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VIRTUAL COMMISSIONING AS A FINAL STEP IN DIGITAL VALIDATION OF THE ROBOTIC MANUFACTURING SYSTEMS

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Abstract: *The Virtual Commissioning (VC) concept is the final phase in develop and simulate the robotic manufacturing systems which, together with all other benefits, allows companies to have a more efficient handling of the complexity in robotic assembly systems, a great decrease of the plant start-up time, and a resulting shortening of the product's time to market. This paper presents the VC concept and all the resources and technology involved in development of a robotic manufacturing system and an environment setup proposition. The complete workflow of the virtual validation of the system is presented, and the implementation requirements and specifications are discussed.*

Key words: *Virtual commissioning, simulation, robot, process simulate, digital manufacturing.*

1. INTRODUCTION

Presently, a key aspect for all the manufacturing companies around the world, in remaining competitive is timing. Part of the timing is being first to market and a critical aspect of being first to market is the launch curve that sometimes can be seen after the design and build activities are finished, and are actually ramping the plant up to production [1]. One frequently term for this concept is "flawless launches" which is the ability to take the designed system, go into the plant, and get up to production as quickly as possible. This is a real challenge for companies because the actual manufacturing systems are by far more complex than the systems from 10 years ago. Different model mixes, different variants, options, all these of different things add to that challenge. Because the consumers' needs and demands are growing up every day, the complexity and variety of the products is increasing continuously. To adapt this situation, the manufacturing companies should have sufficient capabilities to speed up the development of the product in parallel with the manufacturing systems (the term in automotive industry is simultaneous engineering) [2].

All along the develop process the companies want to be able to make the right decisions, and if they struggle too much to make the right decision they need to make today because they are worried about the future, then they delay the inevitable. So, what the companies want to do here is have the ability to make decisions, but have systems that can react to the challenges and environmental changes that occur every day. Therefore, is it possible to make changes and continue to move forward and not be afraid about the wrong decision, because at this point is it possible to adjust the automation that is in place and adapt to that environmental parameter that may have changed. For instance in automotive industry, fuel prices go up, the automotive companies which are building SUVs (Sport Utility Vehicles), can now be able to build smaller cars. Again, the companies must be prepared for that change.

Most of the companies have clearly identified these challenges, but have also thought about strategies to deal with this. Is it possible that technology could be a key enabler to solving these challenges that the companies deal with. They obviously look at utilizing standards and standard components and reuse of information in order to, for instance, complete an engineering cycle faster. From old products to the new products the companies can therefore reutilize a lot of the knowledge, tooling, and equipment items. Nevertheless, this standardization is not by itself capable of guaranteeing that the designed assembly and production systems will be fully operational after their physical deployment. The complexity and diversity of the system manufacturing components, in terms of control systems and communication protocols, requires a great amount of time for onsite installation, testing, and validation of the assembly equipment. This is translated into actual production system downtime and the costs that follow it. Digital simulation of the robotic assembly process has emerged over the last 10 years as a means of partially handling the validation of such systems prior to their installation. In addition IT systems have been over the past years an evolutionary technology, forwarding the concepts of digital manufacturing. These systems are based on the digital manufacturing concept, according to which production data management systems and simulation technologies are jointly used for optimizing manufacturing systems before starting the production and supporting the ramp-up phases.

However, the actual systems for digital manufacturing concept seem to be inefficient when integrating

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product design and production (robotic manufacturing) planning [3]. Virtual commissioning (VC) on the other hand, goes a step further by including more validation capabilities from the mechatronic behavior of the resources. Virtual commissioning is the process by which a physical system can be evaluated, tested and optimized in a hybrid environment that includes both hardware and software. This hybrid environment enables realistic robot and device validation through the signal mapping of robot programs from simulation software to the PLC (programmable logical controllers), also testing and optimization of robot programs in virtual environment. The application of the concept may lead to reduction of the errors detected during the ramp-up phase that necessitate reworks in upstream processes, since it enables the verification of real PLC engineering with virtual line and cell in the early production design phases. As a result, virtual commissioning decreases ramp up and commissioning time and costs, delivers fully proven robot and PLC programs, and enables efficient data exchange between manufacturing, simulation, and automation engineers.

The main objective of this paper is to present and analyze the virtual commissioning concept and all the resources and technologies involved and to propose an environment model which can be used in a real automotive plant.

2. VIRTUAL COMMISSIONING CONCEPTS

A description of virtual commissioning concepts, requirements and simulation tools are presented in this paragraph.

2.1. Virtual commissioning concept

Virtual commissioning is the process by which a physical manufacturing system can be simulated, tested and optimized in a hybrid environment that includes both hardware and software. This hybrid environment enables realistic robot and device validation, signal mapping of robot programs to the PLC (system controller), testing and optimization of robot programs, reliable verification of safety procedures and fault logic, and cycle-time verification and debugging against real production hardware (PLC, HMI) and executed PLC code. This means that VC involves two major distinct jobs:

- Mechanical designer: responsible with mechanical design of the manufacturing system, layout design, kinematics, robot programs (path definition), mechanical clearances, cycle time.
- Automation / electrical designer: responsible with inputs / outputs signal definition, logic definition, interlocks, HMI programming, safety definition, PLC programming (Fig. 1).

Currently there are three approaches of a VC concept [4]:

- Software in the Loop (SIL) method: the control programs for the resource controllers (PLC, HMI) are downloaded to virtual controllers and IP/TCP connection is established between the 3D model of the manufacturing system and the software-emulating controllers. The main advantage of this approach is the low costs with software emulated PLCs and robot controllers.

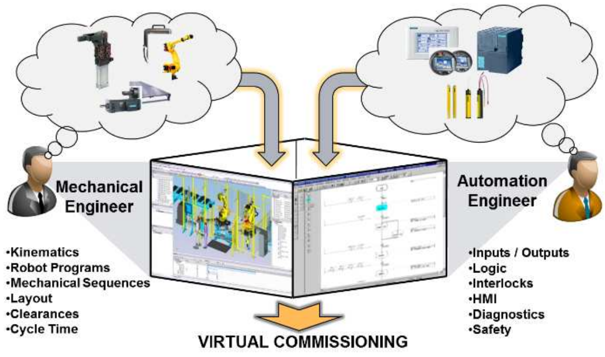

Fig. 1. Virtual Commissioning's involved jobs.

- Hardware in the Loop (HIL) method: the manufacturing system simulation involves using of real PLCs hardware controllers connected to simulation software via fieldbus protocol, real robot controllers in which the programs are loaded. The main advantage of this method is that the real PLCs can be tested with production programs in real time. The main disadvantage is high cost with hardware especially if we must simulate a production line which involves more hardware equipment. However, this method is close to 1:1 ratio comparing to physical commissioning.
- Hybrid simulation: combines HIL and SIL, means that we can use robot controller also called RCS (developed by robot manufacturers) installed on our simulation environment for a real robot simulation (RRS), virtual PLCs (also developed by every PLC manufacturer)

2.2. Important input data for virtual commissioning

To have a accurate virtual commissioning it is important to have the following input data from both mechanical and automation departments:

- Detailed layout of the plant in which all the resources are precisely positioned.
- Advanced 3D simulation of the robotic manufacturing system which includes: 3D geometry of the system, kinematics of devices, robots and all other resources in motion, safety definition (sensors and other electrical devices), path definitions for all the robots.
- Material flow (assembly process): sequence of operations.
- Precise definition of input and output signals for each component part of the process.
- Control system for the validation of the prototype: real or virtual PLC.

2.3. Virtual Commissioning software applications

During the last years, all the major software developers of robotic simulation on the market invested a lot of effort in creating new software modules which allows manufacturing companies to implement virtual commissioning.

Delmia by Dassault Systemes [5] allows the virtual prototyping of PLC control systems for cells, machines and production lines which uses object linking and embedding for process control (OPC) communication for the coupling of the real control system with the simulated resource. In Fig. 2 is presented a screen capture from

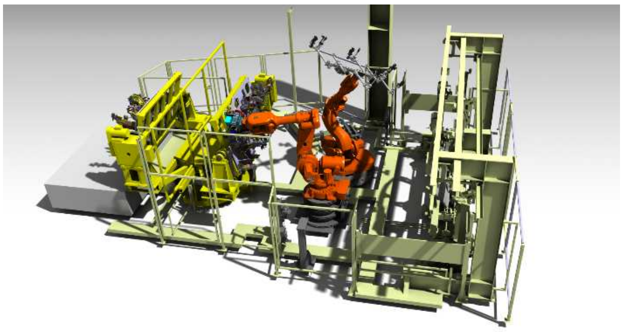

Fig. 2. Delmia Virtual Commissioning.

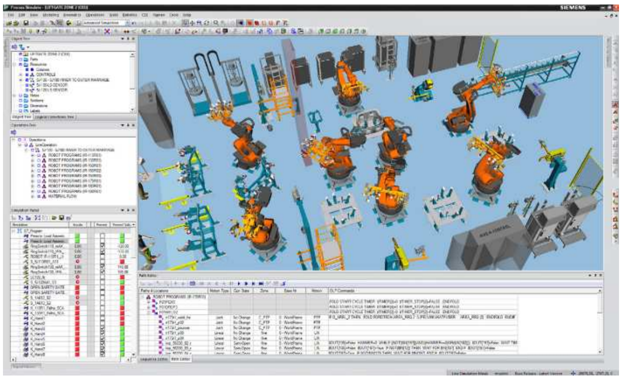

Fig. 3. Process Simulate Virtual Commissioning.

Delmia connected to a real robot controller via Realistic Robot Simulation II interface (RRS-II).

Process Simulate Virtual Commissioning from Tecnomatix package [6], part of Siemens PLM Software, allows users to simulate real PLC code with the actual hardware using OPC and the actual robot programs, thus enabling the most realistic virtual commissioning environment (Fig. 3). From this reason, into the next sessions the virtual commissioning workflow will be presented using Process Simulate VC. Virtual commissioning with Process Simulate decreases ramp up and commissioning time and costs, delivers fully proven robot and PLC programs, and enables efficient data exchange between manufacturing, simulation, and automation engineers.

3. VIRTUAL COMMISSIONING ENVIRONMENT

This section is dedicated to present the environment setup of a VC project.

3.1. VC environment setup prerequisites

Based upon a conventional sequence-based or time-based simulation model, new technologies have been introduced into the environment to enable more realistic simulation. In Fig. 4 a diagram with the new technology of event-based simulation is presented.

- The CEE (Cyclic Event Evaluator) is used for event-based simulation within a mechanical system simulation.
- Material flow support by the creation of appearances of parts assemblies based on events within the simulation sequence.
- Sensors support to allow for proper control of event triggers according to real system behavior.

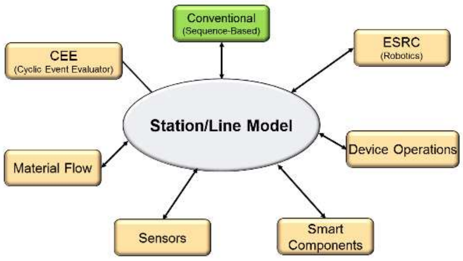

Fig. 4. New Technologies to Support Realistic Simulation.

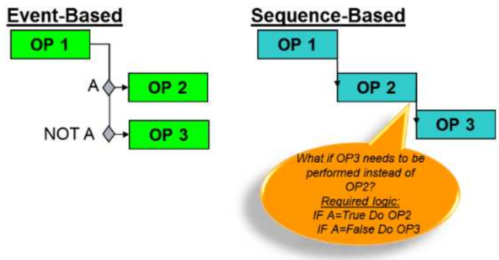

Fig. 5. Event-based vs. time-based simulation.

- Smart Components to allow for the creation and storage of logic blocks within standard components to ease the process of connecting those components up within the simulation and to the PLC.
- ESRC (Emulated Specific Robot Controller) modules or teach pendants for robotic programming, allowing for the creation and execution of robotic programs in the native language of the machine, including logic.
- Device operation automatically creates an *operation_end* signal. This signal is used as default condition in the transition between one operation and the successor operation.

3.2. Cyclic Event Evaluator

The CEE eliminates the need to add program logic into the simulation, as required by sequence-based simulations, by supporting the execution of operations and actions as a result of specific events or triggers. In this manner, simulation models can now be used to support variants or alternatives based on style, simulation of periodic operations, and for the execution of multiple cycles without resetting the simulation to an initial (zero condition) state. In Fig. 5 the conceptual difference between time-based simulation and event-based simulation is presented.

3.3 Material Flow Simulation

It is realized by the creation of appearances of parts and assemblies based on events within the simulation sequence. Parts and assemblies are generated and destroyed automatically based on process flow. This enables the simulation of style-specific logic, triggers program branching, and allows for the understanding of system behavior based on batch runs. An appearance allows placing one reference to a specific product (structure or part instance) in a study and to view it at multiple locations simultaneously (i.e. several copies of the part moving down a line). In addition material flow is another way to verify the assembly process.

3.4. Sensors

Light (photoelectric) and proximity sensors enable you to detect 3D-visualized parts and resources which come near or enter the sensors detection range (i.e. collision detection or near miss detection). They are used for: part detection (is the part at the right place?), interlock detection (stop robot if it moves too near the security area of another robot or a security fence) and so on.

Position sensors allows for the indication when a mechanical device has reached a predefined position and the start of operations based on that position. These poses support various built-in behaviors, depending on the application (range, peak, less than or more than). This is important for the VC because allows for the monitoring of device behavior for the purposes of initiating (triggering) I/O (events) that can be evaluated within logic expressions. In Fig. 6 is presented an example of pose sensor definition of a clamp unit.

Proximity sensors allow for the detection of parts or resources for the establishment of part/resource presence and signal default conditions. This type of sensors has the ability to define "detection range" depending of the sensor manufacturer or setup, also allows defining what parts or assemblies should be detected. Defining of these type of sensors is important for the VC because it allows for the monitoring of sensor status for the purposes of initiating (triggering) I/O (events) that can be evaluated within logic expressions. In Fig. 7 it is presented the interface of proximity sensor definition.

When a proximity sensor is defined, Process Simulate configures a 3D sensor for a specific item or location (checks for collisions/near misses with existing components). The sensor is activated when one or more predefined elements enter its predefined detection range (near-miss). A proximity sensor can be set for all items, with the exception of devices and device groups.

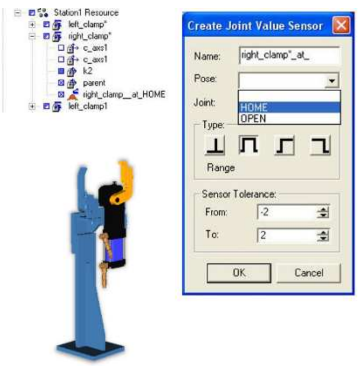

Fig. 6. Pose sensor of a clamp unit.

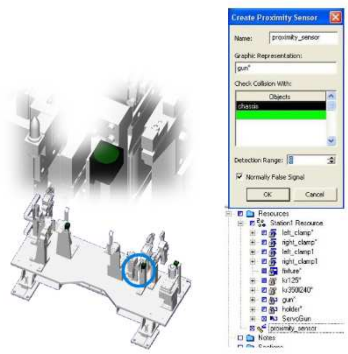

Fig. 7. Proximity sensor definition.

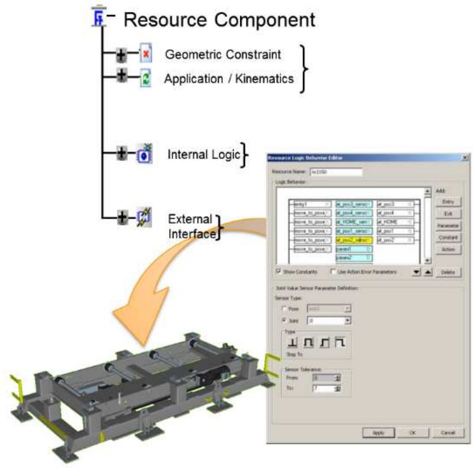

Fig. 8. Logic block definition.

Property sensors allows for the identification of parts based on specific properties, such as barcode, temperature, color and type, and for the definition and storage of such properties within a logic block.

3.5. Smart components

Smart Components are models within the simulation that include pre-defined logic and/or specific behavior. A smart component can include motion actions, such as distance, pose and speed, which are stored with other logic inside of the associated JT (direct model) data for that component. This means that the intelligence in the model is stored at the prototype level, making it available every time that the particular component is introduced into the simulation. These smart components help to reduce the time required to create simulations, and encourage and support the use of standards and best practices within the simulation environment. In Fig. 8 is presented the logic block definition and behavior of a smart component (conveyer).

It is very common, that several parts of the equipment will not be modeled neither 2D nor 3D. Nevertheless there is an urgent need to include them in the simulation to achieve realistic results. Therefore the Logic Block Simulation gives the user the option to add any type of "virtual" equipment with predefined behavior. This means, as presented in Fig. 9, that Process Simulate smart components can be used to define any kind of equipment (logic resource) in the manufacturing system. Each PLC output signal is an entry signal into a device and therefore into the logic resource and each feedback (= exit signal) from any equipment is an input signal into the PLC.

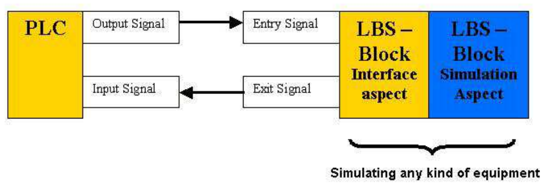

Fig. 9. Logic blocks for any kind of equipment.

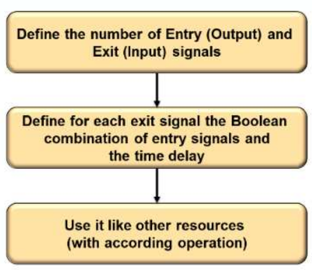

Fig. 10. Logic block modeling diagram.

A logic resource is a resource that has no kinematics and there is also no need for a graphic representation. Instead, the logic resource contains a defined logical behavior derived from one or more specified inputs and outputs in an equation or formula. For example, a logical resource can be used to describe the operation of an air conditioning system, which activates to change the temperature to a predefined level according to inputs it receives (I/O signals), such as current readings from a thermostat. The logic resource contains the logic that is the formula, used to determine when to activate the air conditioner.

Logic resources contain at least one entry value and/or exit value, as well as any number of parameters and constants. Expressions can be created that determine which exit value is triggered and under which conditions.

Logic block modeling diagram is presented in Fig. 10.

When define the number and type of entries it must be considered that only the following types are possible: BOOL (1 bit), INT (16 bit), DINT (32 bit), REAL (32 bit), BYTE (8 bit), WORD (16 bit) Boolean, DWORD (32 bit) Boolean. After defining the number and types of entry/exit signals it is also possible to give them meaningful names and edit the relationship between entry and exit signals.

Not all the relevant behavior can be simulated with a simple time delay. The need for more complex modeling can be given with a simple counting behavior, e.g. upon some start signal and until some target value is reached a motor should be operated and then stopped, the parts moved away and start again. It is very likely that such a target value may by itself a variable.

3.6. Emulated Specific Robot Controller (ESRC)

Complete robot programs can be defined in Process Simulate, including program structure, allowing for the proper definition and execution of specific programs and relevant subroutines within the simulation environment. This can help to enable and enforce the use of company standard robot programming practices, meaning creating templates. This further improves simulation accuracy by extending simulations to include actual program content and execution scenarios and eases the maintenance and editing of robot programs.

Enhanced robot I/O behavior is supported through simulation by using status signals to control or simulate behaviors such as, start/ready, part number and emergency stop, pose signals, error information among others. This allows for the emulation of exact robot behavior, which in turn increases simulation accuracy. In this manner, evaluation of various specific robot program scenarios is enabled.

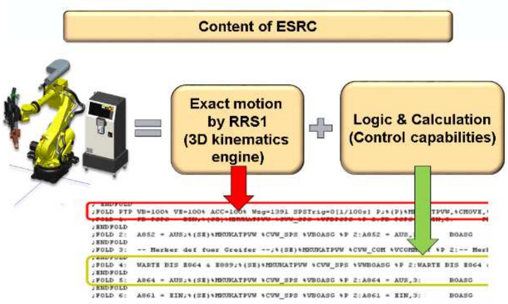

Fig. 11. Content of ESRC.

Enhanced OLP capability allows for the assignment of OLP instructions on robotic operations, not just paths, allowing for commands to be issued before the initial location with in a program sequence. Value evaluation and behavior, for supporting counters for instance, is supported, like the inclusion of logic instructions within OLP commands. In Fig. 11 is presented a schematic picture of emulated specific robot controller, which is the latest technology for virtual robot controller. The RRS 1 protocol was developed last decades (around 1990) as an international standard by robot manufacturers and CAD/CAM companies. The standard specifies communications algorithms and protocols to communicate with software model of the robot controller (RCS module). In addition to RRS, the emulated specific robot controller has control capabilities added by logics and functions.

This capability is important because it allows for the emulation of exact robot behaviors and the evaluation of both logic and motion parameters, which increases the accuracy of simulations.

3.7. Virtual Commissioning Environment

Assuming that all the above prerequisite conditions are met, in order to be able to setup the VC environment there are other components required:

- **OPC** (Object Linking and Embedding for Process Control) client/server, or other PLC connection mechanism allows for the execution of PLC program code, the real-time signal exchange between hardware and software (virtual model in Process Simulate), and the execution of the simulation via interaction with HMIs and other software triggers (simulated events) to virtually commission the system.
- **PLC** (Programmable Logic Controller) hardware or emulated.
- PLC code from automation engineers mapped with simulation model (logic blocks in Process Simulate)
- HMI (hardware or emulated) for trigger the events.

In Fig. 12 a schematic virtual commissioning hybrid environment is presented.

All the process knowledge together with digital process design and automation validation are stored in Process Simulate software environment and on the other hand the system controls is done by real hardware equipment (PLC, HMI etc.). This type of environment offers up to 100% accuracy of the simulation data comparing to real behavior of the manufacturing system. When commissioning the system it is important to put in

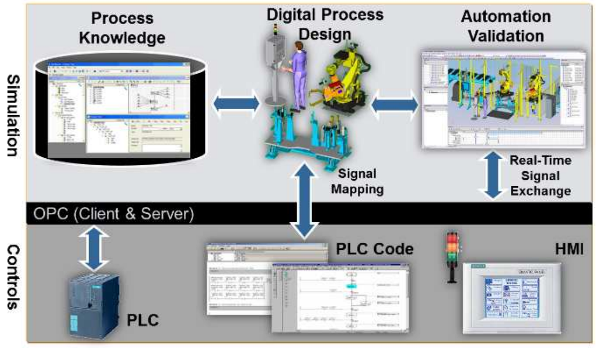

Fig. 12. Hybrid Virtual Commissioning environment.

place and synchronize the real layout with the virtual one. In this way the accuracy of the virtual commissioning will have desired effects.

4. CONTRIBUTIONS

It is obvious that faster production ramp-up requires virtual commissioning, especially in automotive industry where usually on the same line are produced few different car models with lot of variants. What is happening when a facelift is designed or a new model will be produced on the existing, running line? The costs with downtime for assimilating new or modified production equipment are not acceptable for most of the companies. In order to be able to keep the production line running, all the new or modified equipment has to be simulated, validated, tested and optimized with Virtual Commissioning concept, using specific technologies. Virtual Commissioning also enables manufacturing companies to optimize and troubleshoot both mechanical and control aspects of a robotics work cell.

In this paper a hybrid VC environment setup was presented, which can be improved or changed according to manufacturing system.

5. CONCLUSIONS

The main benefits of the proposed environment setup of Virtual Commissioning, which provides a reliable process for validation of robotic manufacturing systems prior to physical installation, are:

- Decreasing ramp-up time which affect the total installation time up to 20–30 percent. Having validated all the programs through VC, the ramp-up time, where errors in the code might appear, is drastically reduced.
- Reduce cost of change with early detection and communication of product design issues.
- Reduce number of physical prototypes with upfront virtual validation.
- Optimize cycle times through simulation considering event-based simulation in which logic blocks are defined to simulate the behavior of the equipment (devices) from the robotic cell.
- Minimize productions risk by simulating several manufacturing scenarios considering the logic blocks and signals defined in each manufacturing equipment, running "what is" scenarios.
- Early validation of the mechanical and electrical integrated production processes (PLC and robotics). Before virtual commissioning, the PLC codes could not be tested in virtual (simulated) environment, until the installation.
- Early validation of production commissioning in a virtual environment, where the PLC codes can be testes in a virtual environment.

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