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Modular configuration and control concept for the implementation of human-robot-cooperation in the automotive assembly line

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Abstract: The automotive industry is facing significant challenges due to shortened product lifecycles, increased product variances, and fluctuating markets. The current assembly systems are unable to handle the increased requirements for mass customization, so they need to be optimized with new technologies. Human-robot collaboration has evolved as a solution to overcome these difficulties and create flexible and customizable automation processes. To simplify the integration of human-robot cooperation into the automotive assembly line and expand the range of applications a methodology for the implementation of cooperative robot systems into the assembly line is introduced. This paper presents a modular means of production kit combined with an integration- and control concept. This will allow for a flexible and easy implementation and reconfiguration of cooperative robot systems.

Keywords: Automobile industry, Human robot cooperation, Human centered automation, Assembly, assembly system design, Production planning and control, Industry 4.0

1. INTRODUCTION

Many companies are under pressure to increase their productivity to remain globally successful in competition. Simply increasing the degree of automation is not very promising because of the complexity of the assembly operations and the high number of variants and fluctuating quantities (Westkämper 2006). An empirical study in the German industry gives evidence that automation has been implemented in many companies beyond economical value and often in an inappropriate manner. Approximately one third of all companies that invested in high automation recognized that these solutions are not flexible enough and reduced again their level of automation (Bley 2004). As a consequence, a significant number of tasks in the assembly and commissioning line − especially in car manufacturing − are performed by manual labour. Newly developed HRC robot systems in combination with the latest sensor and safety technology have created the opportunity to overcome these difficulties with a physical cooperation of humans and robots (HRC) in the same workspace. The automotive industry is especially interested in implementing these new systems. They are facing the problem that their assembly systems are unable to cope with increasing requirements of mass customisation and need to be enriched with new technologies for a higher flexibility potential (Michalos 2010). In order to maintain their competitiveness the car manufacturers are searching for future oriented concepts to increase the performance of the assembly line and reduce costs at the same time (Meier 2005). Human-robot cooperation and the possibility for customized automation are identified as new key technologies to enhance the efficiency of assembly processes and the overall productivity of the factory.

This paper delivers an approach for a methodology to implement HRC robot systems into the continuous automotive assembly line. A modular means of production system is presented together with an integration and control concept. Using this procedure all suitable assembly operations can be reviewed and the robot can be integrated as a co-worker wherever it is capable to optimize the process.

2. State of the Art

2.1. Automotive assembly line

In the last decades the automotive industry changed from mass production to mass customization which was based on the need for more customized vehicles and providing many models, with the use of fewer resources and materials in the shortest time possible (Westkämper 2006). An increasing number of driver assistance, electronic comfort systems and alternative drives like hybrid or electric drives, leads to a higher complexity and a large number of variants. On top of that new product models and facelifts are frequently introduced into the market due to rapid technological advancement and varied customer preferences. The sales volumes wildly fluctuate caused by unforeseen changes in the market situation (Takata 2011). New production technologies are necessary to increase the productivity, achieve flexibility and transformation ability.

A high number of variants, mixed model assembly and the requirement of complex movements are the main obstacles for automation in the assembly line (Westkämper 2006). Conventional automation strategies are limited for these applications because a majority of the task execution requires a high level of perception, dexterity and reasoning which cannot be met technically in a cost-effective or robust way (Haegele 2002).

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2.2. Hybrid assembly systems

Hybrid assembly systems or also called semi-automated systems are characterized by a synchronous cooperation of humans and machine, without taking the humans self-determination away (Westkämper 2006). In order to attain the full potential of the physical cooperation, an optimal division of labour on the process level should be aimed for. In terms of cost a customized automation process, whereby humans and robots can each be allocated a specific type and/or amount of work, seems to provide an optimal balance between the cost of manual labour and the capital investment (Thiemermann 2004). In addition, a product-independent process station layout and the flexible nature of human workers should provide high conversion and transformation flexibility. Because of the shared workspace, the factory layout can be used very efficiently and enhance the capacity utilisation. The removal of safety fencing gives the worker the opportunity to enter the robot's workspace at any time without hazard. Malfunctions can be rectified easily without disruptions of the overall process and a continuous availability is ensured (Krüger 2009), (Bicchi 2008). The robot offers high reproducibility; hence a subjective influence on the tasks can be excluded. The process capability is increased and a permanent quality control is set in place.

2.3. An object oriented approach for assembly system design

Object orientation is described as an integrated design principle starting for an analysis to the development and implementation to the maintenance of the system. To be able to manage the complexity of the system the principles of a true modelling of the reality, reusability and easy expandability are used. A system in the object orientation contains of objects which communicate with each other with messages. Every object has attributes and methods. The values of the attributes describe the status of the object. The methods describe the possible procedures of the object. The object are defined by classes which can be described as a template. They define the type of the object and their functionality. Every object is an individual instance of a class and uniquely identifiable (Lackes 2016).

The object oriented approach starts with a system analysis and a definition of the requirements. Then the necessary methods are determined and furthermore the required objects or modules. The task is manly solved in the problem/application area. This means system structure is oriented on the application functions which should be fulfilled. Only after this the solution area is considered and the technical realisation is designed. This concept is transferred into technical solutions within the system design (Goll, 2011).

Automation modelling language

The automation modelling language (AML) was designed with the goal to reduce engineering costs. To be able to manage the complexity AML is using object orientation. This allows for a hierarchical modelling of the structure or topology of a process station. The real elements of a production system are saved in the data format represented by objects. Information which needs to be exchanged by the individual elements are described by the specific properties of the objects. This allows for a manufacturer independent description of the object's function in the overall system. By using interfaces and relations objects can be connected independent to their hierarchical order (Lüder 2014), (Schleipen 2014).

2.4. Technical set-up of an assembly station using modularisation and integration

Modularisation provides the opportunity to reduce the complexity of comprehensive systems. This is achieved by subdividing the system into manageable parts. A modularization in functional units is pursued by relating to the planning and technical implementation of hybrid assembly systems. This creates a comprehensive systematic understanding which can be used for an effective, efficient, and flexible configuration (Landherr 2015).

For the implementation the modules need to be integrated into a control concept. Integration describes the set-up of a functioning system built out of modules (Weerth 2016). A configuration concept is necessary to fulfil the demand for increased efficiency as well as achieving flexibility and versatility. This concept must be able to find a suitable module feature based on the systematic description and combine those with a complete customized system (Landherr 2015).

3. Methodology for the Implementation of a cooperative process station into the continuous assembly line.

The development of the methodology is illustrated in a use case of an automotive assembly line process station. In this process station product the underbody panelling is manually assembled on the vehicle. Human and robot share the assembly task with an intelligent skill oriented task distribution. The worker is in charge of feeding the components, align them on the underbody and ensure the accessibility for the robot. The robot performs the joining processes automatically with an attached tool and sensors for the detection of the joining areas. This optimisation enhances the ergonomics, productivity, and allows to save costs.

3.1. Approach

As described in the section 1 and 2 the conventional assembly systems reaching their limits meeting the requirements of mass customization, quality and costs. The human-robot cooperation and the possibility for customized automation are identified as new key technologies.

The main questions are:

- How can an integrated procedure be designed starting from assembly planning to the technical realization?
- Which means of production are necessary how can they be determined efficiently and integrated in a safe control structure?