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Planning Operator Support in Cyber-Physical Assembly Systems

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Abstract: Due to the complexity of assembly processes, a high ratio of tasks is still performed by human workers. Short-cyclically changing work contents due to smaller lot sizes, especially in the varied series assembly, increases both the need for information support as well as the risk of rising physical and psychological stress. The use of technical and digital assistance systems can counter these challenges. Through the integration of information and communication technology as well as collaborative assembly technologies, hybrid cyber-physical assembly systems will emerge. Widely established assembly planning procedures only facilitate the design of purely manual work system. In this paper, two new planning approaches for digital and technical support systems in cyber physical assembly systems will be outlined and discussed with regard to synergies and delimitations of planning perspectives.

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1. CYBER PHYSICAL ASSEMBLY SYTEMS

Assembly systems especially in high-wage countries are faced with the challenge of tackling rising product and process complexity in terms of individualized customer needs and an aging society by demanding preservation of efficiency as well as productivity at the same time. Assembly systems, as they are established in the industry, are reaching their limits increasingly when encountering these challenges. By networking digital data and modern forms of information and communication technology with physical production and assembly processes, altered forms of assembly processes will be possible (Dombrowski et al. (2013)). Assembly processes will be upgraded in this way to adapt economically to requirements of costumer-individual products (Schlund and Gerlach (2013)). Cyber-physical systems (CPS) realize a connection between the physical and the digital world. CPS are composed of a surrounding physical object and an embedded computational system, which collects and processes digital data and interacts with physical processes via actuators. These systems are linked through digital networks and use available data and services globally. CPS are not (technically) closed units. They are defined as open socio-technical systems, which are characterized by a high degree of cross-linking of the physical, social and virtual world as well as by the intelligent use of information and communication systems (Geisberger et al. (2012)). By integrating assembly equipment with CPS-characteristics into assembly environments, so called cyber-physical assembly systems (CPAS) will emerge. Existing examples for such equipment are fastening tools that identify product variants through ICT and parameterize automatically in accordance or small parts containers which are able to determine their fill level and communicate with the parts supplier to assure accurate replenishment.

In addition to cost pressure in global competition and the need for age-appropriate work environments, more frequent changes of work contents as a result of higher product variance, reduced lot sizes and shortened product life-cycles make it more difficult for assembly operators to build-up task routine. In this regard, industrial robots have been used already in the past to automate certain tasks for improved production economy and to relief human workers from rough and strenuous working conditions (Krüger et al. (2009), Drust et al. (2013)). At the same time, information provision was used to deliver operators with instructions and details required to successfully fulfil manually executed tasks, mainly paper based (Wiesbeck (2015)). During recent years, *collaborative robots* have been developed, which, due to their on-board sensitivity as well as communicative and cognitive capabilities, are better than ever able to directly support humans physically in manufacturing processes, as shown in Michalos et al. (2015) and can therefore be called *technical assistance systems*. Simultaneously, latest developments in the field of augmented reality as well as mobile and wearable devices have enhanced possibilities to provide information to operators right on the work process as needed and in a digital format – *digital assistance systems* emerge (Hold et al. (2015)). In this regard, industrial and system engineers are

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supposed to develop and deploy an appropriate as well as technically feasible degree of operator assistance to achieve a human-oriented, efficient work environment. Therefore, the authors' research reflected by this paper is supposed to identify and develop an integral methodical approach that helps engineers to design CPAS which integrates technical and digital assistance systems. Beyond technical feasibility and temporal aspects of robot use, an important design dimension to be considered is capabilities of humans and robots and actual need for assistance.

2. TECHNICAL ASSISTANCE SYSTEMS

In a simplified perspective, robots for example have advantages in carrying out monotonous, repetitive tasks that require high precision and path accuracy, while human operators are better skilled for tasks which require situative force regulation or vision-hand coordination. Under purposeful consideration of human and robotic skills and strengths, ergonomics can be improved in hybrid over manual work systems. The result is a *hybrid* assembly system (Consiglio et al. (2007), Lotter (2012)).

Human-robot collaboration was standardized most recently by ISO/TS 15066 and can take place within four essential collaboration modes:

- *Safety-rated monitored stop*: Robot stops operation as soon as an operator enters the collaborative workspace.
- *Hand guiding*: Robot motion happens only through direct, manual operator input.
- *Speed and separation monitoring*: Robot decelerates as distance between robot and operator decreases, and comes to complete stop if a minimum distance is fallen short of.
- *Power and force limiting by inherent design or control*: In collision events, robot imparted forces are below threshold values that may cause substantial injury.

For immediate human-robot collaboration in assembly, primarily power and force limited robots are suitable, as only they allow concurrent action of human and robot within narrow work environments and action distances. Fig. 2 shows the overlap of reach and gripping areas of operators and robots in a joint workspace. Such robots are for example equipped with force/torque sensors or they monitor motor currents to detect collisions and stop movements. From a work organizational perspective, integration of robots and humans is conceivable in assembly lines of any shape to single workstations and in parallel as well as face-to-face arrangements.

3. DIGITAL ASSISTANCE SYSTEMS (DAS)

Operators are supported by DAS during the execution of their activities with the aim to minimize or to eliminate the discrepancy between available operators' knowledge and the required knowledge to successfully fulfil a certain assembly task, in order to increase the productivity (Spillner (2015)) through thought-out digital representation of information. The primary objectives of DAS are reduction of training time, search times, operating errors and improving the work force in stressful situations (Zaeh et al. (2007)). The functionalities of modern DAS come far beyond sheer representation of information, but provide a real-time, synchronous, and thus situational support through networking with the assembly periphery (tools, material, work piece, etc.). This means, work instructions are automatically synchronized in accordance with work progress and without any manual interaction with the system. The assembly sequence provides therein the use of the correct work piece, the correct fastening tools, materials etc. - monitored by sensors and cameras. Through logical relations of their signals with corresponding process data, the right work instruction is provided to the operator. In case of assembly mistakes, appropriate software identifies the correct support and generates a specific information in order to have the mistake corrected right in the moment, at the right location to achieve product quality as desired. To be able to define the advantageous components of DAS already within in the planning phase of complex assembly systems, it is necessary to identify the specific DAS needs and to derive the specific requirements for technical components for an adequate provision and also in regard to evaluate the economic and productivity impact of the assistance service system on the entire assembly system.

4. PLANNING AND ANALYZING OF ASSISTANCE FOR CYBER-PHYSICAL ASSEMBLY SYSTEMS

Although hybrid set-ups allow a combination of the flexibility of manual systems with operating cost baseline of automated systems and optimal capability utilization of both human and robotic resources, around 84% of industrial assembly systems in Europe are still dominated by purely manual labour, while only in 12% operators are technically assisted in task execution (Spena et al. (2015)).

The implementation of technical assistance systems requires detailed planning of the proposed process, the required equipment and the evaluation of system design variants with regard to capacity and cost. Thorough research has been conducted on determination of the optimal automation degree (Westkämper (2001), Lotter (2012)), but does not focus on direct interaction of humans and robots. Beumelburg (2005) found that any of the prevalent methods for the design of assembly systems takes it into account at all. According to Lotter (2012), the fundament for the planning and design of a hybrid work process is the manual process.

As for technical assistance systems, methods to determine the necessity of information provision, communication technology requirements in regard of productivity potential in the context of the complexity between human, technology and organization are not mentioned in existing work adequately. The comparison of different variants of assembly process planning approaches demonstrates that planning and analyzing of DAS and their components, especially in regard to answering the question, what impact a DAS will have on the performance of the operator and on the productivity of the assembly system (and of CPAS in particular) is currently one of the key problems (Spillner (2015), Wiesbeck (2015), (Konold and Reger (2013), Lotter (1992), Bullinger (1986)).

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