VIRTUAL PRODUCTION FOR INDUSTRIAL MANUFACTURING PLANTS WITH TRANSPORT SYSTEMS

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Abstract

Automated industrial manufacturing plants are complex systems which are planned, built and operated by many different people in sequent phases. Virtual Production can help to obtain a plant of higher quality at earlier time by optimizing the workflow in the planning and building stages and by parallelizing phases. In this paper, we suggest an approach to implement Virtual Production and present the 3-D modeling and simulation system COSIMIR® which supports the whole lifecycle of a plant from planning to shop floor operation. We introduce the different phases of Virtual Production and analyze the benefits of each stage. As manufacturing plants with carrier based transport systems are especially complex because of their above-average usage of sensors and actuators, we will focus on the integration of these. Engineers can produce and verify control programs with the digital model of the plant long before the real plant is set up. These control programs are written in the native language of the employed robot or PLC and thus can be directly loaded into the real controller. Furthermore, methods of Virtual Reality enhance the digital model to ease communication among engineers, to intuitively present the plant and the processes, and to train operating personnel without occupying the real plant. Finally, we describe applications together with gained benefits and discuss future potentials of Virtual Production.

Keywords: Automation, Virtual Commissioning, Simulation, Transport, Virtual Reality

Presenting Author's biography

Roland Wischnewski studied applied computer science with focus on engineering technology at the University of Dortmund. From 1999 to 2005 he worked as a scientific assistant at the Institute of Robotics Research (IRF) of the University of Dortmund. Since April 2005 he works at the Department of Robot Technology at RIF e.V. in Dortmund as head of the team Industrial Simulation Systems.

ISBN 978-3-901608-32-2

1 Introduction

Today, automated manufacturing plants are present in many industrial branches. A common problem is the complexity of the plants concerning their mechanical and electrical design and the programs used to control the systems. This complexity leads to unpredictable problems and may result in a delayed start of production or even in plants not functioning at all. Virtual Production has already been identified by leading companies in different industrial branches as a means to reduce the risk of drifting away from the planned path of production. Additional operational processes and resulting costs in the planning stage are widely accepted in expectation to reduce overall project costs. A practical problem is the fact that only large companies can afford to buy expensive PLM or CAM software and to employ specialized personnel to implement Virtual Production for the whole product lifecycle. Small and medium enterprises usually apply digital engineering only in some project stages. In this paper, we present an approach to implement Virtual Production with focus on Virtual Commissioning considering mechanical, electrical, and control aspects. The method is kept as simple as possible, follows common procedures of engineers and can thus be easily integrated in existing workflows. We will describe the 3-D simulation tool COSIMIR® [1,2] to conduct the proposed stages.

2 Virtual Production with COSIMIR®

Even when trying to keep the approach simple, Virtual Production must necessarily cover all major phases of the lifecycle of a plant i.e. planning, construction, programming, commissioning, and operation. Especially small and medium enterprises often use different software tools to cover these phases. This leads to the problem that digital models which have been created in one tool to meet the requirements of one stage can be used in a different tool for a subsequent stage only with big effort or not at all. To avoid the need to convert models or to create them anew, the used software tool must be able to continuously cover all main phases. To support the enterprise's usual workflow and to obtain acceptance for the tool, the handling of the software must resemble known procedures as closely as possible. As a software tool usually forces a stricter workflow and does not permit any deviations, the use of such a tool itself may help to identify problems in any stage of the project.

Fig. 1 shows the relations of the different phases of the lifecycle of an automated manufacturing plant. All the phases are considered in Virtual Production and covered by the software tool. At first, mechanical engineers design the plant with respect to shop floor layout restrictions. Electrical engineers then close the gap between field devices and controllers by designing the electrical wiring. Subsequently, programmers can begin to create control programs which can be tested during virtual operation. Finally, operation of the real plant can begin.

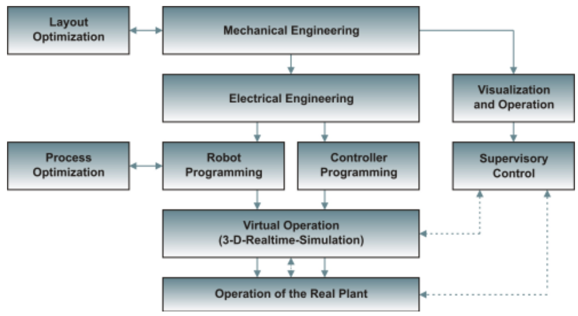

Fig. 1: Virtual Production for an industrial manufacturing plant.

The continuous use of the same software even allows capturing of small design modifications in preceding stages. Especially results of the virtual operation phase may cause changes even in the mechanical engineering stage, for example in case a robot cannot reach a certain position, a work piece may be repositioned. If a new virtual operation validates the new position the changes can be communicated to the department building the real plant. Bigger problems, which are revealed during virtual operation, may lead to bigger backflows which cannot be solved by slight changes to the digital model. In this case, the new ideas must be considered as a production variant and a new digital model has to be set up.

In general, modeling always faces the trade-off of easy and user friendly modeling on one hand and detailed and exact modeling on the other hand. To achieve both objectives at the same time, a two-level modeling concept has been designed. Low-level modeling is executed by modeling and simulation specialists who additionally have knowledge of the devices to map. The software offers many possibilities to create realistic models, but engineers need a certain amount of training and – for complex devices – even some experience. In high-level modeling, plant engineers without deep simulation knowledge can use predefined models from low-level modeling to easily combine them as they would do using a manufacturer's catalog.

2.1 Mechanical Engineering

Mechanical engineers usually know about the components and devices they will use for a plant to solve a certain production problem. Normally, these parts are looked up in manufacturer's catalogs and assembled in a 2-D or 3-D CAD/CAM tool. In our approach, these parts are directly assembled in COSIMIR®. Model libraries supply visually and functionally correct models like robots, grippers, etc. which can be easily assembled in 3-D space. If a certain component is not available, CAD data (STEP, IGES, VRML, STL) can be imported and enhanced with functional behavior. Many mechanical motions can be mapped using linear and rotary axes, kinematic chains, grippers, and even restricted movements. Model states can be detected by pushbuttons, switches, different sensors (optical, acoustic, tactile, inductive, etc.), cameras and transceivers. The mechanical engineering stage of the Virtual Production leads to a fully functional simulation model of the plant.

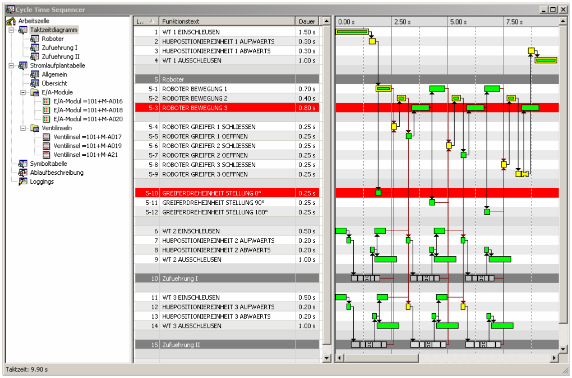

Fig. 2: Modeling cycle time sequences.

Moreover, engineers can build a model of the partial processes to predict the resulting cycle time. Fig. 2 shows actuators (middle column) and action instances (green and yellow bars on the right) which are connected to map the required sequence of execution. Even branches and merging points can be used to finally obtain the overall cycle time along the critical path of the network. This work is often still done using spread sheet software which does not offer many features. Furthermore, the cycle time sequence can directly control the 3-D simulation model and thus show the resulting process. Experiments with variants of the model and/or the cycle time sequence can help to optimize processes in an early development stage.

2.2 Electrical Engineering

In the next stage, the wiring diagram for the mechanically functional model is created. Electrical engineers define I/O modules and valve clusters and connect I/Os and pneumatic valves of field devices. Sometimes the model of a field device does not have the identical I/O map as the real component. In this case, a Boolean logic converter can precede the device model to achieve a reality conform I/O map which is essential to be able to test original control programs.

2.3 PLC and robot programming

A benefit of Virtual Production is the possibility for programmers to create and test their control programs against the model of the plant – without needing the real plant. Programming and testing can start early in the process. This way, problems arise earlier and can be solved without time pressure resulting in better control programs at the time of real commissioning.

Robot programs can be developed within the simulation system using the native language of the robot. Identical programs control the simulation model and later the real robot. Development within the software is supported by syntax highlighting, error reporting, and help features. Optimization of the robot programs can be done using a script interpreter which helps to create programs and paths automatically [3].

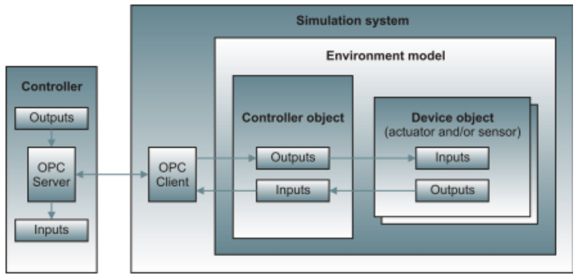

Fig. 3: Connecting an external controller to the simulation system using OPC. Controller I/Os are directly visible and can be connected to device I/Os.

PLC programs are created using the original development environment of the manufacturer (e.g. Siemens STEP 7) and can be interpreted within the simulation system or run on original hardware and coupled to the simulation system via OPC [4]. Fig. 3 shows how I/Os of the original controller are integrated into the environment model using a controller object.

Another way to create PLC programs is to use the cycle time sequences defined in a previous step. As mentioned before, these sequences define actions of actuators within the model and can directly control the model during simulation. Somehow, this does only work one-way as responses of the model in the form of electrical signals, e.g. digital outputs of sensors, are not evaluated. To integrate these signals into the cycle time sequences, the actuator actions are fitted with start and end conditions which must be met before the action can be performed. The enhanced sequences now contain all information for bidirectional control of the model and can be automatically converted into a sequential function chart (SFC) according to IEC 61131-3. These diagrams can directly control the simulation. Moreover, the simulation system can export the diagrams to allow import into the development environment of a PLC.

2.4 Virtual commissioning

After the mechanical and electrical model has been set up and control programs have been written, the whole digital model of the plant can be used to perform a virtual commissioning. The 3-D digital plant is run in real time simulation using original control programs to validate the design of the plant or to reveal errors and problems. The simulation system offers the following possibilities:

- multi robot simulation with original robot programs,

- PLC simulation with cycle time sequences, sequential function charts or original controller programs (STEP 7, CoDeSys),
- simulation of actuators and sensors,
- transport simulation, and
- coupling of original human machine interfaces (HMI) to the model.

Multi robot simulation allows simulation of different types of robots in their native language, e.g. RAPID (ABB), KRL (Kuka), and Melfa Basic IV (Mitsubishi). External robot controllers, e.g. the Stäubli CS8 emulator, can be coupled to the simulation system to send axis values and exchange I/Os. This way, the robot's motion and the consumed time can be considered.

Altogether, virtual commissioning can reveal problems in an early stage to save time when it comes to real commissioning. A delayed start of production may be prevented this way.

3 Integration of transport systems

Automated industrial manufacturing plants often contain track guided transport systems. To enable Virtual Production to consider the whole plant, the simulation system must be able to model, simulate and control these transport systems. A concept to achieve these goals has already been presented in technical detail in [5]. The following section will describe the use of this concept in Virtual Production. Although different track guided systems can be modeled and simulated, we will assume that the transport system uses carriers in the following examples and figures.

3.1 Modeling

The two-level modeling concept of high-level and low-level modeling also applies to transport system modeling. In low-level modeling, special transport components are described in detail. Fig. 4 shows the combination of a "dead" CAD model with an "invisible" functional model from a library. The latter defines a 1-D transport track between two nodes and can be easily scaled to match the length of the CAD model by moving the end node.

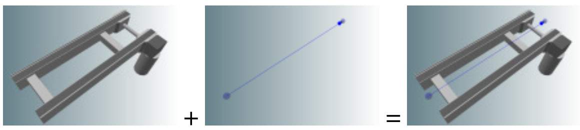

Fig. 4: Low-level modeling of a belt track by combining a "dead" geometric CAD model and an "invisible" functional model.

If the component shall be intuitively scaled without distortion, the single parts of the assembly must be provided with rules to translate fuzzy scaling commands like "length 1200 mm". These are mapped onto exact commands for the geometric and functional elements of the part. Fig. 5 shows two examples for this intelligent scaling. If the whole track on the right is scaled in length, the motor is not stretched but moved to its new position. Note that also the length of the 1-D transport track is adjusted. The track on the right contains many small rolls. If the track is extended, new rolls are produced at the correct positions.

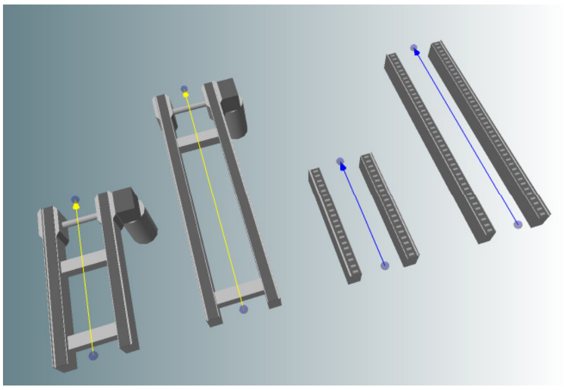

Fig. 5: Intelligent scaling of transport components.

After low-level modeling and testing the component model, it can be incorporated into a model library for high-level modeling. Fig. 6 shows a typical example of high-level modeling. A belt track, a curved track, a lift unit, and two stoppers are taken from a model library and added to the model. After this, the components are snapped together by moving them with the mouse in 3-D space to achieve a fully functional small transport model. No additional data must be supplied – the overall functionality results from aggregating data given in each component model.

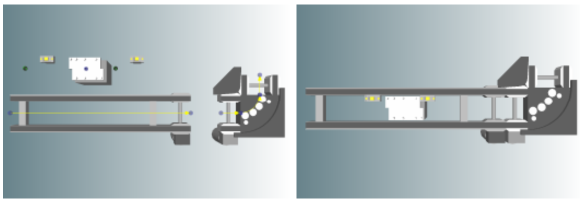

Fig. 6: High-level modeling: snapping together components from a model library in 3-D space.

3.2 Simulation

After modeling the transport system and the carriers, the complete model is ready for simulation. The simulation concept uses a hybrid approach: the transport simulation is embedded in the simulation system COSIMIR® which uses time-based simulation with a fixed cycle time. This time-based simulation is used for all robots, PLCs, actuators, and sensors. As transport processes are very time-critical, the transport simulation uses an event-based simulation within each single cycle of the "outer" simulation system. The point of time of every single transport event is calculated exactly. Transport events are e.g. a carrier hitting a stopper or another carrier. As the state of the whole model is calculated for every cycle and the 3-D

ISBN 978-3-901608-32-2

scene is redrawn after every cycle, the real time simulation can be directly observed. User inputs are always accepted during simulation enabling the user to change the view or interact with the model e.g. to grab a carrier from a track and put it back onto another track to observe the reaction of the control programs.

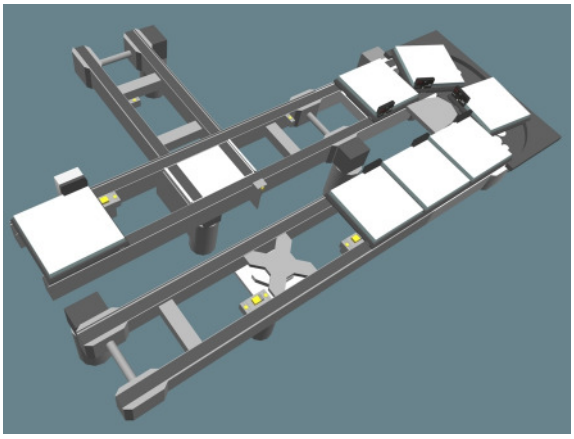

Fig. 7: Part of a transport system: carriers queue up on a curved track.

The simulation of the transport processes calculates the movement of carriers along 1-D paths. Drives can be assigned to tracks and/or carriers and have a maximum speed v and an acceleration a. Simulation also considers some physical effects like gravitation and sliding friction. The latter requires the global or local definition of friction values μ_K. The calculation method does not need to know any masses of carriers so that the effort of collecting model data is kept small. The contact behavior of carriers is simulated considering their outer geometric boundaries. Fig. 7 shows a small transport model with carriers queuing up on a curved track.

3.3 Example

Fig. 8 shows an example model of a transport system with belt tracks, curved tracks, a sloped track, a vertical lift, a lift turn unit, lift position units, and several carriers. The controller program for all the components has been written using the original Siemens STEP 7 development environment for Siemens S7 PLCs. The resulting program has been imported into the simulation system and is interpreted in real time when running the simulation.

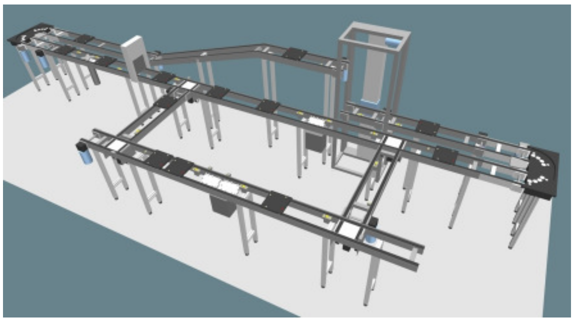

Fig. 8: Example model of a transport system.

4 Virtual Reality

An import benefit of Virtual Production is the ability to communicate ideas, designs, and processes using digital models and simulation results. The basis are high-quality 3-D models which allow the observer to recognize the modeled components. Communication among engineers is supported even better if the models are presented on large screens using 3-D stereo projection. Such projection systems are already used in industry, especially to support continuous improvement processes (CIP). One advantage is the possibility for a group of people to discuss the same view without gathering around a small monitor. The next level is the use of surrounding stereo projection systems in which the observer can turn around and look at the whole scene.

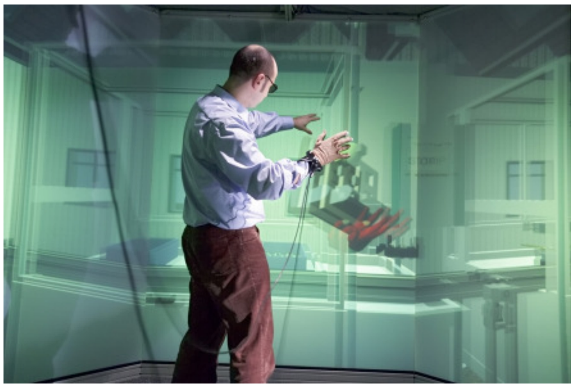

Fig. 9: Handling the model of a carrier of a transport system inside a 3-D virtual environment.

To create true Virtual Reality, the user must also have the opportunity to interact with the model. As user inputs are always possible during simulation in COSIMIR®, different VR methods can be used for interaction [6]. Space mouse, joystick, data glove or WAND can manipulate objects of the virtual world. A WAND is an input device whose position and orientation inside a room can be tracked and evaluated. Manipulation of the model includes e.g. pressing buttons, handling machinery, or moving parts. Fig. 9 shows a picture taken inside a seven walled stereo projection environment. The model shown is a whole factory with a carrier based transport system. It is important for the workflow that the same COSIMIR® model which has been created for Virtual Production can also be used for Virtual Reality applications. In the picture, the operator takes a carrier from the conveyor belt for inspection. He uses a data glove to perform this interaction which cannot only be used to test the controller programs in error cases. Another important use is the training of the operating personnel of the plant to build. The benefit is that the personnel can already be instructed while the real plant is not available yet.

5 Applications

We will now present some applications which demonstrate the use of Virtual Production.

5.1 Education

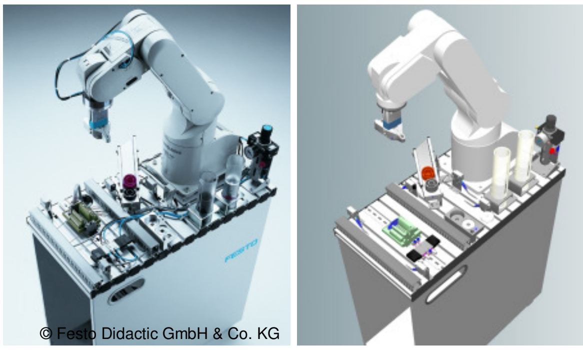

Fig. 10: Educational system "MPS Robot Station".
Left: Catalog photo. Right: Screenshot of a functional model from the 3-D simulation system COSIMIR®.

The methods of Virtual Production and especially the transport simulation have for example been used to model the hardware of the learning system MPS® (Modular Production System) by Festo Didactic. Fig. 10 shows a catalog photo of the "MPS robot station" on the left and a screenshot of a fully functional model taken from the simulation system COSIMIR® on the right. Both down pipe magazines and the cylinder slide use transport simulation. Especially the abilities to consider gravity and queuing behavior are important. In education practice, not all students can access hardware components at the same time as these are expensive and universities or schools usually buy only one item of each modular system. The benefit of the digital model is that students can experiment with the reality conform model at a simple workstation to exercise the handling of the system. The following operation of the real hardware can thus be trained avoiding additional costs for more hardware.

5.2 Exhibition

Fig. 11: A virtual factory:
carriers supply work pieces to robot stations.

Fig. 11 shows the model of a production line which has been modeled for layout planning and process presentation. The methods of the transport simulation enable carriers to move between robot working stations along a belt system. In this case it was not necessary to model the I/O map of all components realistically. Control of the forks and merging points is implemented by a simple IRL (Industrial Robot Language) program which can be run like a PLC program with a fixed cycle time within the simulation system. Work piece carriers hold a transponder for identification at the bottom. This transponder tracks the assembly state of the work piece and is read in every robot station before the work piece is treated. The local robot controller then decides how to handle the parts and writes a new state code into the transponder after work is done. Colored tags at the four sides of the carrier code the orientation of a work piece carrier. A color sensor in each robot station reads these tags and allows every carrier to run into a station with an arbitrary orientation. The system thus allows a carrier to be taken from any position of the belt and set back to any other position and orientation on the belt.

The virtual factory is presented in a seven walled stereo projection system at the German Occupational Safety and Health Exhibition (DASA [7]). Visitors wear glasses with polarized lenses to get the 3-D impression and interact with the model using a simple joystick.

5.3 Industry

The Dutch company Van Beest BV, a leading supplier for standard fittings for chain and steel wire rope worldwide, models heavy industry manufacturing plants to test robot programs and PLC programs in simulation. Robots are programmed in their native language and an external soft PLC is coupled to the simulation model using OPC. This use of Virtual Production allows the development of control programs in a much friendlier environment than the heavy industry shop floor. Moreover, production needs not be stopped to verify changes and optimizations of running control programs.

6 Conclusion and prospect

Virtual Production for automated manufacturing plants optimizes the engineering workflow, increases the quality of control programs, and thus leads to better plants earlier. Efforts and costs for buying a software system, integrating it into the operational workflow and modeling plants are compensated by the mentioned benefits. The software tool to use must be capable to cover the whole lifecycle of the plant and to consider all relevant aspects of the plant. This is especially true for transport systems as these use large and complex control programs which need to be verified in detail.

The need of employing just one software tool for all phases of Virtual Production may decrease in the near future. In the past, many independent organizations have tried to establish an automation data exchange format to store geometry, kinematics and programming logic together. All attempts have failed in the way that none of these formats is supported by any tool manufacturer. At Hannover Fair 2007, the German automotive company DaimlerChrysler announced the new open exchange format AutomationML™ [8, 9] and demanded that all of their tool suppliers will have to support this format by the end of 2009. The market power of DaimlerChrysler may lead to a fast implementation of AutomationML™ and thus bring up an exchange format which may close the gaps between different modeling and simulation tools for Virtual Production.

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ISBN 978-3-901608-32-2