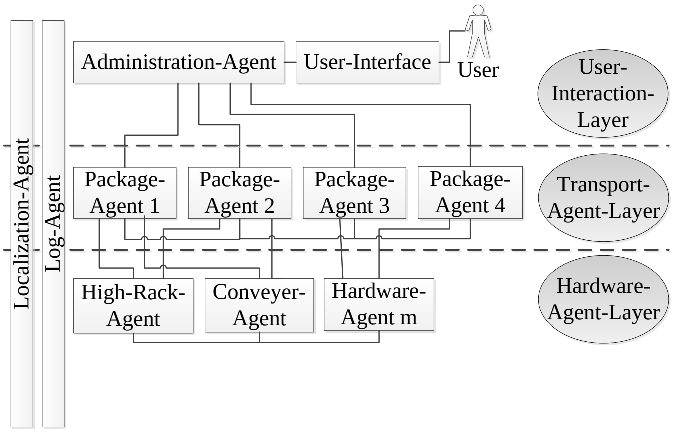

Fig. 1. General architecture of the multi-agent system

A. *User-Interaction Layer*

The User Interaction Layer provides a Graphical User Interface (GUI) to maintain, control, and configure the multi-agent system. The commands prompted over the GUI are handed over to the Administration-Agent. After checking the commands the Administration-Agent creates a Package-Agent for each transport item, for organizing its transport through the logistic system.

B. *Transport-Agent-Layer*

All Package-Agents are hosted within the Transport-Agent Layer. The aim of the Package-Agents is to reach their destination in the most efficient way by choosing optimal routes with minimum distances and shortest travelling times. Therefore the Package-Agents communicate with each other and with the Hardware-Agents in the Hardware-Agent-Layer.

C. *Hardware-Agent-Layer*

Every Hardware-Agent is responsible for the control of one machine. The machines are controlled based on the transport requirements expressed by the Transport-Agents. For fulfilling the transport tasks the Hardware-Agents must identify the agents of the machines being physically linked in order to communicate with them. Communication and interaction is required for realizing the handover of the physical transport items between the different machines of the logistics system.

D. *Log-Agent and Localization-Agent*

In addition to agents representing real objects or handling user commands, two agents are responsible for the management of the multi-agent system. The Localization-Agent handles all data while considering the position of each transport item within the logistic system. The second agent is called Log-Agent. Its task is to store and organize the log data generated by machines and agents. The log agent provide total access to all errors of the multi-agent logistic system for maintenance as well as process monitoring.

III. EVALUATION BASED ON INDUSTRIAL MATERIAL HANDLING TECHNOLOGY

The proposed concept of an agent-based architecture for automation technology of an in-house logistics system is evaluated by means of implementing a prototype with real industrial material handling equipment. Within the LogDynamics Lab at the University of Bremen [18], an in-house logistics scenario consisting of four different material handling elements is available and applied for testing:

- High rack storage system
- Conveyor system for mass feeding
- Conveyor system and basic sorter
- Conveyor system and outward transfer

The following Fig. 2 gives an overview about the scenario which is applied for the evaluation.

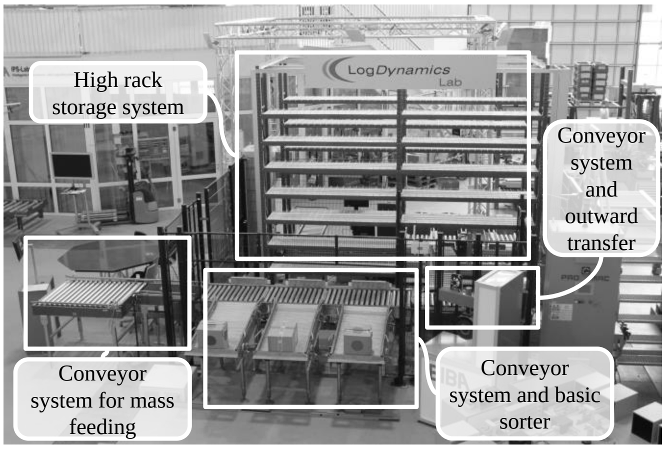

Fig. 2. Overview about the components of the evaluated material handling technologytechnology

The hardware of the high rack storage system is operated based on the provided interface of the manufacturer (connection via Transmission Control Protocol (TCP)). The Hardware-Agent is responsible for the abstraction between the presented high rack storage system and the multi-agent system.

Further elements of the conveyor with mass feeding, sorting, and outward transfer options are individually operated with Programmable Logic Controller (PLC). No interconnections are realized via low-level hardware-based integrations. Instead the individual Hardware-Agents of the modules are responsible for the interaction between the different modules.

Processing a transport task within the multi-agent system is shown in Fig. 3. At first a Package-Agent is created from the Administration-Agent. Afterwards the Package-Agent triggers all the handling processes within the logistic system for reaching its destination. For triggering the physical transport a so called transport order is send to the Hardware-Agent 1, where the transport item is physically located at the moment.

The transport order determines the transport item it wants to be transported next. Next, it sends the result to the adjacent component of the logistics system, represented by Hardware-Agent 2. Based on this information Hardware-Agent 1 sends a handover requested to Hardware-Agent 2. If Hardware-Agent 2 has enough capacity for the physical transport item, it sends a handover acknowledgement. If there is no capacity available the handover request is repeated after a given period of time.

Next the physical transports starts and the transport start information is handed over from Hardware-Agent 1 to Hardware-Agent 2. When the physical transport item has reached the adjacent physical component represented by Hardware-Agent 2 the transport end information is send to the component (Hardware-Agent 1), where the transport process started. Moreover the information, that the transport order is completed is send to the Package-Agent.

When the final destination is reached, this information is send over to the Administration-Agent and the Package Agent terminates itself. If the current destination is not the final destination, the Package-Agent sends a new transport to the Hardware-Agent, where the transport item is located at the moment.

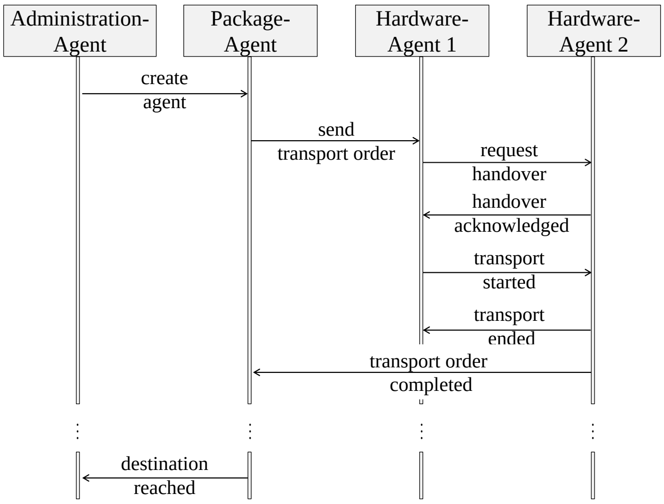

Fig. 3. Example of a communication sequence of a transport task

IV. RESULTS

The implementation process showed that the use of the software agents together with traditional small PLC programs is more clearly arranged and accordingly less complex by mean of arranging hardware and software to control the whole material handling system.

The main result of the evaluation was that the high level communication between the different materials handling equipment within the multi-agent system works well even in complex situations. These situations occur if a high number of transport items are transported within the material handling scenario. Moreover by adding more machines to the scenario, the concept was tested regarding its scalability. Result of the test was that it is easy to enlarge the scenario without changing the software agents of all objects involved.

In conclusion, the tests suggest, that a multi-agent system based on JADE is also feasible in real world environments. Moreover multi-agent systems offer the opportunity to handle the increasing complexity of nowadays logistics processes by offering a higher flexibility within the material handling system.

V. DISCUSSION AND OUTLOOK

The paper investigated the application of multi-agent systems for the control of industrial material handling technology. Therefore, real world industrial components, namely a high rack system, conveyor belts, and sorting systems are modeled and operated via agents in a multi-agent system. The system gives an insight into developing material handling equipment towards cyber-physical system components which can be adjusted flexibly and modularly into an in-house logistics system.

Different advantages in comparison to traditional approaches are pointed out. The system architecture permits the process planning and control to be delegated to individual mechanical sub-systems represented by agents. The connection to further sub-systems is designed via a fixed and central electrical wiring, as in traditional systems. A flexible, free, and definable interface through agent communication within the multi agent system enables the integration of upcoming requirements. The presented approach promises a higher flexibility through modularization of the whole system, reduction of complexity, as well as the opportunity to maximize efficiency for individual systems with minimum effects on other existing components of the system.

Based on the achieved results more research will be done on the given demonstrator. First it is planned to add even more material handling equipment, to experience more about the scalability and the agent implementation process. Along with this, limitations will be analyzed. In addition to the implementation of more material handling equipment, IT systems for locating the transport items will be installed. It is planned to track and trace the transport item with passive RFID. Therefore conventional RFID systems will be implemented as well as a Mojix system. Data generated by the RFID systems will be stored in an Electronic Product Code Information Services (EPCIS) repository linked to the multi-agent system. This offers the possibility to develop the Localization-Agent further on. All approach will support the ongoing process to make automation technology in in-house logistics part of CPS concepts.

ACKNOWLEDGMENT

The authors would like to thank the students being part of the student project “Virtual Logistics Lab 2.0” for their significant contributions to the paper and the practical evaluation: Benjamin Brieber, Jan Kuschan, Lukas Szymanski, Oliver Schnieders, Paul Heckmann, Subi Aili, Thomas Pfennig and Tim Schleier.

REFERENCES

[1] H.-J. Bullinger and M. ten Hompel, *Internet der Dinge*. Berlin, Heidelberg: Springer-Verlag Berlin Heidelberg, 2007.

[2] K. C. Arora and V. V. Shinde, *Aspects of materials handling*. New Delhi, Boston: Laxmi, 2007.

[3] G. Weiss, *Multiagent systems: A modern approach to distributed artificial intelligence*. Cambridge, Mass: MIT Press, 1999.

[4] R. Brooks, “A robust layered control system for a mobile robot,” *Robotics and Automation, IEEE Journal of*, vol. 2, no. 1, pp. 14–23, 1986.

[5] A. Rao and M. George, “BDI Agents: From Theory to Practice,” in *ICMAS-95: Proceedings First International Conference on Multi-Agent Systems*, Menlo Park, London: AAAI Press/The MIT Press, 1995, pp. 312–319.

[6] M. J. Wooldridge, *An introduction to multiagent systems*, 2nd ed. Chichester, U.K: John Wiley & Sons, 2009.

[7] D. Weyns, *Architecture-based design of multi-agent systems*. Heidelberg, London: Springer, 2010.

[8] P. Skobelev, “Multi-Agent Systems for Real Time Resource Allocation, Scheduling, Optimization and Controlling: Industrial Applications,” in *Lecture notes in computer science, Holonic and Multi-Agent Systems for Manufacturing*, V. Mařík, P. Vrba, and P. Leitão, Eds.: Springer Berlin Heidelberg, 2011, pp. 1-14.

[9] Klaus Fischer, Jörg P. Müller, and Markus Pischel, “Cooperative Transportation Scheduling: an Application Domain for DAI,” *Journal of Applied Artificial Intelligence*, vol. 10, pp. 1–33, 1995.

[10] A. Schuldt, *Multiagent coordination enabling autonomous logistics*. Berlin: Springer, 2011.

[11] K.-J. Park, R. Zheng, and X. Liu, “Cyber-physical systems: Milestones and research challenges,” *Computer Communications*, vol. 36, no. 1, pp. 1–7.

[12] E. A. Lee and S. A. Seshia, *Introduction to embedded systems: A cyber-physical systems approach*. Morrisville, NC: Lulu Enterprises, 2011.

[13] F. Ganji, E. Morales Kluge, and B. Scholz-Reiter, “Bringing Agents into Application: Intelligent Products in Autonomous Logistics,” in *Artificial Intelligence and Logistics (AiLog) - Workshop at ECAI 2010*, 2010, pp. 37–42.

[14] E. Morales Kluge, F. Ganji, and B. Scholz-Reiter, “Intelligent products - towards autonomous logistic processes - a work in progress paper,” in *PLM 10. 7th International Product Lifecycle Management Conference*, Bremen, 2010.

[15] T. Kruhn, S. Falkenberg, and L. Overmeyer, “Decentralized control for small-scaled conveyor modules with cellular automata,” in *Automation and Logistics (ICAL), 2010 IEEE International Conference on*, 2010, pp. 237–242.

[16] JADE Board, *JADE: Java Agent DEvelopment Framework - an Open Source platform for peer-to-peer agent based applications.* Available: http://jade.tilab.com/ (2013, Feb. 13).

[17] IEEE Foundation for Intelligent Physical Agents, *The Foundation for Intelligent Physical Agents.* Available: http://www.fipa.org/ (2013, Feb. 13).

[18] University of Bremen, *LogDynamics Lab: Demonstration and Application Centre for Technology in Logistics.* Available: http://www.logdynamics.de/lab.html (2013, Feb. 14).