Towards automation of low standardized logistic processes by use of
cyber physical robotic systems (CPRS)

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Abstract: Global logistics networks have an increasing demand for handling of general cargo. Particularly, hub-and-spoke networks require a lot of handling actions in order to realize benefits in comparison to point-to-point networks. The use of automation technologies for improving the handling efficiency is still very challenging because of low standardized logistic processes. Depending on requests of suppliers and customers the logistics service providers have to develop individual solutions of logistic processes. In most times, it requires the flexible use of industrial robots and leads to complex and time-consuming tasks of robot programming. In order to face this challenge, this paper presents an approach for intuitive control of robots by using the idea of a cyber physical system (CPS). Thereby, challenges for automation of logistic processes are described and the main idea of cyber physical systems is discussed. Subsequently the concept of cyber physical robotic systems for logistics (CPRSL) is depicted and an example application is given, which bases on robot programming by demonstration (PbD).

Key-Words: cyber physical systems, industrial robots, cooperative robotics, virtual reality, human machine interface, human computer interaction

1 Introduction

The given trend of globalization demands for efficient logistics processes, which enable the global sourcing and manufacturing. One option to improve the efficiency of such processes is to increase the degree of automation. The automation of logistics processes is an upcoming research field, which is focused on the improvement of material handling by the use of robotics and mobile technologies [1],[2]. Because of dealing with low standardized processes, the approach of using PbD is very promising. Low standardized processes need a lot of cognition for analyzing the actual situation and planning the operations. This cognition has to be taught by humans.

Therefore the field of PbD deals with the interpretation of human actions in different contexts [3]. Such interpretation can be done for example by the use of machine learning techniques or intuitive teaching devices. The main idea of this paper is to use such an intuitive teaching device by integrating it into the concept of cyber-physical systems (CPS), which allows to interact with other embedded systems via a cyber network or in this case via a virtual reality environment.

2 Challenges for automation of logistic processes

Logistics have to deal with a lot of external and internal disturbances. External disturbances can be for example bad weather, traffic or production delays. Also some internal disturbances can occur, like e.g. wrong labeling, wrong lot sizes or machine breakdowns. All disturbances affect the logistics performance in a negative way, because the optimal scheduled allocation of resources and materials is hindered. Besides, the system load varies strongly because markets and products change very fast and global. Such a dynamic environment encourages the low level of process standardization, which is common in logistics. Therefore the automation of logistics processes is a very big challenge.

The automation of logistics processes affects all kinds of system inherent flows: information, control and material. In general, the objective is to reach an integrated automation of all flows in order to improve the overall process efficiency. Thereby it is a requirement for at least synchronized flows. In an ideal cycle the information and control flow precede the material flow in order to get more time for allocating and setting up needed resources.
“Logistics automation is the application of computer software and/or automated machinery to improve the efficiency of logistics operations.” [4]

With focus on material flows, the core operations of logistics are packaging, handling, storage and transportation (PHS&T)[5]. It is useful to design automated logistics systems based on these physical operations, because the installation of information technology is more flexible than the machinery hardware for PHS&T. In general, each logistics system has to be tailor-made. By developing automated logistics systems a couple of different hardware and software components have to be implemented [4], [6], [1]:

- mobile & fixed machinery
- identification & tracking technologies
- monitoring & control software

Mobile & fixed machinery is needed for the execution of the PHS&T-processes. Automated cranes, conveyors, power & free systems, sortation systems and industrial robots provide amongst others the backbone of the machinery. In general, the use of robotics in logistics is a very auspicious field [2]. The RoboScan’07 study shows that 41 percent of the questioned logisticians are already using robotic systems in their application areas and over 60 percent wants to introduce or enhance the automation of logistic processes with robotic systems [7]. Additionally, automated guided vehicle allow the automation of transports. In order to control the logistics processes also identification and tracking technology is needed. Based on bar codes or RFID-tags, the products and materials may be identified automatically whilst moving through the machineries. As a result, the system situation can be captured and used as input for the monitoring & control software.

A monitoring and control software is for example a MES-System, which is used at an operational level in a production environment. MES is the abbreviation for manufacturing execution system. A MES-system gets production plans as input data from an enterprise resource planning (ERP) system. By considering sensor data from machine monitoring, it provides real-time decision capabilities for smaller production sub systems. Only smaller production sub systems can be controlled in such a way, because the data volume is too big for complete control with ERP. Therefore, a hierarchical approach is commonly applied by using ERP-systems for mid- and long-term planning and MES-software for short term planning.

GUDEHUS defines some directives for the automation of logistics [8]:

- Higher rate of mechanization and automation of logistics requires a good utilization in order to face the higher fixed costs
- Conventional transport and warehouse equipment are more flexible but have higher variable costs
- Costs of highly mechanized and automated systems can be less than half of conventional systems compared with same system load
- If only small capacities are required or the system load varies strongly it is more efficient to use conventional systems
- In order to get an higher system load it is useful to centralize logistics functions and consolidate transports and stocks

Additionally, some more directives can be defined:

- Centralisation of logistics functions can be increased by standardization of logistics processes
- Development of more universal machineries improves the possibility for consolidation and allows handling of low standardized processes
- Implementation of new planning and control strategies is necessary for balancing the system load

In conclusion, logistics have a high demand for intelligent automation, which is able to face the challenges of high dynamic logistics environments. The RoboScan’07 study shows that only 25 percent of the questioned logisticians demand for a full automation of their processes. Cyber physical systems provide an opportunity for further development of such intelligent automation, which can also interact with human workers.

3 Cyber physical systems

The term of cyber physical systems (CPS) is characterized by the integration of computing and physical processes[9]. Differentiating to “embedded systems” the aspect of networking is emphasized. There are a lot of successful applications for embedded systems, like e.g. automotive communication devices and control systems, which show the general demand for such close interaction between computing and physical process. The next step in evolution is the enhancement of embedded systems with networking capabilities[10].
Such cyber physical systems can communicate with each other in the cyberspace, which leads to networks and the capability of interaction. Figure 1 depicts the architecture of CPS.

![Architecture of CPS](image)

Fig. 1: Architecture of CPS [11]

The connection to other systems allows the consideration of different local information for the information processing and evaluation. The objective is to enable the CPS to execute tasks (controlling, regulating, monitoring, communication and signal processing) in an efficient and autonomous way[12].

### 3.1 Design challenges of CPS

A general challenge in the design of CPS is the integration of analog-physical with digital-cyber world[11]. In consequence, the different model types of these two disciplines have to be integrated. The analog-physical world is described by continuous mathematical models, while the digital world is based on discrete logic. In order to face these challenge six prioritized research directions are identified by DAMM [13]:

- seamless interaction
- autonomous systems
- distributed real-time situational awareness and problem solving
- safe and secure systems
- principles of architecture
- virtual engineering

In order to get a seamless interaction between different IT-systems, it is necessary to overcome language barriers by establishing secure authentication self-explanatory to interaction interfaces. Besides, the CPS should be able to behave as autonomous systems in order to reach a good performance even in unknown environments. The objective of distributed real-time situational awareness and problem solving is to create a joint picture in real time conditions in order to realize coordinated actions of the semi-autonomous sub-systems. It is necessary to develop safe and secure systems in order to establish and maintain confidence. One key to success is the design of standardized domain-independent principles of architectures in order to reach higher goals in complex systems, like e.g. sustainability. The last direction of research is the improvement of development processes by methods and tools, like e.g. virtual engineering, which help to design complex and cross-domain systems. SZTIPOVITS refers to a new generation of CASE (computer-aided software engineering) tools, which gives the opportunity for convergence in control, system and software engineering built on the principles of model-based design[14].

In addition, SHA defines four challenges of cyber-physical system research with focus on telecommunication [15]:

- real-time system abstractions
- robustness of CPS
- system QoS composition challenge
- knowledge engineering in CPS

The real-time system abstraction deals with the need for novel distributed real-time computing and group communication methods for dynamic topology control in wireless CPS systems. By developing safe and secure systems, the robustness should be improved in order to handle unknown environments and events. The system QoS composition challenge addresses the requirement for regarding not only the composability at each QoS dimension but also the question of how protocols interact. In order to interpret the many types of data in many different physical domains and application contexts, it is necessary to use machine learning and real-time stream data mining techniques. Thereby, it is a challenge to integrate distributed, dynamic, heterogeneous information sources, which can include data streams from the physical and cyber-world.

### 3.2 Networked robots

The concept of networked robots is linked to the concept of CPS but refers only to the field of robotics. The main idea of networked robots is the cooperation of several robots in order to perform tasks, which cannot be executed by a single robot or multiple uncoordinated robots [16]. Therefore, it is very necessary to establish network communication
between the robots and additionally stationary sensors, embedded computers or human users[3]. The IEEE technical committee on networked robots defines that a networked robot is a robotic device, which is connected to a communication network such as the Internet or LAN networks. Thus, the connection to the network can be wired or wireless.

Three classes of networked robots can be identified [17]. The first class comprises teleoperated robots, which have human supervisors sending commands and receive feedback via the network. The second class covers ubiquitous robotics, where networked robots are integrated into ubiquitous computing environments that include networked sensors, actuators and human users. The third class contains sensor networks, which allow robots to measure spatially and temporally distributed phenomena more efficiently, in particular when the robots are mobile.

4 Concept of CPRS for Logistics

The concept of cyber-physical robotic systems for logistics (CPRS) defines an application-oriented research field, which includes aspects of CPRS and networked robots. With respect to logistics and the PHS&T-processes, the focus of CPRSL is handling of goods. This includes all kind of logistics scenarios, like activities of grasping, picking and placing goods. The concept of CPRSL includes the following principles for the development of robotic systems:

- consistently use of virtual environment for coordination
- integration of human users as co-workers, supervisors or teachers
- using learning techniques and innovative input devices
- knowledge engineering for sustainable use of learned tasks
- using flexible and modular equipment

4.1 Robot programming by demonstration

As mentioned above, the knowledge engineering of CPS is one of the most challenging research questions today. Without knowledge, no intelligent automation can be done. Due to high dynamics in logistics as e.g. fast changing processes, the robots must be adaptable to different local environments and tasks. The faster they learn new processes or can be taught to them, the more profitable do they work. Therefore, innovative methods and techniques for rapid robot configuration are required.

The field of PbD is not new and started about 30 years ago[18]. Nevertheless, it pursues the training of robots with very flexible user-based interfaces instead of preprogramming robots offline at the computer. Thus, the concept is still contemporary. In the fields of logistics, the programming by demonstration seems to be one of the key elements for a rapid robot configuration, because each robot has to be taught to his very special task belonging to a superior process.

PbD belongs to the class of imitation learning, which is a powerful technique to classifying attempts in good and bad examples. The figure 2 shows such an imitation learning, where a reproduction attempt is evaluated by a user or the robot itself.

![Fig. 2: Programming by demonstration with additional learning techniques [18]](image)

Thereby, the user evaluation gives a direct feedback, while evaluation by the robot itself is known as reinforcement learning. In such a scenario, the user defines lacking process parameters and knowledge for the robot. Thus, he is a mediator between the robot-system and its surrounding.

State of the art techniques of PbD for manufacturing tasks [19] are not practicable in logistics, since critical process parameters such as position, orientation and sizes of cargo are highly variable. Thus, direct guiding of a robot to the corresponding handling points leads to time-consuming programming, nevertheless due to low velocities in the human-machine interaction.

4.2 Example application of CPRSL

The following scenario uses new techniques of PbD developed for workers instead of technical service personal in order to depalletize different homogeneous parcels from a pallet. In general, also palletizing scenarios can be imagined. By using this scenario as an example of a CPRSL, there is the definition for five subsystems:
Due to the chosen scenario, parcels represent the handling-objects, which should be depalletized by a standard industrial robot.

The robot simulation tool, EASY-ROB™ is used in order to give a visual feedback and to interpolate the movement of the robot between user defined points. Within this tool, a complete motion planning for industrial robots can be done. The visual feedback allows the user to detect collisions while moving the tool center point (TCP) of the robot along a generated trajectory. A robot program, generated in the system specific code, can be exported. In order to define the task specific handling points by the user, a manual controlled 6 DOF-tracking input device is tracked by IR-cameras. Specific interfaces between the tracking system, the software and the industrial robot ensure the communication of the parts. Figure 3 shows the scenario represented in the simulated virtual world.

The demonstrator operates as follows: The user places a filled pallet within the workspace of the robot. In the software he has to define if the parcels on the pallet are available in straight stacks or nested. The position of the pallet is given to the system by three edges of the pallet. For this purpose, the user has to detect the edges with the “6 DOF-tracking device”. The tracking system detects the position within the system coordinates. The size of the parcels is given to the system in the same way: the user detects three edges of one parcel.

Subsequently, the positions of the parcels have to be defined. The operator selects the center point of the top package surface with the input controller (Figure 4). Thus, the position and orientation of the controller is relevant to the location of the parcels. The user has to detect all parcels at the highest position of the pile. By selecting a top surface of a parcel the system generates a model of the parcel within the software at the defined position automatically. Due to the selected modus – stacked or nested accumulation of parcels – there will be only one parcel at the position of the input controller or a straight pile of parcels from the detected position down to the pallet. Depending on the selected modus the software calculates trajectories for the highest parcels of the pile (nested) or for all parcels (straight).

The user can check the planned motion of the robot within a simulation on a screen. Collisions or singularities of the robot can be identified and counteracted. If the movement of the robot is without any malfunction and approved by the user, a system specific robot program will be generated and transferred to the robot automatically. The robot executes the planned movement and can be used for the next task. In addition to the motion planning by defining the gripping points of individual handling tasks, the system may also be used by the continuous tracking of the “6 DOF-tracking device” in order to generate a program on the base of the hand-movement of the user. Examples for this are painting or welding operations of components in small batch production.
5 Conclusion

Due to the fact, that such processes are low standardized and vary strongly, the automation of logistics processes is one of the most challenging research fields. Therefore, the concept of cyber-physical robotic systems for logistics (CPRSL) was derived from the original idea of CPS. According to the defined principles of CPRSL, an example application was given by using techniques of PbD together with a standard industrial robot for a depalletizing scenario of homogenous goods. The used setup shows a lot of potential for further development and more complex scenarios, like e.g. unloading of mixed containers with chaotic packing patterns.

References:


