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Introducing process building blocks for designing human robot interaction work systems and calculating accurate cycle times

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Abstract

In comparison to classic automated solutions, the direct cooperation of human workers and industrial robots offers new potential regarding flexibility, cost and ergonomics. However advantages are mostly not obvious and only few applications using human-robot interaction have found their way to the shop floor. Reasons for that are the lack of knowledge about this new technology, its capabilities and the availability of planning tools supporting the design of hybrid work systems.
This paper presents an approach to describe robotic motions based on process building blocks as they are used in productivity management methodologies like Methods-Time Measurement for manual assembly. In combination with existing process building blocks systems it is possible to describe and design hybrid assembly stations taking mutual motions of human beings and robots into account and to extract accurate cycle time information.

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1. Introduction

In order to sustain competitiveness within production of industrial goods, further automation of processes is still one of the main strategies in industry, especially in high wage countries. In this context industrial robots have been also used to improve quality and to relief human workers from rough and strenuous working conditions. Over the last years collaborative robots were developed. Supported by computer vision systems and equipped with sensitivity to fulfil assembly tasks and to enable collaboration with the human, they offer potential to lead to productive and flexible solutions [1], [2]. Using collaborative robots it is possible to eliminate ergonomically critical tasks in work systems where it was not possible before. Additionally lower unit cost can be achieved for production volumes where classic robot automation is not economically beneficial in comparison to manual assembly [3].

The capabilities of human operators are cognitive skills, flexibility and versatility whereas robots show benefits when it comes to lifting high weights and executing highly repetitive tasks at constant quality [4]. Human Robot Interaction (HRI) pursues the goal to combine the strengths of both resources in bringing robots and humans together in hybrid work systems.

However considering such collaborative robots, the planning of work systems becomes more complex. Tasks have to be assigned to the human operator and to the robot, so that their collaboration is defined in an efficient way. The decision where to use hybrid work systems is usually solely based on experience and intuition since there are only few planning tools available for the design of hybrid assembly lines [5].

During the initial stage of planning a work system a quick and easy way to generate exact cycle time information is mandatory [6]. However as of the current state of the art the planning of hybrid work systems is only possible using computer-simulation. These simulations are very time- and therefore cost-intensive. Hence these methods are not suited for the early planning stage of work systems.

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This paper introduces process building blocks (PBB) to describe, simulate and evaluate robotic motions, which can be performed simultaneously to human motions. In combination with the existing Methods-Time Measurement (MTM) PBB-system MTM-1 it is possible to design work systems using HRI and directly generate cycle time information. This is especially useful in the early planning stage of work systems, where different alternatives can be assessed with a relatively low analyzing effort.

2. State of the art

2.1. Robot assembly planning

The modelling of robotic workstations is a complex task usually done using 3D-computer simulation. Almost all robot manufacturer offer a virtual development suite, including exact path planning algorithms to extract cycle time information. There are also simulation programs available featuring the possibility to simulate manufacturer independent but cycle time information is entailed with uncertainty, since models of the robot controller and thereby exact path planning algorithms are not freely available. All 3D-simulation software, however, require training for using the particular program and generating 3D-layouts is time intensive. This limits the usability during the early planning stage of assembly work stations.

One specific approach for planning robotic assembly stations, called Robot Time and Motion (RTM), was developed in the late 1970's. RTM is a system of predetermined motion and it is possible to generate cycle time information for robotic motions. In RTM five groups of elements are distinguished [7]:

1. Movement elements: Reach, Move and Orient
2. Sensing: Stop-on-error/force, Touch & Vision
3. Gripper or tool elements: Grasp and Release
4. Delay Elements: Process-Time-Delay and Time-Delay
5. Mobility: straight, spin turn, curve and diagonal moves

RTM is only applicable when the exact motion of the assembly task are available. Therefore an attempt was made to compare RTM and MTM in order to establish a link of the resulting cycle time and to simplify cycle time estimations. However it was found that the accuracy of these predictions is not good enough for actual implementation [6].

2.2. Human assembly planning

One of the most complex elements in assembly planning is modelling the human being. In order to use this resource in an industrial setting efficiently, it is necessary to create system models of human work. With these system models the work of the human being is described in an abstract way and can be evaluated [8].

The first description model of human motion in this context was created by Frank Bunker Gilbreth in the course of his motion studies in the early 20th century called Therblings [9]. Having an inventory of 17 basic motion elements, workplace analysis could be performed in terms of an economic assessment. Those motion elements have been subject of an ongoing development. With the assignment of time values they have been the basis of the PBB-system MTM-1 (MTM stands for Methods-Time Measurement) and have formed the cornerstone for the process language MTM used in industrial engineering for planning human work all over the world. The core element of this process language are MTM-PBB [10]. A MTM-PBB consists of a well-defined section of the process, the appropriate time value and a distinct codification [11].

Furthermore MTM-systems were developed as aggregations of the basic system. For example for small and single batch-production (MTM-MEK) or for series production (MTM-UAS), yielding reduced analyzing effort [12].

2.3. MTM Process language

The MTM process language has the following four functional properties [10]:

1. Immanence of modeling: Productivity management is based on standard of results; these are target results for the operation of work systems. A work system is a model and for this reason target results are formed directly and not indirectly. E.g. desired values are determined directly and do not have to be derived from measured values.
2. Simulation capability: Using MTM-PBB-systems is also possible with virtual work systems, e. g. when work systems are still in the planning phase of the product creation process phase or if alternatives are evaluated. This is possible because no physically existing work system or hardware is required when using an MTM-PBB system.
3. Variation of complexity: All PBB are ordered hierarchically regarding their complexity. The granularity of process modeling can therefore do justice to any practical requirements such as mass- or serial production.
4. Reference performance trustworthiness: All MTM-PBB-systems are based on MTM standard performance as reference performance. This reference performance is used worldwide.

With MTM-PBB-systems it is possible to design work systems as a fundament for determining also cycle time information. This way the boundary conditions of production are described (e.g. design of the work system, product variety, material supply, cycle time). In connection with resulting parameters, like for example the target time, different layout options can be evaluated in the early planning stage.

2.4. Scientific Gap

The planning and design of work systems usually starts in the early phase of the product creation process. Different options are evaluated in the concept planning phase of the work system. In order to consider HRI in this concept phase and to make a comparison of different solutions it is necessary to determine assembly times for the human being, for the robot as well as for their mutual motions in a simple and easy way.

If there is a close link between the work of the human and the robot, the work of the human can be modelled using PBBs such as MTM. However this is not possible when it comes to the robot and even more for HRI. The planning and assessment of solutions using HRI is only possible under high effort - for example with 3D-simulation. Other approaches for robotic

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