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Virtual Commissioning-Based Development and Implementation of a Service-Oriented Holonic Control for Retrofit Manufacturing Systems

Francisco Gamboa Quintanilla, Olivier Cardin, Anne L'Anton and Pierre Castagna

Abstract While cyber-physical systems probably represent the future of industrial systems, their development might take some time to be extensively applied in industry. This paper presents the implementation of a service-oriented holonic control on a pre-existing system. The development of the control system is based on a virtual commissioning phase, developed with a Rockwell Arena simulation model.

Keywords HMS · SoA · FMS · Emulation · Virtual commissioning

1 Introduction

One of the key objectives of current research activities worldwide is to define best practices for implementing agile manufacturing systems. One very promising trend deals with the breakthrough induced by cyber-physical systems technology [1–3], for production [2], maintenance [4, 5] or logistics issues [6] to name a few. Even if these technologies are of a great interest and innovative solutions will appear soon on the market, the fundamental change induced and the cost of system's enhancements might impose a delay of a couple of decades between their industrial maturity and their exploitation in a large scale. Based on a size 1 experimental platform, this paper intends to define a framework for implementing an agile control

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on a pre-existing manufacturing system. The chosen *control is a service-oriented holonic manufacturing system* control (SoHMS) [7, 8] developed on a multi-agent platform. To reduce the cost of development, a virtual-commissioning based approach is presented, with all the constraints it implies on the control architecture.

Section 2 describes the system under study. Section 2.4 presents the current and targeted control systems. Section 3 describes the virtual commissioning phase and finally Sect. 4 explains the integration on the real system.

2 System Description

2.1 Flexible Manufacturing System

The application of the SoHMS is made to a small production line located at the University of Nantes, France. This production line, Fig. 1, is an automated assembly line composed of three workstations and a conveyor system formed by four conveyor loops of which three serve as buffers for each of the workstations and the other, the main loop, serves for transportation between the workstations. Product goods are transported by the conveyors with pallets having an intelligence level 1 [9], containing capabilities of self-identification with RFID tags in order to allow the transport resources to direct the pallet through the conveyors diverters from one port to another.

Workstations are composed of 6-axis robotic arms, a stock of Lego® blocks, a temporary stock and a workspace location for incoming pallets, Fig. 2.

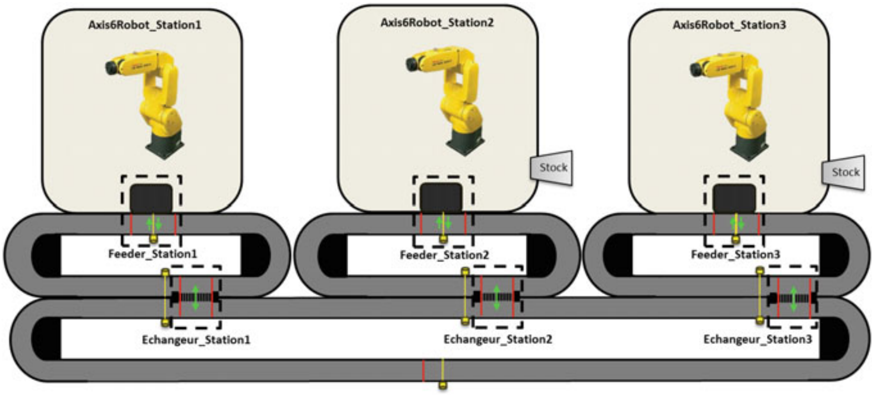


Fig. 1 Production line layout

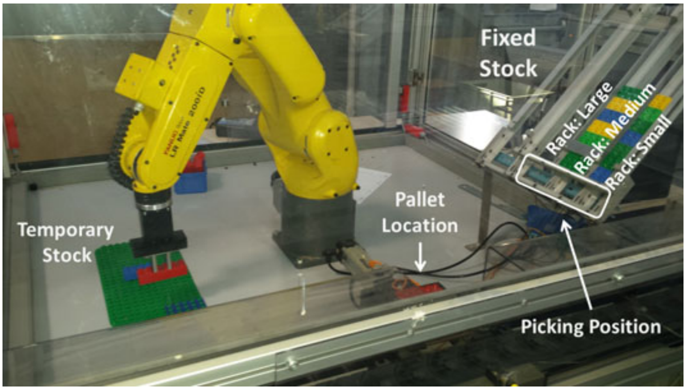


Fig. 2 Workstation layout

2.2 *Products*

The main function of the robotic arm is to perform pick and place assembly operations. The main task of the robot is to pick a corresponding Lego® block from the fixed or temporary stock and assemble it on the product under treatment. The fixed stock has three different racks, each rack for a different size of Lego® block. Within a rack, blocks of different colours may arrive randomly way. When a special colour is demanded and is not available in the picking position of the rack, the robot can use the temporary stock to remove blocks from the rack to make the desired colour available.

The product is a structure of Lego® blocks compiled in a specific configuration. Figure 3 illustrates a product family with two versions sharing the same product

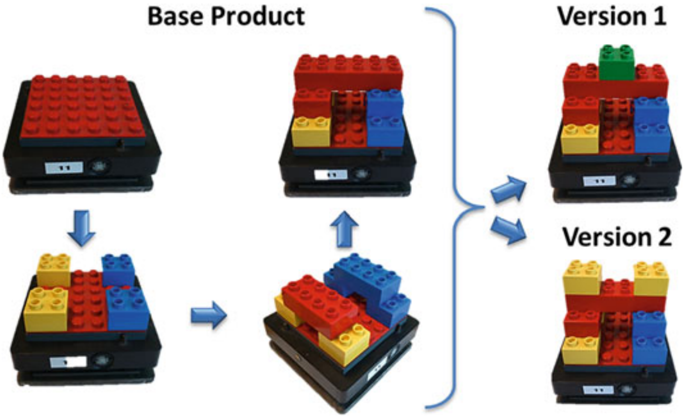


Fig. 3 Product example, with possibility of customization in 2 versions

feature, therefore all members have the same process structure up to the third level. Differentiation occurs at the fourth level where two versions can be issued.

Lego® structure is formed by three types of blocks namely; a small 2 × 2 block, a medium 2 × 4 block and a Large 2 × 6 block. These blocks can be assembled in any position (X, Y, Z and W axes). Added to this, each block is available in four colours: red, green, yellow and blue. Hence, there is a great flexibility to create a vast variety of structures. Customization for such product family happens at a scalable level with the choice of colour and at a modular/structural level with the choice of version. The Lego® structure results to be an ideal alternative in order to illustrate, in a very simple manner, the dependencies between the different components of the structure.

2.3 Services Definition

In the SoHMS there are the product-level services which are offered by workstations and transport resources. This service library belongs to the production line which can be viewed as a resource itself thus having a service offer of the different product families it can produce. Lego® blocks are used to represent the different manufacturing services, Fig. 4. In this way, taking the three types of blocks available, the service ontology for this application is formed by three types of services per layer. Differentiated by their size; a 2 × 2 block represents a service class A, a 2 × 4 block a service class B and a 2 × 6 block a service class C. This constitutes an ontology of 4 × 3 = 12 services types namely; A1 for a small block at level 1, B2 for a medium block at level 2, C3 for a large block at level 3, etc. Moreover, each of these services has a set of parameters. These parameters are the colour and position of the block only in x and y coordinates as the vertical position forms part of the service type definition. Other product-level services are the Transport_Pallet service and the

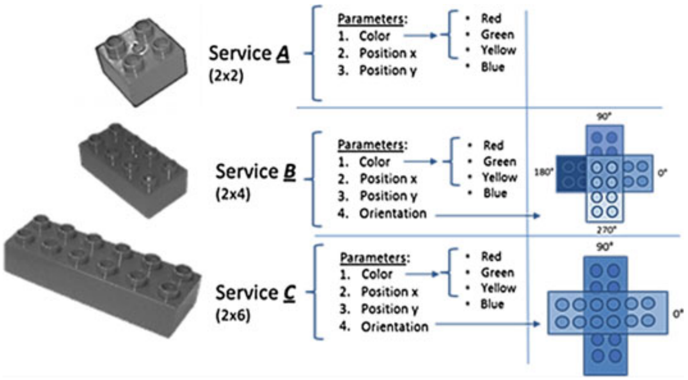


Fig. 4 Types of assembly services

Supply_Base service. The transport service has parameters: startPort and endPort while the supply service has the parameter colour of the base.

As the production line represents a flexible job-shop, service redundancy is included. Workstations 2 and 3 provide all the manufacturing services for the assembly of Lego® block of the three sizes. However, even though both workstations provide the same service types, these do not have the same capabilities at any time, considering the range of possible colours in stock for example.

2.4 The Control System

The system is equipped with control equipment settled on a TCP/IP network (Fig. 5). The robot controllers are able to communicate on Modbus TCP, same as the I/O on IP modules. On these modules, sensors and actuators (electro valves, lamps, relays) are directly wired and RFID readers are connected in RS485, communicating with serial Modbus. This architecture was originally dedicated to welcome a classical PLC. Field level orchestrations could be implemented as

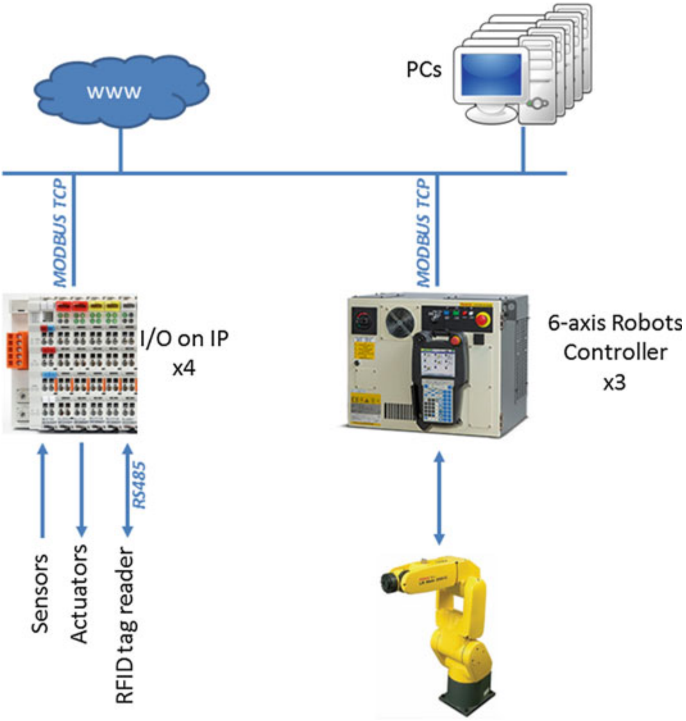


Fig. 5 Pre-existing control hardware

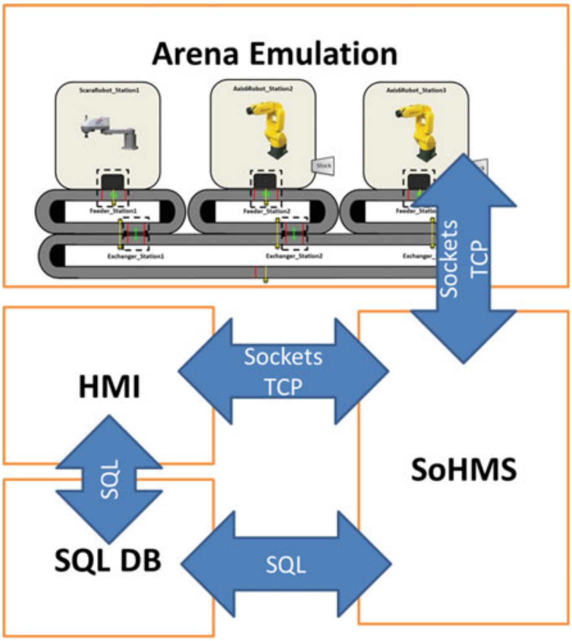
described in [10]. The choice made on this system is different. On the network, industrial PCs are set up and emulate a java virtual machine in order to run different programs, each having a specific function.

3 Virtual Commissioning

The emulation model was implemented with a discrete-event simulation tool, namely Rockwell Arena. Such tools are quite efficient to model activities based on queues management. In this model, queues are extensively used to model the synchronization between the events occurring on the emulation and the orders coming from SoHMS (Fig. 6).

For validation purposes, it is necessary to have a behaviour of the emulation mimicking the behaviour of low-level devices, as expressed in [11]. A TCP socket interface is therefore integrated in the emulation model, which both triggers orders and sends events information to SoHMS. It is able to understand orders such as "TRANSPORT TransporterID FROM InitialZone TO FinalZone" or "PICK RobotID Store". This emulation does not contain any intelligence, but is only able to execute a set of pre-programmed list of orders in reaction to a high-level order on the socket. The actions of the robots are transformed into delays of predetermined length.

Fig. 6 Integration of the emulation model in the control architecture



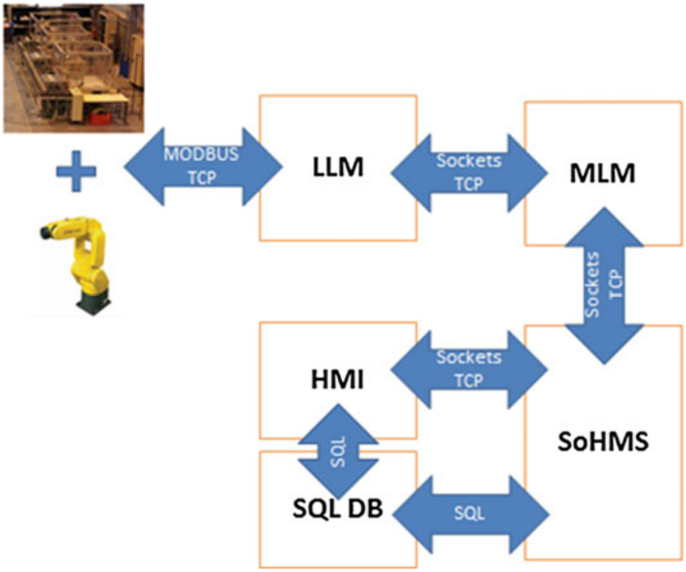


Fig. 7 Targeted control architecture

4 Integration on the Real System

The choice made on this system is to replace the PLC by ad hoc programs (Fig. 7), able to handle higher semantics than PLC do and more flexible in configuration for experimental purposes. First, a Low-Level Middleware (LLM) was created. The objective of LLM is to synchronously retrieve the state of each sensor of the system, asynchronously inform the upper layers of any change of value of the sensors and asynchronously modify the state of actuators on upper layers' order. Functionally, this is close to what OPC[1] servers do, but adapted to the hardware configuration.

Second, a Medium-Level Middleware (MLM) is in charge of aggregating the data coming form LLM for upper layers and time macro-actions requested by upper layers in high level semantics. For example, when a pick service is requested on a robot, MLM communicates to LLM all the configuration bytes to modify on the controller, waits for an acknowledgement, sends the program start order, sends an acknowledgement to upper layer that the service is running, waits for the

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[1] www.opcfoundation.org.

acknowledgement of program end and sends an acknowledgement of service end. These functionalities are close to those of a PLC, but with higher level semantics.

Finally, the SoHMS is connected to MLM, a Human-Machine Interface and a SQL database, storing production data and results. Validated with the emulation phase, it is plug-and-play on the system.

Alternate architecture solutions can also be implemented on this system. Figure 8 shows a configuration where several SoHMS are connected to the system. This is fully transparent for the system, as MLM does not differentiate orders coming from the upper-level. Another alternate solution is presented in Fig. 9. The virtual commissioning phase is oriented toward a monolithic architecture, as the emulation model was. However, it is absolutely possible to decline the holonic architecture induced by the SoHMS to an actual decomposition with each holon having its own MLM-LLM couple. The necessary step to ease this decentralization is to make these programs dependent of configuration files, indicating the limits of the considered holon.

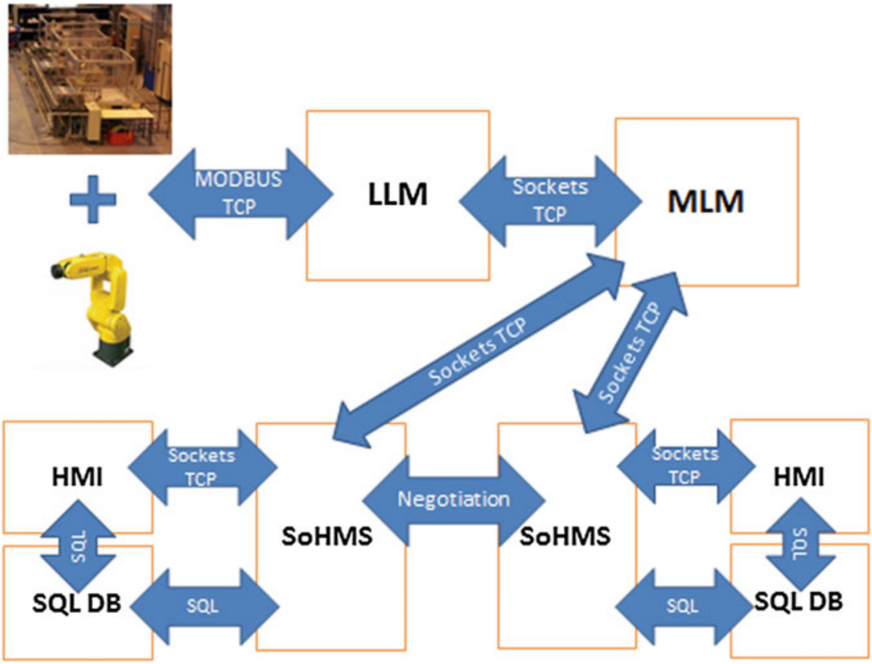

Fig. 8 Multiple SoHMS alternative architecture

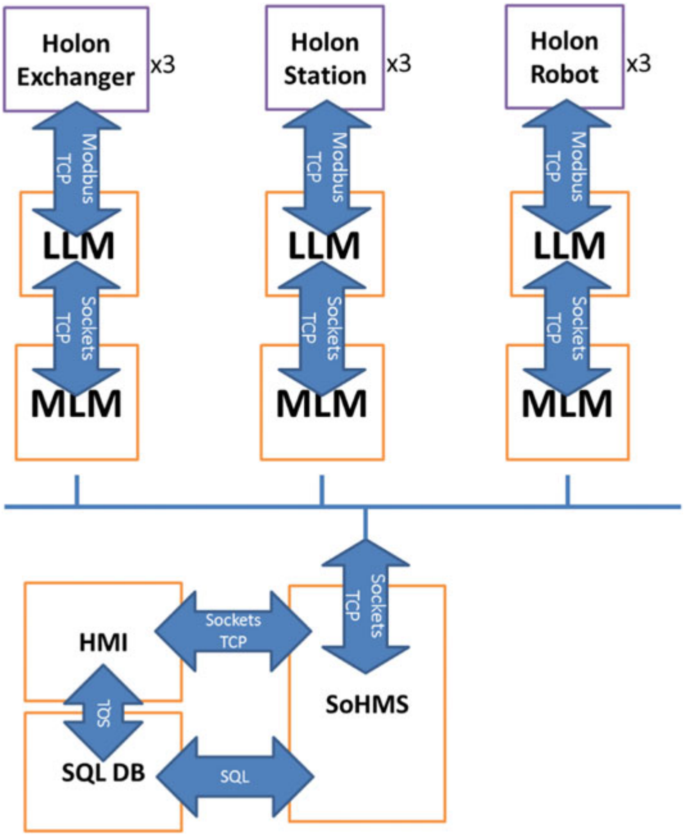

Fig. 9 Distributed alternative architecture

5 Conclusion

This study introduces a new experimental platform, built up around conveyor loops, three robotic stations and a control architecture fully programmed in ad hoc Java code. A SoHMS was implemented, thanks to a virtual commissioning phase performed via a Rockwell Arena simulation model. The next step is to generalize the programs in order to distribute the control and enhance the autonomy of holons.

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