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Review Article

Digital Twin and Virtual Commissioning of FANUC Robotic Cells based on the Industry 4.0 Context

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ABSTRACT

The objective of this research is to develop a methodology that makes use of the Digital Twin calibration and Virtual Commissioning to digitally validate robotic mechatronic cells, and minimize the time of installation and implementation of the project on the "factory floor" in the context of I4.0. Currently a major problem related to Virtual Commissioning activities is the lack of precision between the virtual model and the physical model, due to the difficulties related to the construction on the factory floor of the previously generated 3D model. The proposed methodology of calibration, calibration and validation of the digital twin can be applied to different production segments, and this is a competitive differential in relation to automation solutions strictly developed for the automotive industry, also allowing professional qualification at a distance with virtual reality that the project will make it possible as an unfolding. The impact of the results is the reduction of technical errors in the robotic engineering project during the initial phases of the digital twin, the time savings of the "roboticists" on the factory floor solving rework and automation professionals avoiding irregularities during all stages of the robotic simulation. Using the benefits of the digital twin and the simulation tools, it is possible to increase the communication and coordination advantage between the manufacturing areas, allowing smarter decision making. This allows automated systems and robotic cells to run (running) much faster and with fewer errors.

Keywords: *Digital Twin, Virtual Commissioning (VC), Industry 4.0, Roboticist, Robotic Engineering.*

1. INTRODUCTION

The Industrial robotics and the complexities of 4.0 processes are rapidly reshaping the manufacturing industry. Succeeding in this new scenario means adopting this complexity and using it as a market advantage over competitors who implement legacy and less sophisticated processes. The factories of tomorrow will be more integrated, robotized and will allow greater flexibility in products and services [1]. The production systems of the future must be significantly flexible and respond dynamically to continuous changes in orders, ensuring high productivity [2]. This adaptation process must be fully automated to maintain considerable levels of efficiency. Therefore, it is necessary to include not only the specifications of each order, but the status of all production components and even external information, such as transportation systems, in the decision-making process [3]. These resources can be achieved with the integration of advanced information and communication technologies in the production process. This integration of technologies in physical processes is leading to cyberphysical systems (CPS) [4,5]. By providing updates and services to CPS, customer loyalty can be increased [6]. The machine manufacturer can decide whether to provide these services himself or whether to publish the relevant specifications to allow independent developers to offer services. The quantity and quality of these services can have a major impact on customers' purchasing decisions. Another important factor in the customer's decision process for the acquisition of robotic cells is the demonstration of the viability of the solution through simulation. In this context, the digital twin (digital twin) standardized and well elaborated, favors the results of the simulation because it reproduces in a more reliable way all the real characteristics of the predicted applications of the robotic cell [1,7,8].

In [9] it was reported that the Companies aim to implement sustainable manufacturing of robotic cells, in order to improve profitability, reducing resource consumption, global expenses,

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as well as satisfying the regulatory input of ecological impacts. In addition, the widespread adoption of industrial robots, are needed to satisfy the ever-increasing requirements in terms of manufacturing quality, customization and flexibility, further increased the need to improve the energy efficiency of robotic cells.

2. STAT OF ART

This section describes the main themes that were used for the development of this proposal, they are: RAMI 4.0 (Reference Architectural Model for Industrie 4.0) and the Digital Twin.

2.1. RAMI 4.0

RAMI 4.0 (Reference Architectural Model for Industrie 4.0) is a reference model for Industry 4.0, by definition, a set of standardized elements for designing and implementing flexible and decentralized solutions. Thus, the term RAMI 4.0 is used to conceptualize a type of model used for implementations of the most diverse solutions for projects related to Industry 4.0. The model provides practical guidelines for the entire production chain to be involved in the cybernetic atmosphere and high performance, characteristic of the fourth industrial revolution [2]. The (Fig 1) shows the RAMI 4.0 model.

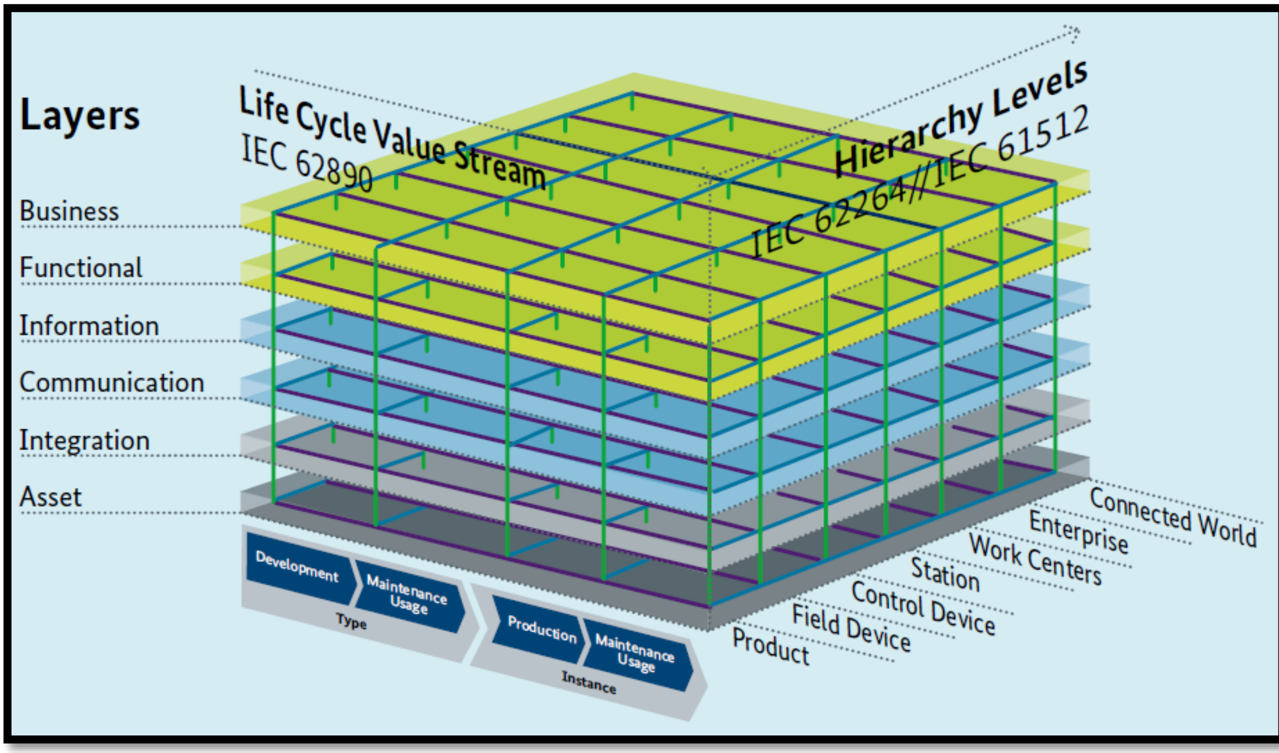

Fig 1. Reference Architectural Model for Industrie 4.0- RAMI 4.0 [8].

The RAMI 4.0 today symbolizes one of the best known models due to its three-dimensional representation, structured and present in the entire production chain. RAMI 4.0 promotes the connectivity guidelines for systems and processes within the reality of Industry 4.0 [3]. According to [8], RAMI 4.0 is divided into three areas (axes) of application, covering all stages of the production chain, providing an order between the processes and controlling the life cycle of an industrial operation. The axes are:

• **Hierarchy:** In this stage, the internal connection model of all agents that make up production, from people to data and equipment, is defined, providing a clear and efficient communication between all the actors in this framework. The hierarchy has flexible and interoperable characteristics, distributed across the various sectors and stages of a production process.

• **Architecture:** Architecture is responsible for verticalizing the data flow of the industrial production process, as well as the interfaces that will be used in the operation by employees and managers. It is up to the architecture to transcribe physical data into intelligible and rational information, collecting the data necessary for production efficiency and relating the devices, machines and people according to their functions.

• **Life cycle:** The life cycle of the manufacture of a given product goes through its idealization and extends to phases of research, development, testing, validation, production and completion. These are essential points to guarantee the productivity and success of the operation.

The RAMI 4.0 operates from a set of components with the same information and control semantics, called I4.0. The sets of I4.0 form production cells that work in a flexible, decentralized and interoperable manner in this context. After that, it is essential to turn attention to the I4.0 components for maximum control and interconnection. Finally, one must seek to efficiently configure the system for complete interoperability within the three axes (dimensions) of RAMI 4.0. Thus, allowing flexibility, customization and personalization. For the implementation of RAMI 4.0 to occur, it is necessary to follow some considerably structured steps. Starting with the basic automation project in a decentralized and interconnected way with all devices [9]. Within the production line, as soon as information about the status of an asset is received, it automatically relates to the three axes of RAMI 4.0 management. Observing that the pattern is vertical, the value of this type of information is contained in the entire production chain, being available with the same data from the management of the business, prototype, production to the final consumer. Among the several benefits that can be provided in the adoption of RAMI 4.0 as a standard for application in Industry 4.0 we can mention [3, 9]:

• Improvement in the structuring for security and privacy; Service-Oriented Architecture (SOA);

• Division of processes to facilitate communication and data processing;

• Connection of the Information Technology components in certain layers of the life cycle.

The RAMI 4.0 model can be used to describe any I4.0 asset. The I4.0 component allows you to create an information or technology link, using the administration shell, between any asset and Industry 4.0. According to RAMI 4.0, all assets can be registered simultaneously at a given time T1 together with their states and locations in the physical world. As a result, it is possible to correlate and evaluate the state of the general system, including the local deployment of individual assets in the information world. The instantaneous asset created provides a consistent time reference and, thus, establishes a temporal relationship between assets [4].

2.2. Digital Twin

The greatest benefit of the digital twin is the representation of the physical characteristics of a real prototype through a reliable mathematical model, which allows time savings and cost reduction in the project simulation [7]. There is a possibility to analyze in advance an investment that would be very expensive, and to check its feasibility [1]. It is important to follow the project from the beginning using the digital twin of the robotic cell: from the concept phase to the development for testing and optimization during operation. Due to simulation and future virtual commissioning, it is possible to reduce the Time To Market (TTM), reduce error costs, increase quality and reduce risks during actual commissioning [9,10]. The greatest benefit of the digital twin is the representation of the physical characteristics of a real prototype through a reliable mathematical model, which allows time savings and cost reduction in the project simulation [7]. There is a possibility to analyze in advance an investment that costs the digital twin of a robotic cell allows to parallel the mechanical, electrical and automation design as well as systems engineering tryouts. Waiting times for phases of information exchange between equipment can be avoided in this way. Through the simulation of industrial robots, extensive tests allow to detect and correct errors in the design and functions, making real commissioning very fast [10]. According to the Six Sigmas management system, error costs increase by a factor of ten with each stage of development. With simulation, perceptions of virtual tests can improve engineering quality at an early stage [8, 9]. Testing the PLC code during virtual commissioning increases the confidence that the interaction of the electrical, mechanical and the robot controller are working as intended by the analyst and robotist [6]. This helps to avoid high costs and minimizes errors. Problems during real commissioning take time and increase labor and material costs, especially with international projects [4]. To get around these difficulties, everything can be tested safely virtually without the need for the operator of the robotic cell. Industrial robots are designed to work constantly, with no downtime. Optimizations or renovations require access to the machine, which is not always possible. Finally, through the digital twin of the real robot, it is possible to validate all actions during the operation, this reduces downtime to a minimum [4, 11]. It would be very expensive, and check its feasibility [1]. It is important to follow the project from the beginning using the digital twin of the robotic cell: from the concept phase to the development for testing and optimization during operation. Due to simulation and future virtual commissioning, it is possible to reduce the Time To Market (TTM), reduce error costs, increase quality and reduce risks during actual commissioning [9].

3. RESULTS AND DISCUSSION

In Standardization of the digital twin enables engineers to verify communication between robotic devices, I4.0 components and industrial robot controllers across the shop floor to ensure that signal exchanges are efficient and appropriate before installing any physical equipment or starting processes of running. This is vital in order to automate production processes later in the integration of robots. The RAMI 4.0 model was used for administration, standardization, organization of files, conversion of components, definition of operations, creation of kinematics, elaboration of input and output signals, development of logic blocks and programming of the trajectories of the robotic manipulator. The tests were carried out in a Robotic cell at the Advanced Robotics Institute - I.A.R. using the LR Mate 200iD industrial robot with M30iB plus controller from the Japanese manufacturer FANUC CORPORATION (Fig. 2).

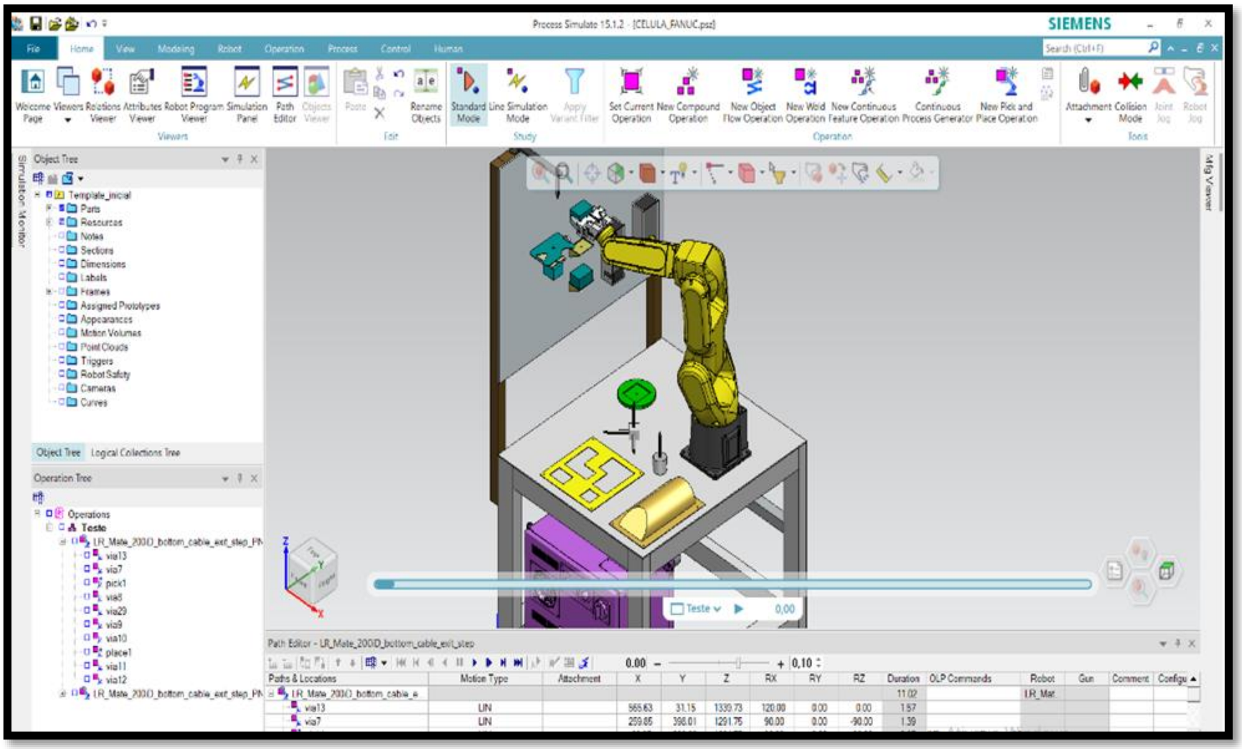

Fig 2. Example of a robotic cell developed at the Advanced Robotics Institute - I.A.R.

Just like the robotists who prepare their respective programming codes offline before the first physical contact with the industrial robot and the manufacturing cell, automation analysts lack the same working conditions. They need to convert the 3D model files of the main CAD software to the extent to which the objects will be used in the digital twin creation software. Among the various objects (sensors, actuators, devices, conveyors, rotating tables, claws, resources and others), one of the most complex is the industrial robot. In its specifications it has internal files (motion parameters, kinematics of the equipment manufacturer itself, machine data, joint information, linearized mathematical models, decentralized control systems, among others) that characterize a robot. (Fig. 3) presents the main files that represent Kinematics of a robot in Process Simulate in version 15.1.2.

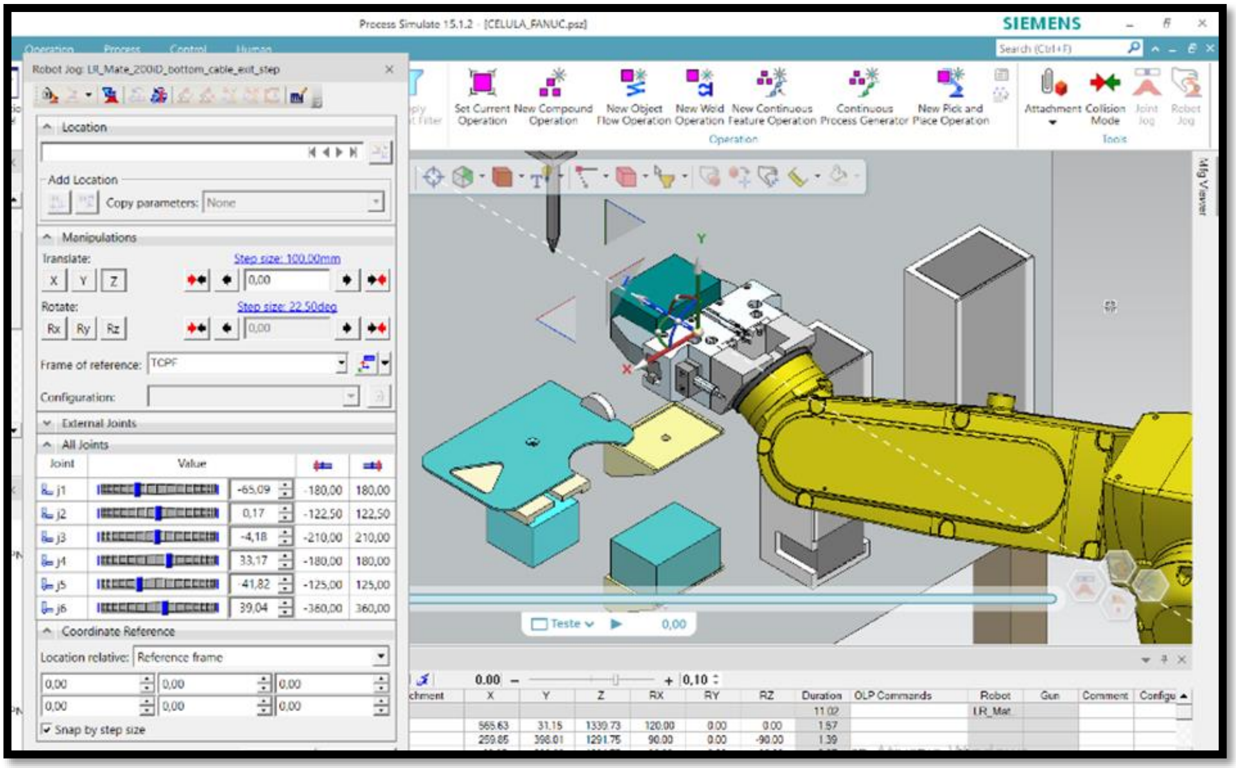

Fig 3. Example of creation of kinematics

This work was developed in a virtual environment using Process Simulate software in version 15.1.2. from the manufacturer Siemens Digital Industrie Software. The challenge is the integration of the standardized digital twin with the simulation of a robotic cell.

One of the main motivations of Industry 4.0 for our project was the creation of automated manufacturing systems, which can produce products tailored to the customer with high levels of efficiency. The information of the entire simulation system was accessible with the completion of the digital twin that was standardized following the RAMI 4.0 model [12,13]. All stages of the process have been continuously adapted to obtain optimized results with the aid of Process Simulate resources. Another advantage of this concept is that the production system is highly flexible, so adaptations to new technologies and products can be made with little effort. This can be a major competitive advantage, considering the constant decrease in the product's life cycle and time to market for new products [14, 15, 16].

4. CONCLUSION

The standardized acquisition and integration of the digital twin with the simulation of a robotic cell was the challenge of this work. The current approach met the proposed objective applying to a robot manufacturer; however it can be used for other manufacturers. In many cases, robotic cell simulations are more complex and require more analysis time. This result can be extended to different robot manufacturers, automation suppliers and robotized processes, as it requires a comprehensive solution based on a more sophisticated digital twin. It is also possible to use different manufacturers of simulation software where the focus is on process simulation, combined with factory simulation to achieve flexible production for increasingly personalized products. The benefits of the robotic cell simulation brought technical gains for the robotists and financiers for the companies that reduced tryouts and the number of engineers and technicians during the running of the real robotic cell. It can be said that the RAMI 4.0 model was fundamental as a guide in standardizing the results of this work, as it was important to interrelate several I4.0 components and, subsequently, organize these components into entities and compounds for specific purposes. This organization, including for example modularization based on the principle of representation of I4.0 components and robotic engineering file standards. Thus, it is promising to continue scientific research using this same approach proposed for other applications. Finally, it is very important to increase the number of integrated devices to verify system performance. The projected increase in the use of robots reinforces the commercial potential of this project and will enhance the provision of consultancy services in virtual commissioning, which will allow integrating companies and end customers to become more competitive and productive, enabling fairer competition in the global market. The unfolding of the project, results in good practices in the process of validating the commissioning and all its complexity of calibrating the study and simulating the “virtual to the real” and implementation on the factory floor. To be successful in this result, a lot of practical experience in the area and research applied to problems that have not yet been solved, and that companies need solutions are needed. Virtual Twin has gained significant momentum as a technological development breakthrough with the potential to transform the reality of companies. Digital twin, acting as a mirror of the real world, provides a means of simulating, predicting and optimizing physical manufacturing systems and processes. Using Digital Twin, together with intelligent algorithms, organizations can achieve data-driven operation monitoring and optimization, develop innovative products and services, and diversify value creation and business models.

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