Keeping Track of the Physical in Assembly Processes

A Conceptual Architecture for a Process-driven Assistive Assembly System

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***Abstract*—Assembly processes are a particular class of production processes that have gained increasing importance as to their impact on flexibility and efficiency of the overall process. Assembly processes are characterized by high variability concerning the type and logical flow of tasks to be performed, the devices and tools used, the materials and information to be processed. Due to the complexity of such processes a relatively high ratio of tasks is still performed by human workers. Keeping track of materials, devices and tools used and at the same time providing digital assistance for increasingly complex assembly tasks requires adequate modeling techniques as a prerequisite for respective systems design. In this paper we discuss challenges for modeling assembly processes based on a real-world assembly line from our learning factory lab. Finally, we propose an architecture for a process-driven assistive assembly system which shows the interplay between process based monitoring, task assistance and workplace sensors.**

Keywords—manufacturing, assembly, process management

I. Introduction

The increasing demand for highly customized products has enforced manufacturing companies to seek ways to efficiently deal with an inherent increase in process complexity. Today's manufacturing companies therefore usually follow an approach where products are highly modularized. Therefore, high volumes of individual parts are still manufactured at low cost (economies of scale) and are assembled to customer needs at a relatively late stage in the production process [1]. Thus, tie-up of capital in product specific inflexible production lines and stocks can be kept at minimum.

These assembly processes are characterized by high variety regarding the type and number of tasks to be performed, the devices and tools used, the materials and information to be processed [2]. Although recent technological developments, e.g. in robotics, fueled an increase in assembly automation there is still a relatively high ratio of tasks that needs to be performed by human workers [3]. However, due to the complexity, human workers are frequently exposed to a high cognitive [4] and motor load which often leads to significant decrease in process quality (e.g. unsynchronized processing time) and product quality (e.g. bad fitting of assembled parts).

In recent years, academia and industry have proposed a large variety of approaches to reduce both cognitive and motor load in assembly processes. These approaches can be classified into those that aim at product design and those that aim at process design. In practice, both approaches are usually combined to support a human worker in assembly tasks. As a result, many assembly lines are nowadays equipped with some kind of on-site assistance system for the human worker.

Although these systems have proven to be effective in reducing assembly errors they are mainly limited to provide on-site assistance and are not adaptive with regard to changes of product features ("lot size 1"), related changes of assembly processes. These shortcomings are due to the fact that current systems are not designed to be integrated with production planning and control systems and the fact that manual tasks are not easy to track automatically on a fine-grained level.

In this paper we propose an architecture of an assembly system that features a highly responsive human task assistance system. The proposed assistance system makes use of fine-grained motion pattern based models of manual assembly tasks that are related to more coarse-grained process models. The motion patterns together with a special sensory equipment are used to keep track of the status of individual assembly tasks and process instances. A respective process engine allows for detailed monitoring of assembly processes and at the same time enables task-specific and event-based worker assistance. In section 2 we describe related work. In section 3 the characteristics of assembly processes and the problem of tracking assembly tasks is outlined. In section 4 we describe our conceptual process architecture for a future process-driven worker assistance system.

II. Characteristics of Assembly Processes

A. General characteristics of assembly processes

According to the Association of German Engineers (VDI) assembly is defined as the set of all processes that serve the assembly of geometrically defined objects [2]. These processes are essentially tasks like joining and work piece handling [3]. In addition to that, operations such as adjusting, checking and specific operations such as marking, heating, cooling, cleaning, deburring are often carried out during assembling. Assembly tasks partially require materials, tools and devices (e.g. screws, hammers, measuring instruments). Recently, especially assistive devices such as screens and eyeglasses are increasingly employed to display task-specific information.

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As can be seen from the short general description of an assembly process above, a large quantity and diversity of technical systems and human agents is involved in the actual execution of assembly tasks to transform input materials into finished products or semi-finished components.

B. Exemplary assembly process

The characteristics of a concrete assembly process are illustrated by a simple example – a toy truck assembly. The assembly process presented here is part of our Learning Assembly Lab (LAL) at the Institute of Management Science (IMW) at TU Wien.

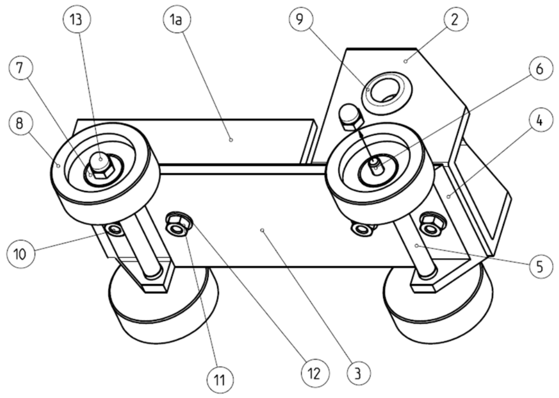

Fig. 1. Product structure of examplary product - toy truck

Figure 1 shows the design and product structure of the toy truck. Although a relatively simple product, the truck consists of 34 components (13 are different). which have to be assembled successively. The whole process is executed by one or more human workers at an assembly line consisting of multiple mobile assembly stations (see figure 2).

Each assembly station is equipped with flow racks that hold containers with necessary parts (e.g. platform, loading unit, wheels, axes) and materials (e.g. screws, nuts, washers, boxes for packaging). In total 13 containers for parts and materials are placed on conveyors that ensure a constant flow of materials towards the assembly table. The tools (e.g. electric screwdriver) necessary to perform the assembly tasks are positioned overhead and are fixed on flexible self-reeling lines that reduce tool weight and allow the worker to release the tool immediately after usage without the need to remove it manually. Each station is additionally equipped with a screen and computer that can be used to display relevant information such as the work orders, bill-of-materials, and drawings relevant for assembly tasks. At the beginning of an assembly process on each truck platform a RFID tag is applied to allow for a tracking of work progress and localization of work piece across the whole assembly line.

The whole assembly process is composed of 64 elementary tasks in sequence of which many tasks are repeatedly executed. In total about 193 task instances are executed, e.g. mounting of tires to rim is repeated 4 times. The most frequent tasks can be classified into fetching, picking, positioning tasks, pressing, screwing, packaging. In fact, almost half of the tasks is targeted at fetching, picking and movement of parts and material.

The Learning Assembly Lab can be regarded a state-of-the-art assembly line that reveals important features such as RFID tagged work pieces and computer equipped work stations. However, several features for automated work progress and material tracking as well as task-specific automated assistance is not implemented yet. As we are currently merging our LAL and our Learning and Innovation Factory (LIF) towards a next generation Industry 4.0 Pilot Factory, we are planning to upgrade our Learning Assembly Line towards a fully integrated process-driven Industry 4.0 Assembly Line. For this purpose, we propose a respective architectural concept in the next section.

Fig. 2. Assembly line for truck assembly in TU Wien Pilot Factory

III. Conceptual Architecture

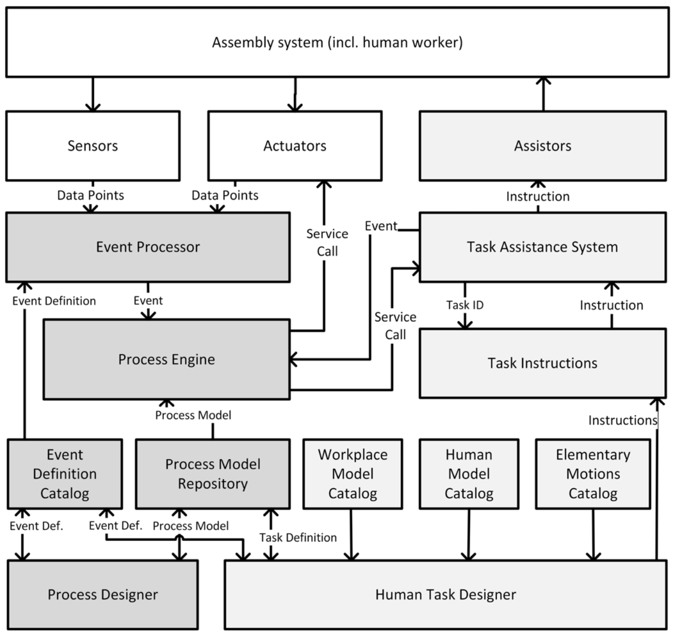

Fig. 3. System architecture for process-driven assembly system

In this section we describe a conceptual architecture for a responsive assembly system. The architecture as it is proposed here is planned to be implemented in our Industry 4.0 Pilot

Factory in Vienna. However, in the following sections we describe the architecture from a general point of view. Figure 3 shows the main components and their interactions which will be described in the following subsections.

A. Assembly Station

The assembly station is the workplace of the assembly worker. Depending on the actual product to assemble it typically consists of a table, a rack with boxes for storing the different parts needed, and a set of tools that support the worker. Assembly stations can be grouped together to form an assembly line or cell. In this case each station is responsible for a particular assembly task.

B. Sensors, Actuators, Assistors

Assembly stations are equipped with sensors, actuators and assistors. These devices serve as the interface to the workplace and the worker. Sensors are used to keep track of the parts' stocks and the tools state of operation. Moreover, we use an array of ultrasonic sensors to keep track of workers' assembly operations (see figure 4). An array of three sensors receives ultrasonic signals from respective ultrasonic transmitters which

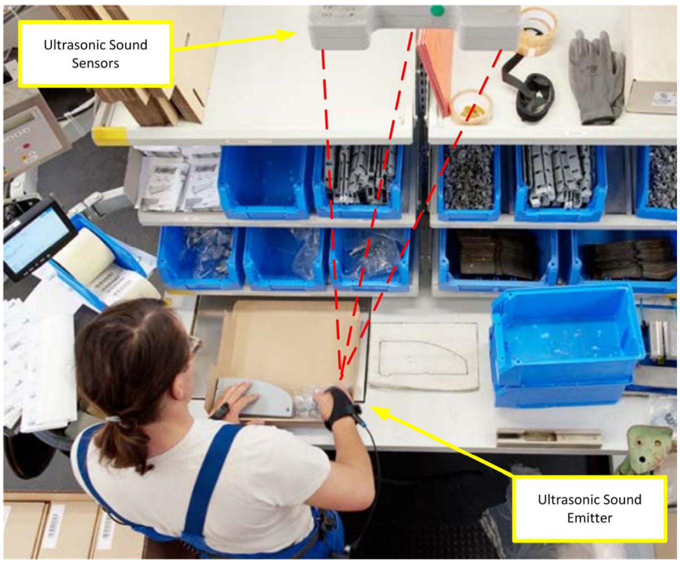

Fig. 4. Tracking system for motion tracking (courtesy of Sarissa Gmbh)

are installed on the worker's hand or on a tool, e.g. an electric screwdriver. From the ultrasonic signals the exact position of the hand or tool can be computed. All signals captured by sensors are transformed into interpretable data sets. These data sets are collected by the Event Processor (see section E).

Actuators in an assembly station are devices that help a worker in physically demanding tasks with some sort of drive. They are typically used to position or join parts together. Increasingly also robotic actuators are used. As tasks are accomplished primarily by humans these devices mainly have a supportive function. Devices such as an electric screwdriver can be programmed and controlled during execution according to certain characteristics such as torque or speed.

Assistors are devices that help a worker with cognitively demanding assembly tasks. Assistors can be manifold. Examples of such devices are screens that display a simple task list and task-specific information regarding such as a drawing and information regarding the correct positioning of parts. Another example are LEDs that indicate the correct part and its box to be picked in an assembly task. Increasingly also smart glasses are used to show information or graphical guides for difficult positioning tasks. Assistors are activated in response to a specific task or event taking place.

C. Task Assistance System

The application logic of the assistors' features is covered by the task assistance system. The task assistance system communicates with the process engine and provides task-specific logic and content for the interface level – the assistors. For example, a screen displays task- and material specific instructions.

D. Human Task Designer

The Human Task Designer is used to define and specify assembly tasks in detail. These task models complement coarse-grained process models with fine-grained information about the different elementary operations needed to handle, position and

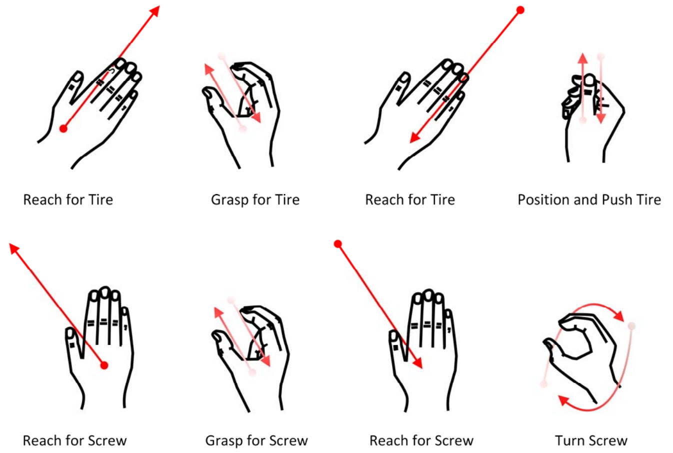

Fig. 5. Motion patterns (left-to-right) for toy truck assembly. Upper row shows sequence for tire mount. Lower row shows sequence for chassis mount.

join the different parts of a product. For the purpose of defining events that trigger assistors and actuators workplace models, human worker models [5] and reference models for elementary human motions [6] are combined to allow for a detailed specification of human motions and operations.

The detailed specification of assembly tasks is the prerequisite for a fine-grained tracking of work progress and tracing of materials. For a detailed monitoring of an assembly task physical motion patterns are matched against actual motions during task execution. Matching actual motions through ultrasonic sensors or cameras against typical patterns leads to the throwing of events which lead in turn to an assessment of work progress and triggering of assistors and actuators that support the worker. Examples of motion patterns based on the MTM [6] reference tasks are shown in figure 5. The Human Task Designer is also used to create task-specific instructions for the human worker, e.g. a video tutorial generated form a human worker and workplace model. These instructions can be called by the Task Assistance System and are shown to the worker at the workplace.

E. Event Processor

The Event Processor is used to collect data points from sensors and to detect events that trigger subsequent tasks. For this purpose, the event processor matches single or multiple data points against event definitions. Event definitions are created through the Process Designer. The Process Designer is a process modeling environment that is used for coarse-grain process flow definition. Process definitions (or models) can be enriched by fine-grained human task models created through the Human Task Designer. For example, the positioning of the screwdriver at the charging station (movement together with charging signal) can be defined as the end-event of a screwing task.

F. Process Engine

The Process Engine (PE) is the core component of the whole Process Management System (PMS). Together with the Process Designer and the Process Model Repository it constitutes the PMS (dark gray in figure 3). It keeps track of task instances and is the primary control unit of the whole production process. Task instances are triggered by events which are thrown by the event processor. Task instances are the virtual counterparts of the physical assembly tasks. Depending on the tasks instantiated physical actuators and assistors are executed or activated. E.g. a screwing task may be assisted by a screwing instruction, a LED that indicates the nuts and bolts to be taken and a screwdriver which loads a special screwing program.

IV. Related work

The work presented here is the continuation of our research work on optimization of assembly processes, e.g. [7], our work on learning factories, e.g. [8], and has recently been fueled by a public funding for a next generation pilot factory. The proposed architectural concept is based on fundamental work in the area of business process management systems and assembly systems design and the relatively new domain of cyber-physical production systems [9], [10]. In the following we outline only the most relevant and recent developments in the area of assembly systems design.

Shanti et al. [11] propose a method to identify assembly events based on data streams from electro-magnetic detection of body postures. In contrast to their approach we targeted a low-cost and minimum-intervention apparatus for motion tracking based on ultrasonic capturing. We also intend to use combinations of sensor data from different sensors to detect events. The usage of elementary task catalogs like MTM in combination with human worker models has been investigated by [12].

Regarding architectural concepts of assembly systems, the works of Thramboulidis [13], Müller et al. [14] and [15] point in similar directions. Thramboulidis uses a model-driven approach to cyber-physical assembly systems design. The author suggests a meta-model for assembly systems modeling including a meta model for assembly processes and related task types. Müller et al. present a conceptual architecture for an agent-based control architecture for a cyber-physical assembly system. In both approaches the integration of process modeling with fine-grained human task and event modeling has not been addressed.

V. Conclusion

In this paper we have presented a conceptual architecture for a process-driven assembly system that we are planning to implement in our Industrie 4.0 Pilot Factory at TU Wien. It is based on the assumption that coarse-grained process modeling in combinations with fine-grained human task modeling enables tracking of work progress and material stocks in assembly lines and at the same time allows for task-specific worker assistance. Although our architecture is still in a conceptual state, it shows the interplay between the physical and virtual world for the rather complex application domain of assembly processes. In the future, we will both extend and detail this architecture towards integration with production planning and control.

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