Sequence Planner: Supporting Integrated Virtual Preparation and Commissioning

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Abstract: It is essential to understand the operation sequences of a production system when designing or changing it. This paper will demonstrate how the software tool Sequence Planner (SP) not only supports this understanding by sequence visualization, but also improves the solution using optimization and verification. SP is a tool for modeling and analyzing automation systems. The tool has been developed since 2007 with an initial focus on supporting engineers when developing control code for programmable logical controllers. Today, SP is a microservice architecture, usable in various areas like runtime control, online monitoring, energy optimization, and even emergency department patient planning. This paper presents a use case at an automotive company, where the operation sequences in a large number of automated robot stations, need to be modified. SP, together with virtual commissioning tools, automates this modification by identifying, optimizing, verifying and simulating operation sequences, and then updates the robot and control programs. This use case demonstrates the strength of SP and its architecture and how it is used for integrated virtual preparation and commissioning.

Keywords: Virtual manufacturing, automation, robot programming, sequence of operation

1. INTRODUCTION

Today’s manufacturing industry is under constant pressure to deliver high quality products at lower cost and shorter time to market. Having robust, efficient, and flexible production systems is a requirement, but the development time of such systems must also be considered. One way to tackle this, is by having appropriate methodologies and tools. While virtual manufacturing tools today contain plenty of support for working with processes and running simulations, there is still a gap to be filled before these tools can support all parts of the design process.

Sequence Planner (SP) is a software developed at Chalmers University of Technology (Sequence Planner team, 2016). The main concept in SP is the formal modeling of operations and operation sequences (Lennartsson et al., 2010). By using visualization (Bengtsson et al., 2012) as well as synthesis algorithms (Bergagård, 2015), the challenging task to model complex systems is simplified in SP (Bengtsson, 2012).

In this paper, the ideas and vision of SP are explored through a case study concerning visualization, verification, and optimization of robot program coordination in an automotive production setting. By integrating a virtual manufacturing tool with SP, a fast iterative work flow is enabled. A formal model of the system is generated and used for verification of robot interlocking and optimized coordination strategies are calculated. Validation of the optimized results are performed in the virtual manufacturing tool, where robot programs can be simulated in conjunction with other devices. In addition to plain visual inspection, these simulations provide collision detection and timing data.

The main contribution of this paper, is that it demonstrates how existing algorithms for formal verification (Ovatman et al., 2014), optimization (Shapiro, 1993) or supervisory control synthesis (Ramadge and Wonham, 1987) can be tightly integrated with currently used engineering tools to enable rapid design with short and fast iterations. SP is used as an enabling technology for these integrated iterations during an industrial use case. This integration is part of a framework called Integrated Virtual Preparation and Commissioning (IVPC) that was introduced by Dahl et al. (2016).

This paper is organized as follows: An introduction to IVPC is given in Section 2 and the ideas and concepts in SP are described in Section 3. In Section 4, the industrial case study is introduced. Sections 4.2 and 4.3 cover how to generate sequences from robot programs and how to verify them. In Section 4.4 the sequences are optimized, followed in Section 4.5 by a description on how simulation is performed.
2. VIRTUAL MANUFACTURING AND COMMISSIONING

Today’s virtual manufacturing tools have the ability to upload and simulate robot programs from the shop floor. The tools also allow simulated devices to be controlled by a real control system. This setup is commonly referred to as virtual commissioning (VC) (Lee and Park, 2014).

The main motivation to use VC is to reduce testing and integration time during development (Hoffmann et al., 2010; Park and Chang, 2012; Lee and Park, 2014). This is achieved by being able to test and integrate the control system before the physical production system is completely installed. The hope is that using a simulation model of the production system, undesired behavior can be detected well ahead of physical installation. In fact, conducting VC enables tests that would be prohibitively expensive or even impossible to run on a physical system. In addition, having the simulation model makes it possible to test changes to the production system while the simulation is running and being able to incorporate last minute changes without worrying about their impact on the physical system.

Because VC uses the real control system, the simulation models need to be specified at the level of sensors and actuators (Lee and Park, 2014). This is now possible in simulation software from virtual manufacturing tool vendors, usually by allowing the user to define signals connected to the simulation and expose them to a control system via some interface (e.g. OPC, see Schwarz and Borcsok (2013)).

Oppelt and Urbas (2014) wrote that according to the The Association of German Engineers, current guidelines state that VC should be the last step in the automation engineering phase. But instead of conducting VC as the last step, Oppelt and Urbas (2014) suggest to extend VC to cover the entire automation engineering phase. This concept is called Integrated Virtual Commissioning since VC can enable continuous testing during the development; “The virtual plant is growing together with the automation software and thus enables simulation supported automation engineering” (Oppelt and Urbas, 2014).

This concept was extended by including a formal model of high level control logic in (Dahl et al., 2016), where a framework called Integrated Virtual Preparation and Commissioning (IVPC) was introduced. A formal model of control logic, combined with having the same simulation model of the production system shared between the preparation, control system implementation and VC phases (see the highlighted area in Fig. 1 in (Dahl et al., 2016)), enables both early validation of high level control and to perform early optimization based sequencing.

The methods described in this work are applied within this IVPC framework. However, the focus here is on not doing a full VC, but to use SP to optimize the robot sequences, and to simulate the optimized sequences in the virtual manufacturing tool. The reason for doing this is that the optimization may return several different robot sequences that are equally “good” according to the optimization criterion, and so an engineer has to be able to simulate these sequences to select the “best” one according to some criteria not expressed to the optimization engine.

3. SEQUENCE PLANNER

Sequence Planner (SP) is a tool for modeling and analyzing automation systems. Initially (Falkman et al., 2007), the focus was on supporting engineers in developing control code for programmable logical controllers (PLCs). During the first years, algorithms to handle product and automation system interaction (Bengtsson et al., 2009), and to visualize complex operation sequences using multiple projections (Bengtsson et al., 2012), was developed. Over the years, other use cases have been integrated, like formal verification and synthesis using Supremica (Bergagård and Fabian, 2012), restart support (Bergagård, 2015), cycle time optimization (Sundström et al., 2012), energy optimization and hybrid systems (Riazi et al., 2016), online monitoring and control (Theorin et al., 2016), as well as emergency department online planning support (Bengtsson et al., 2016).

Fig. 1. Sequence Planner user interface.

SP is developed as a micro service architecture, where various services interact with each other by sending messages. One of these services is a web-server and a modern web-based user interface (see Fig. 1) where users can interact with the system. The user interface consists of so called widgets. A widget can for example show all items of a model, operation sequences, Gantt charts, settings for an optimization service or a control window for interacting with a running system. Fig. 1 shows to the left, a tree view showing the operations in the active model; to the right, an interface for solving the use case in this paper; at the bottom, a sequence of operations representing a possible coordination of the robot programs. In this paper, a number of widgets are presented that have been developed to support this specific case. Any widget can be added to
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