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Introducing students to zero defects, condition monitoring and system integration using a refurbished learning factory

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Abstract

The transition to the fourth industrial revolution brings with it a modernization of the shop floor. This modernization can sometimes be misleading in the way it is implemented, leading to the disposal of old but functional assets. This work applies the concepts of industrial refurbishment and retrofitting to create a learning factory from deprecated didactic material, with economic and ecological savings in mind. Furthermore, it proposes the application of an IEC 61499 framework in the development of applications for learning factories. The IEC 61499 standard describes a visual Function Block paradigm used to create distributed automation applications. This implementation intends to achieve two outcomes: 1) create automation applications to repurpose the learning factory; and 2) use this framework as a platform for students to develop their own applications for the learning factory. While the re-purposing itself is a lesson to be taught, a set of three learning paths were created. These learning paths explore the topics of Zero Defects, Condition Monitoring, and System Integration. Finally, it was demonstrated that the IEC 61499 platform allows learners to explore these topics from a hands-on perspective.

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1. Introduction

A Learning Factory is a production scenario with similar characteristics of a real factory, whose abstraction must be as low as possible, and is used for learning purposes (in [1]). This paper follows along with the refurbishment and retrofitting of new technology to an old FESTO Modular Production System (MPS), based on the integration and interoperability of several modules (stations) that simulate common small-scale automation functions, to create a learning factory.

A legacy FESTO MPS production line with 4 stations (Distribution, Testing, Processing and Validating, and Sorting) was refurbished and integrated with a new robotic arm, which substitutes the original FESTO Transporting station. To bring this system back to usable condition, the most important steps were: 1) converting the old PLC into a remote I/O card and transferring the code to a softPLC that supports OPC-UA running on a Raspberry Pi; 2) ordering and installing broken parts (e.g. pneumatic actuators, structural elements); 3) installation of analog pressure and airflow sensors; 4) integration of a robotic arm to transport items between stations.

1.1. Research Questions

This work goals can be split into three outcomes: refurbishment, teaching, and IEC 61499 application. This leads to the following research questions (RQs):

RQ1: In this case, is it economical and ecologically viable to refurbish and upgrade outdated didactic equipment?

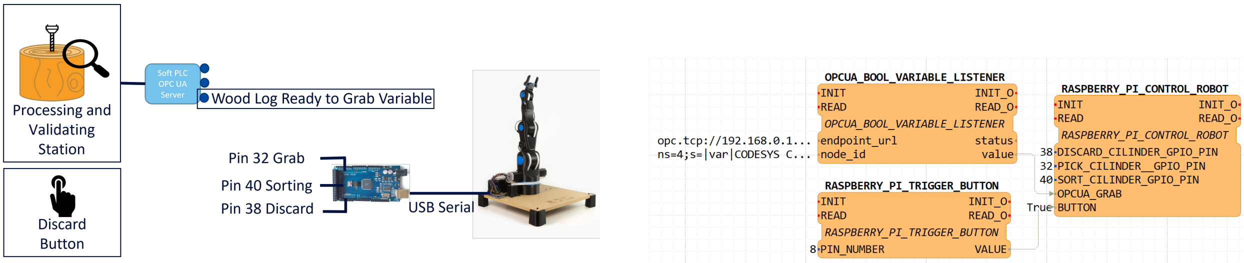
RQ2: What Industry 4.0 concepts can be taught to students using refurbished and upgraded learning factories?

RQ3: Are IEC 61499 components useful, as a means of learning, to test knowledge on different learning paths? If so, is the application of this knowledge on learning factories applicable on de-facto industrial scenarios?

2. Learning Paths

This work was developed in the context of the FactoRIS project, whose objective was to develop Teaching and Learning Factories in participating countries. In parallel, the teaching contents were also developed in a digital format, whose learning path *"Learning Path on IEC 61499 applied to monitor, defects detection and system integration"* is publicly and freely available in [2].

2.1. Zero Defects Manufacturing



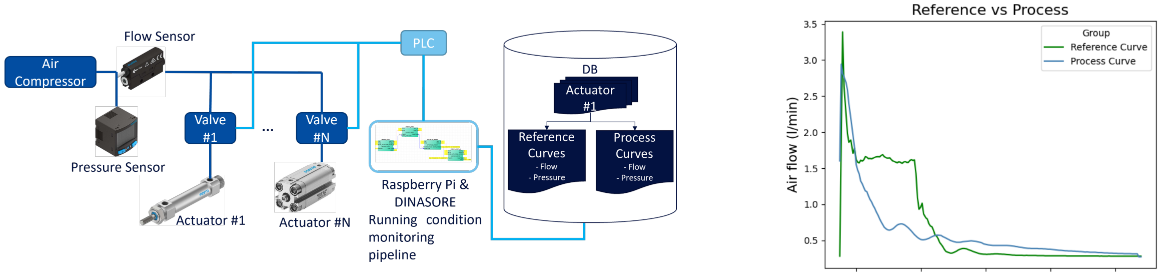
(a) Zero Defects Architecture. (b) Zero Defects Function Blocks.

Fig. 1: Zero Defects Approach

The problem addressed in this topic is the detection of surface defects, because the learning factory does not have technology to detect them. Integration of human observations was the approach adopted for this case. The physical architecture for this solution is depicted in Figure 1a, while the Function Block (FB) pipeline responsible for controlling the process is depicted in Figure 1b. Each time a work piece is processed, the Soft PLC flags an OPC UA variable, monitored by the "Listener" FB, which passes the variable value to the "Controller" FB. This last FB instructs the robotic arm to pick the piece and send it to a position where a human can inspect the object. If the button (detected by "Trigger" FB) is pressed, the robot discards the piece. Otherwise, a timeout occurs and the piece is transported to the next station.

2.2. Condition Monitoring

Maintenance has particular importance to increase the lifetime of industrial equipment. In this context, the learning factory stations are composed of pneumatic actuators, whose seals degrade over time and pistons get increasing resistance due to lack of cleaning, which can lead to actuator failure without warning. Therefore, predictive maintenance comes as a financially sustainable solution. Measuring system parameters and analyzing the data acquired to detect the degradation of the different parts of the system allow deciding at runtime when a part should be repaired or substituted. For that, a flow sensor and a pressure sensor were installed in the air circuit (Figure 2a) of one of the stations to monitor the condition of those actuators. A pipeline of functions blocks was also developed, to read the values of the sensors through an ADC and send the data to a database. Furthermore, the pipeline was also responsible for comparing the runtime data obtained while the factory was operating (process curves) to a reference curve previously acquired, considered to be a correct behavior of the actuator under analysis, as shown in Figure 2b.



(a) Condition Monitoring Architecture.

(b) Reference vs Process curves.

Fig. 2: Condition Monitoring Approach

2.3. System Integration

The last learning path deals with the installation of a new robotic arm into an old working environment. The main problem present is developing a logical connection between the current control loop and the control mechanisms of the robotic arm. The process required to do such upgrade can be split into three steps: 1) Get state data from the old process and define what can trigger the new FB (define the robot's movement); 2) Develop the new FB which is capable of executing the triggered functions (in this case move the robot); 3) Install the new FB, attach it to the control loop, define its interactions with the system and deploy it into the distributed system. The architecture used to solve this problem is described in Fig. 1.

3. Conclusions and Future Work

In conclusion, based on the content exposed, this chapter presents the answers to the research questions.

RQ1: A new system would cost tens of thousands of euros. By refurbishing the present system, it was possible to have a capable system for under 1500€ (without labor cost).This approach is economical and ecologically viable.

RQ2: Besides the three learning paths developed in this work, two other Industry 4.0 concepts can be taught using this approach: 1) The refurbishment process itself can be taught; 2) IEC 61499 specific topics can also be taught. In total, concepts from five knowledge domains were explored.

RQ3: Due to the abstraction provided by the standard IEC 61499, it is easy to integrate new functionalities of data analysis and new equipment into existing systems. Furthermore, this knowledge can also be applied to real production scenarios, since this standard is already used in industry ([3]) and those new capabilities are developed on top of it.

As future work, in the zero defects learning path, a combination of a vision system with a classification technique will be explored for automatic defect detection. For the condition monitoring learning path, a machine learning approach will be applied to automatically detect defective actuators.

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