

Digital Twin Model for Assembly Robotic Cell

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Abstract – The global market is becoming more and more dynamic, is characterized by increasing demand for customized products. The production of these customized goods involves the adaptation or new deployment of manufacturing lines, assembly points, and technological processes. A concept that can support the design process of several implementation scenarios in a short time is a Digital Twin platform. Having a Digital Twin, various manufacturing scenarios can be simulated and compared, thus reaching the best implementation solution. Moreover, when commissioning such a manufacturing system, with the help of the Digital Twin, design problems can be identified from the design phases through virtual commissioning.

This paper presents a virtual platform as a digital twin of an industrial robotic cell that enables virtual commissioning. The Digital Twin offers support in decision making for asset lifecycle management. It serves as a filter for future manufacturing process adaptation. The platform includes the 3D model at 1:1 scale and the functional behavior of each physical unit by combining different types of engineering and operational data produced in the design phase, before the upgrade implementation.

Keywords – Industry 4.0, Virtual commissioning, IIoT, Digitalization, Flexible assembly line.

I. INTRODUCTION

Manufacturing companies must adapt to new trends in the industrial environment in order to remain profitable. On-time delivery of customized products implies a degree of flexibility and adaptation in the manufacturing processes. Moreover, with the advance in the technology field and by relying more and more on machines, the manufacturing systems are getting more complex. This can reduce manufacturing flexibility due to the time required to redesign complex systems. Another factor that influences the ability of production systems to adapt to new market trends is the rigidity of management systems made according to traditional methodologies such as the automation pyramid [1] scaled to complex architectures. Moreover, in the process of designing, developing, and implementing a manufacturing system, many programming frameworks are used. Traditionally, the data generated by these programs (a large volume) are isolated from each other and most of them cannot be correlated from the design stage; this correlation can identify functional errors from the design phase [2]. Thus, the concept of Digital Twin appears as a normal evolution of the technological advances made in big data analysis in order to increase system performance.

The Digital Twin appears to be the most promising technology to implement smart manufacturing and Industry 4.0 by combining virtual space with real space, but the concepts lack standardization and a unified method for modeling and implementation [3,4]. In [5], the authors define the Digital Twin for a manufacturing system as a data-oriented model of all system elements, value stream, material flow, operations flow, and human resource, which is in permanent connection with the physical implementation. Moreover, the Digital Twin includes all product design system operating data, from all system elements, and historical data. In [6] the Digital

Twin is summarized as the integration between knowledge about the physical implementation and data-driven intelligence in a single model.

By leveraging sensor and historical data, Digital Twin can capture almost any feature of an industrial installation. Its implementation can follow one of two scenarios [7]:

- DT is born in the design phase of the real implementation and provides the method of virtual testing of the solution. After the implementation of the real solution, DT and the implemented installation coexist sharing information with each other
- DT is born after the entry into production of the real implementation (example installation from brownfield manufacturing system) and share information with the physical elements through a communication protocol

The Digital Twin platform must model the functionality of the physical system as well as possible. It must include practically all the functions, the trajectories of the actuating elements, the restrictions, and the process factors [8]. Digital Twin must have access to all data collected over the life of the asset; for this reason, it plays an important role in understanding the real system and provides a means of predicting future behavior based on existing data. Moreover, it can be an important tool for engineers providing technical support for further development decisions [9]. It can be used at different times in the life cycle of a manufacturing facility as a virtual mirror providing information about current and expected performance and long-term system behavior [10]. Another benefit of the Digital Twin is the reduction of the real commissioning time by introducing a virtual commissioning stage, thus eliminating some errors / technical inconsistencies in the design phase and reducing energy consumption (virtual commissioning consumes much less energy than the industrial installation) [11].

In our previous work, we have described the system capabilities for the didactic (training) industry [12]. In this paper, we will present the physical aspects of the robotic cell and the digital representation. In the next subsection, we will present the physical and functional details of the robotic assembly cell, which is important in modeling the digital twin. In section 4 we will present the digital representation of the robotic assembly cell.

II. SYSTEM OVERVIEW

The purpose of the digital twin is to emulate the real implementation by including the 3D representation and the system functionality down to the smallest detail. Ideally, the digital twin and the physical twin are identical but there is always a compromise to be considered between the level of details and the effort to implement them.

3.1 THE ROBOTIC CELL – PHYSICAL IMPLEMENTATION

The robotic assembly cell Fig. 1 is a heterogeneous structure that includes a wide variety of industrial elements. The overall system is able to assemble a flexible finished product consisting of 3D printed subassemblies. The precision is ensured by a synchronous motor conveyor driven by an industrial converter in closed loop of speed and position and by a robotic arm with six degrees of freedom capable of manipulating 3D printed subassemblies.

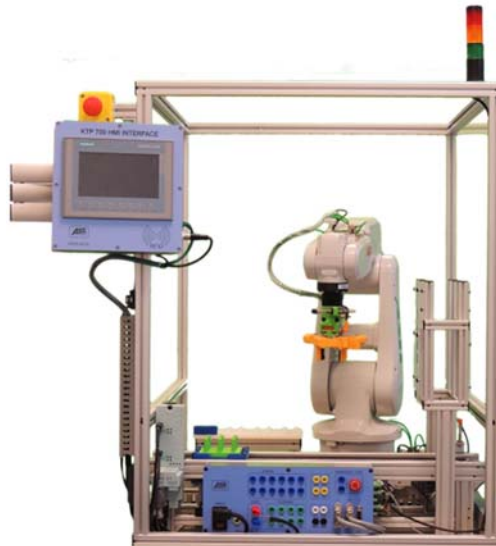


Fig. 1. The robotic assembly cell

Modularity is ensured by the flexible aluminum structure that offers mounting support for the actuating and sensory elements. From a control point of view, the robotic assembly cell includes a local PLC (programmable logic controller) processing unit that ensures local management without continuous supervision. The HMI (Human Machine Interface) interface provides local monitoring of system parameters and allows cell operation manually. Each industrial element represents an independent unit capable of performing several precise tasks; each module includes the ability to communicate process data over an industrial communication protocol (eg. Profinet) thus ensuring the synchronization of individual modules in a homogeneous architecture. Moreover, the cellular robot is able to synchronize with other systems on the same hierarchical level as well as bidirectional communication with higher hierarchical systems such as SCADA (Supervisory Control and Data Acquisition) and MES (Manufacturing execution system) systems through OPC UA (Open Platform Communications Unified Architecture) and MQTT (Message Queuing Telemetry Transport).

The unit is able to assemble more than 50 possible configurations of the finished product due to the assembly flexibility determined by both the assembly system and the product design (abstract 3D printed product similar to an electronic board).

3.2 OBJECTS AND FUNCTIONALITIES

The system architecture is presented in Fig. 2. The main elements are an industrial PLC, a robot with 6 degrees of freedom, an HMI interface and a conveyor with position, and speed control.

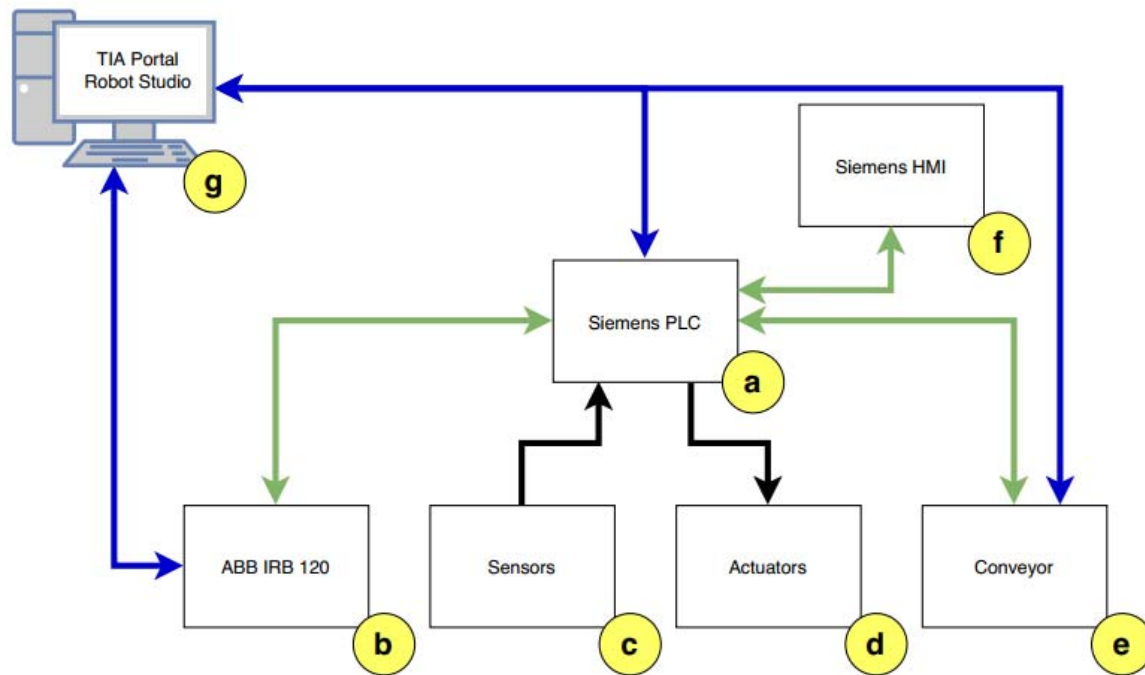


Fig. 2. Robotic assembly cell – components and communication architecture

The Siemens PLC (a) provides the local management framework for product assembly by sharing local information with the robot controller and the conveyor driver via Profinet. Moreover, it includes the communication capabilities for linking the cell with the management program (SCADA). The Industrial robot arm consists of one ABB IRB 120 (b) with six degrees of freedom capable of 580 mm maximum range and the correspondent IRC120 controller with Profinet communication. The robot includes a flexible gripper with three working points for material handle. For position detection are used inductive and optic sensors (c). The PLC acquires the sensors data and compute the command needed for conveyor, robot and multiple pneumatic actuators (d) used for raw material handling. The conveyor (e) includes a synchronous motor for position control and a Siemens driver S120 with Profinet communication. The Siemens HMI (f) provides the local interface for monitoring and controlling the station.

The PLC and HMI are programmed with Siemens TIA Portal. The robot is programmed with Robot Studio using RAPID language. The driver is parameterized with STARTER software. For a better simulation of the physical asset, the digital twin will be compatible with the engineering programming frameworks. Thus, the development of control algorithms can be tested in virtual commissioning using the same structure and programming language as in the real implementation.

III. THE DIGITAL TWIN

The digital twin includes all the assets from the real implementation. It is implemented in CIROS® an industrial framework used for advanced process simulation. The architecture of the digital twin is presented in fig. 2.

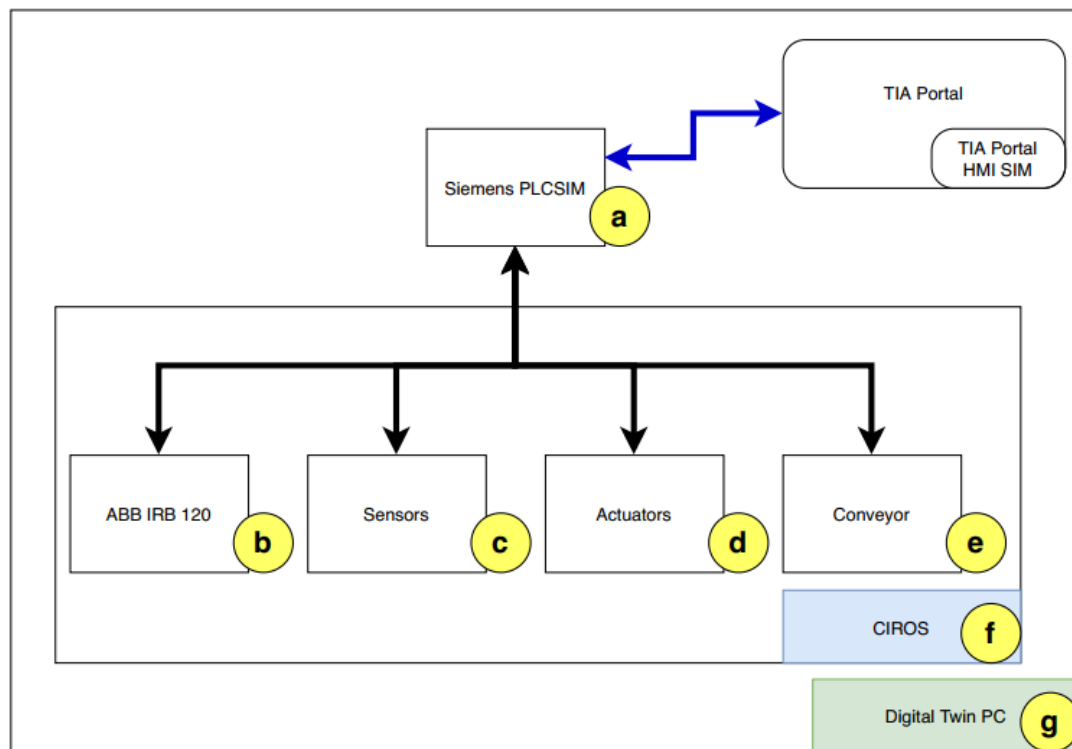


Fig. 3. Digital Twin architecture

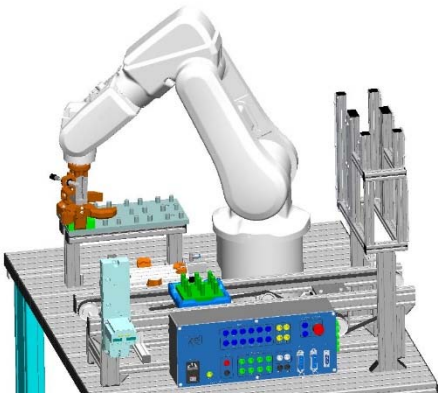
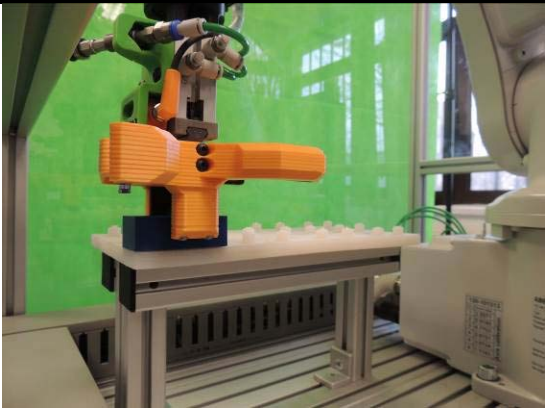
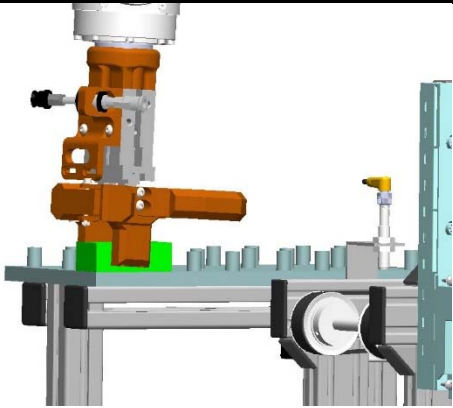
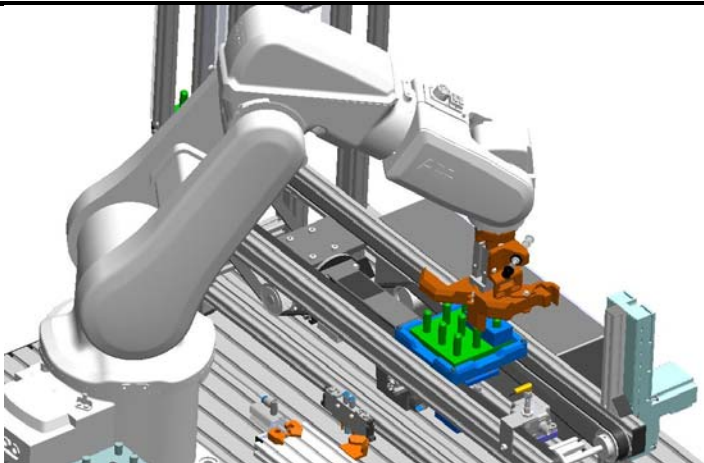
The virtual implementation includes the following digital assets:

- a) The PLC is simulated using PLC SIM, an industrial framework provided by Siemens. It allows the same interaction as with a real unit. The PLC SIM software runs on the same computer as the CIROS® simulation. Between them, data linking is possible due to communication modules inside CIROS®.
- b) Industrial robot arm is included in CIROS® library. The digital twin includes the model from the CIROS® library. The gripper is specific to our application. Thus, it was implemented from scratch. It consists of the 3D model and the functional model with a working stroke of 40mm.
- c) The robotic assembly cell contains industrial sensors such as:
 - Inductive sensor for product detection and for position feedback located at each conveyor limits.
 - The optic sensor for robot proximity detection is placed on the robotic arm. It can detect the raw material, thus allowing the robot arm to adjust the target position.
- d) Multiple pneumatic actuators are included for material handling. Each actuator includes the industrial 3D model provided by the supplier and the functional model implemented accordingly with technical specifications (diameter, stroke length, force).
- e) The conveyor system includes the synchronous motor and driver models, developed in CIROS® with the same parameters as the real unit: speed control, position control.
- f) The simulation engine CIROS® provides a library with industrial components, such as the robot arm, sensors, actuators, and developer capabilities if is needed to implement some units from scratch. Also, it includes a physics emulator that allows simulating the gravity and other forces. The communication with the real implementation is assured by the OPC UA communication.

- g) The PC is capable to run CIROS®, TIA Portal and PLC SIM. It allows data communication with the real implementation and it provides enough resources for uninterrupted functionality.

Table 1 includes 3 frames from the manufacturing job, both in real and virtual environment.

Table 1. Assembly process frames

Physical implementation	Digital Twin
	
	
	

IV. CONCLUSION

In conclusion, the paper summarizes an overview of recent publications about digital twin. The digital twin is presented as a virtual copy of a real asset that can be implemented before or after the physical implementation. The main advantage of the digital twin is that it can allow engineers to have a better understanding of the real asset and can provide a testbed for future development. Moreover, before real commissioning, the implementation can consider virtual commissioning in order to identify potential functionality errors and incompatibilities during the design phase. The article presents an overview of the implementation of a Digital Twin as a detailed digital representation of a physical robotic cell. The article presents the real implementation and details all the physical characteristics considered in the digital representation. The results show the Digital Twin implemented in CIROS® framework.

As further work, we consider improving the digital twin by adding models for power consumption. Also, we consider developing a predictive maintenance application that leverages the data produced by the digital twin and a task optimization algorithm for the assembly process.

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