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Presentation of retrofitting methodologies for automated manufacturing cells for the industry concept 4.0.

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ABSTRACT

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This paper proposes the retrofitting of equipment and processes available in a manufacturing didactic plant, composed of workstations embedded in its automated systems, formed by actuators and sensors connected to the AS-i network and at the PLC of each station, which are connected in PROFIBUS industrial network, concepts of Industry 3.0. The objective is to update it to work applying the concepts of Industry 4.0, emphasizing the integration of information through networks of Industrial Automation and Internet. To achieve this objective integration of Automation Technology (TA) with Information Technology (IT) is necessary. Allowing the integrated educational exercise of the technologies found in the Automated Industrial Manufacturing Systems, such as communication networks, process control and production management, control and supervision of complete automated assembly processes that takes place on the platform is possible through a remote connection via internet (remote laboratory). Thus, teaching and research groups in multiple locations can share information quickly and develop such simultaneously groups in multiple locations can share information quickly and develop such simultaneously.

***Keywords**: Automated Production System (SAP). Automation. Robotics. Integration. Industry 4.0.*

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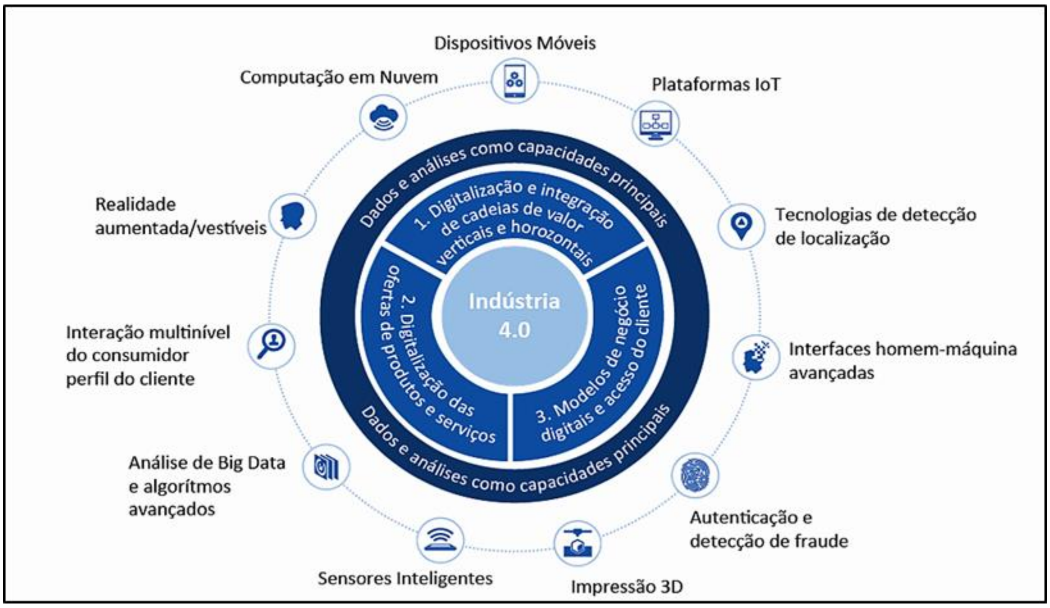
1. INTRODUCTION

The integration of industrial devices associated with information and communication technologies (ICTs) motivates the development of new support tools focused on education, allowing the emergence of new approaches to training in areas with a high technological emphasis such as Automation. Industrial and Robotics (DOMÍGUEZ, 2005; TZAFESTAS, 2006).

The modernization of the productive sector for the resumption of economic growth in Brazil was the focus of the Brazil-Germany Economic Meeting (2015), which encouraged the development of partnership programs between the two countries. According to VDE 2014, the Industry 4.0 project presented by the German government is justified due to the rapid changes in products and manufacturing production systems applied in conjunction with the information and communication technology (ICT) systems, Figure 1 (GEISSBAWER R., VEDSO, J.; SCHRAUF, S., 2016). Against this background, students need to be introduced quickly to existing and future methods, much faster and more effectively through a “teaching factory”, I e real factories can be brought into the classroom (MATT; RAUCH; DALLASEGA, 2014).

Figure 1 - Industry Concept 4.0.



Source: (GEISSBAWER R..; VEDSO, J.; SCHRAUF, S. - PwC - Global Industry Survey 4.0 - 2016).

Industry 4.0 is not just a new way of designing an industrial plant, but it is a strong change from old paradigms that affect all human activities, with the heavy gears at the bottom of the social pyramid shifting and adapting a continual reality of the need to survival and, consequently, making it more dynamic and active throughout the production chain, whether horizontal or vertical (KAGERMANN, 2013).

This paper describes the main steps related to the renewal of industrial automated plants, designed in Industry 3.0 (I 3.0), to integrate systems based on Industry 4.0 (I 4.0), which uses data interfacing through PROFIBUS industrial networks (I 3.0). , for GSD files from HTML (I 4.0) sites through converter CPUs.

To apply the concepts covered in this article, we opted for a case study focused on a didactic industrial plant, assembled at ETEC "Pedro Ferreira Alves", located in the city of Mogi Mirim – SP, which currently works by applying the concepts of Industry 3.0. In this plant is developed the technological update at hardware and software level with the main technologies and concepts of Industry 4.0. With this methodology, it is intended to consolidate to enable a real training of specialized manpower, that properly apply the concepts of Industry 4.0 in industrial plants operating of advanced manufacture.

Therefore, the proposed structure is designed to allow access to the common technological knowledge in industrial infrastructures that the market requires.

In order to provide maximum clarity in the exposition of the content, this work is organized so that: In section 1 the introduction and the positioning of the problem are developed. Section 2 presents the bibliographic review that deals with the topic under study.

Section 3 describes the method applied to develop this work. In this regard, the transition from the Industry 3.0 to Industry 4.0 system is described.

For this, a brief description of the protocol converter CPU operation is developed, citing a list of several manufacturers. In addition, the way PROFIBUS \ ETHERNET (PROFINET) conversion is performed is detailed. The case study is also presented, and for this purpose, the elements of the advanced manufacturing didactic plant composed of modular workstations each with its PLC and a robotic station are described. The acquisition of sensor signals and pneumatic valve actuations for their actuators is done via the sensor interface actuator network (AS-i). The PLCs of each station communicate in PROFIBUS DP network, receiving and sending data to each station of a Supervisory system.

Section 4 reports the analysis and research results, with cost spreadsheets for converting CPUs, their software, and routers. Presenting an overview of the availability of these elements in the current market. Section 5 presents a critical analysis of the advantages and disadvantages of applying renewal. To conclude this article, section 6 presents some conclusions and limitations of the paper.

2. THEORETICAL REFERENTIAL

According to Kolb (1984), teaching in automation has one of the main trends based on the learning by doing paradigm. In this aspect, the student develops as an active element in the process of assimilation of knowledge.

Learning from experience involves components of doing and thinking, according to Leão *et al.* (2007).

The challenges brought by the new teaching / learning methodologies involve more students and teachers in the process of knowledge acquisition. Often in web-based learning environments.

The solution to the new competitiveness demands in the technocentric philosophy presents a technical solution in the investments of new information and communication technologies. Leitão (1997), states that if a medium includes individuals with organization and technology, the synergistic interaction between them provides an anthropocentical environment. There is no doubt that the use of new advanced technologies is the basis for improving the quality of competitiveness while increasing technical flexibility combined with productivity and product quality (Leitão 1997). However, existing organizational deficiencies on the basis of operational rigidity and dysfunctions are not only eliminated by access to new technology resources (MATSUSAKI, 1998).

As an example of a practical model, it is important to mention the need to provide the Laboratory of Integrated Automation and Robotics (LAIR) of the Faculty of Mechanical Engineering of UNICAMP with the necessary resources for the development of research applied to the area of manufacturing automation and robotics. This fact justified the development of the pioneering project of the didactic plant PIPEFA - Industrial Platform for Research, Teaching and Training in Automation, which is composed of a set of integrated production cells dedicated to Teaching and Research in Automation, which has an open architecture with low cost of implementation.

This was inspired by a similar plant built at the Industrial Systems Integrated Engineering Laboratory. (LIISI) from CESTI - ISMCM at the University of Toulon in France. It is important to highlight that PIPEFA provided a base of study for Master and Doctorate works in renovation inherent in each period, such as the works of: Iório, (2002); Koyama, (2001); Silveira Junior, (2016), which are indexers of the base work of this article (BIANCHI, 2018).

In order to achieve a segmented and demanding market in terms of quality and design, as well as flexible equipment in terms of technological adaptability, human resources must be adaptable to new situations in order to respond to the new dynamic and synergistic demands that the market has. imposes acceptance of products (MATSUSAKI, 1998).

Increasing global competitiveness, led by emerging markets such as the BRINCs, coupled with the growing rate of population aging in countries with the most advanced forms of Industry 3.0 (I 3.0), has led to the search for solutions to supply their production vehicle manufacturing facilities. sustainable and cohesive with emerging new IT technologies (KAGERMANN, *et al*. 2013). The debate for market conquest and customer captivation has emerged, and several models of how to act against these new insurgent paradigms. I 3.0 technology leaders realize that the now customized product value addition would captivate yet another customer prone to shell out a little to have a product with their personal characteristics inserted (KAGERMANN, *et al.* 2013). Silva (2015), cites Schuh *et al*. (2015), who point out four facilitators of Industry 4.0, responsible for increasing productivity: the globalization of information technology, the existence of a unified source of consistent data, automation and cooperation.

To get an idea of the definition given to concepts inherent in manufacturing processes, Table 1 shows a comparison between Industry 3.0 and Industry 4.0 (BIANCHI, 2018).

Table 1 - Comparison between Indústria3.0 and Indústria4.0.

FACTORY IN I3.0 X FACTORY IN I4.0					
Action About	**Data Sources**	**INDUSTRY3.0 (today)**		**Indústry 4.0 (I 4.0)**	
		Attributes	**Technologies**	**Attributes**	**Technologies**
Component	Sensor	Precision and Accuracy	Sensors Intelligent and fault detection	Self awareness Self Diagnosis	Predictive monitoring of equipment uptime.
Machine	Controller	Productivity and performance	Monitoring and diagnostic based conditions	Self-awareness Self-evaluation	
Production system	Work network system	Productivity	Reliable work operations and waste reduction	Self Comparison Self Maintenance Self organization	Worry-free productivity

Source: Adapted and translated from Kagermann, (2013).

In the first decades of the 21st century, there is a growing wave of automation of processes and all things with increasingly integrated production chains, and connecting the physical and digital world in various ways with the application of concepts related to “Internet of things” (IoT) (CASSOTI, 2016).

With the introduction of the new IPv62 protocol in 2012 (KAGERMANN, 2013), there are now sufficient numbers of IP addresses available to enable the universal direct network of smart objects via the Internet. Expectations in the industrial area are becoming a reality, for many analysts IoT is considered one of the driving forces of the new industrial revolution that is emerging (CASSOTI, 2016).

3. METHODOLOGICAL PROCEDURES (case study didactic manufacturing plant)

This section describes the FESTO educational platform MPS 500, which was chosen as the target case study of this work. As already mentioned, in this structure, which currently operates with Industry 3.0 technology and fundamentals, an update based on Industry 4.0 fundamentals will be implemented.

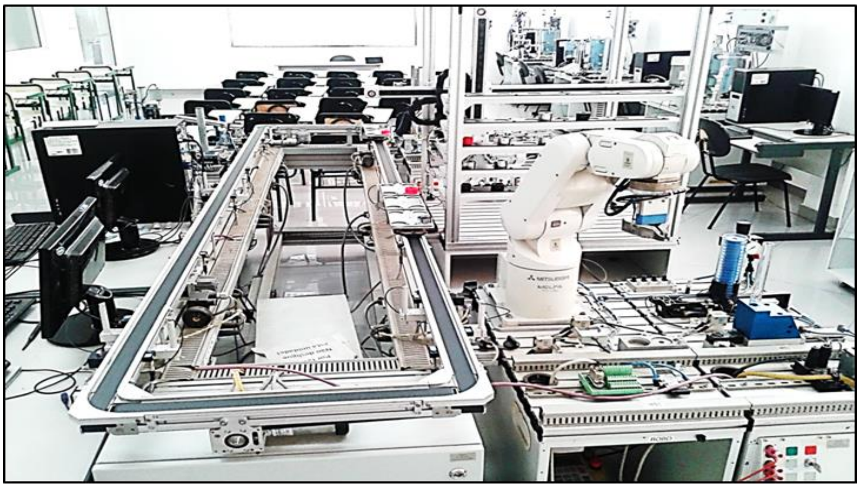
In order to locate the reader of the task to be developed, a description is initially made of the original structure of the plan to be modified.

3.1 - Data collection procedures (Operative and Command Part)

FESTO's MPS 500 educational system (Figure 2) consists of six systems distributed in six electropneumatic stations with their actuator sensors and PLCs and a conveyor with its sensors, DC motors, actuators via electropneumatic control and dedicated PLC. All these PLCs are working in Multi Master system by PROFIBUS network, commanded via WinCC supervisory, in which the desired product is selected and controlling the limits of each system.

The interface for I 4.0 occurs when reading data from the PROFIBUS network already available in the I 3.0 system inserted in the didactic plant. The converting CPU will read the data and make it available in an array that will be interfaced by the GSD file when building the site in PHP or HTML5 language (BIANCHI, 2018).

Figure 2 - View of the MPS 500 Manufacturing plant with the stations.



Source: ETEC Pedro Ferreira Alves, June 2018.

3.2 - Data analysis procedures, Sensor Level Digital Data Transmission Systems.

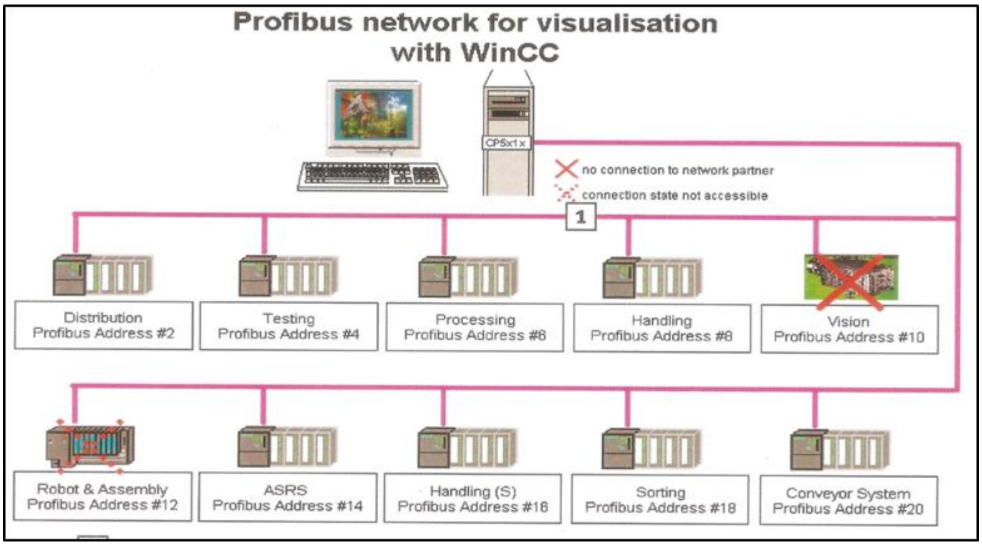
Sensor data collection takes place via an 11-bit digital data envelope characteristic of the AS-I network at each workstation.

The PROFIBUS network data packet transmission system is arranged between workstation PLCs. Being a PLC with a CPU that behaves like Mono Master in relation to the other CPUs of the individualized PLCs in each station. The CPU of this workstation contains the WinCC supervisory program dedicated to monitoring process steps.

The planispheric of this distribution line for the stations with the discriminator of the supervisory in the whole line of PROFIBUS DP can be seen in the figure 3.

The manufacturing plant is made up of six workstations, each consisting of its data collection system, connected via the AS-I network and its PLC. The programs of these stations were modeled using the step path graph (GRAFCET).

Figure 3 - Planisphere of the PROFIBUS network connection of the didactic plant MPS FESTO.

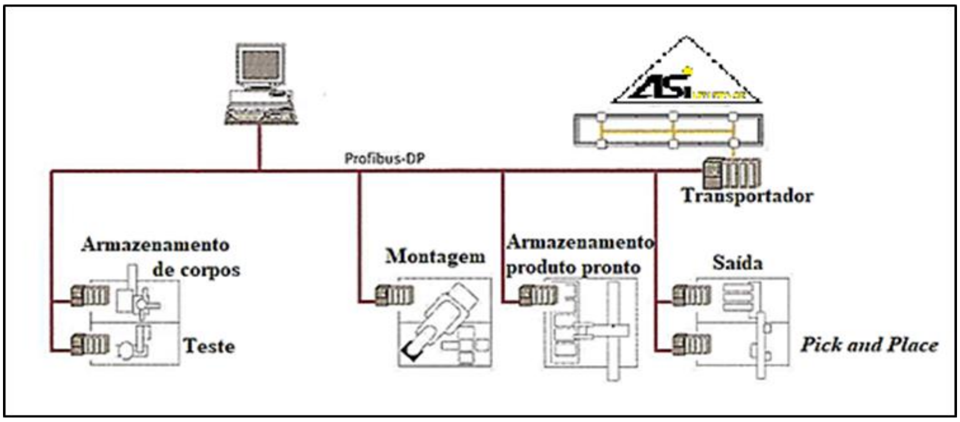


Source: Manual MPS 500. Source: Manual MPS 500 FESTO didactic, (2000).

The conversion from the PROFIBUS protocol to the matrix to be written to the ETHERNET / PROFINET protocol follows the PROFIBUS address line for each workstation (marked in figure 3 with # followed by its address number).

Figure 4, shown below, illustrates the physical position on the floor of the corresponding stations connected to the PROFIBUS network, current position at I 3.0.

Figure 4 - Profibus system with the name of the stations.

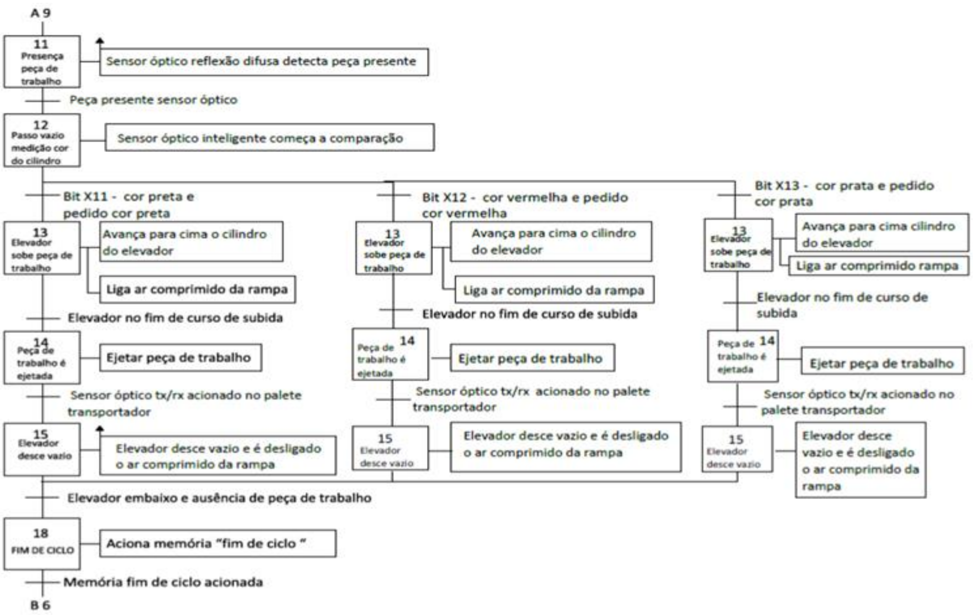


Source: Manual MPS 500 FESTO didactic, (2000).

For all stations the functional GRAFCET was raised and the technological GRAFCET raised, specifically in the selection and testing station a GRAFCET was designed, whose logic is conditioned to two one-bit variables: the digital output of the intelligent color sensor, and the choose the desired cylinder body color selected by the customer on the website.

The logical conditioning "E" applied to these two bits allows the plant production sequence for the customer's desired product color, if the color is different from the selected one the part is rejected. In figure 5 the functional graphet of this step can be observed.

Figure 5 - GRAFCET Functional parts selection system in the case study.

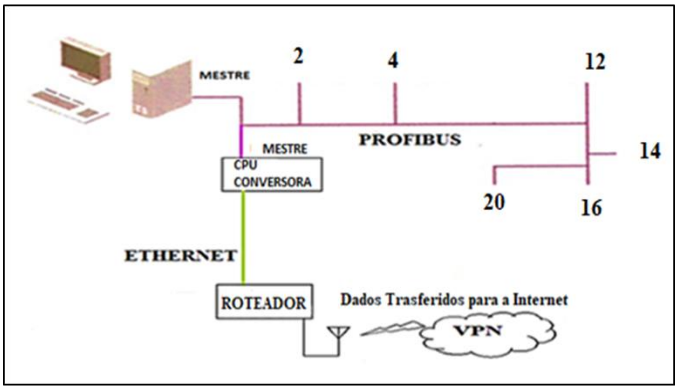


Source: Data collected by the authors, June 2018.

4. RESULTS

"Connectivity" is the key word for entering the world of Industry 4.0, as the initial structure of Industry 3.0 is already up and running (GEISSBAWER R.; VEDSO, J..; SCHRAUF, S., 2016 - PwC - Research Overall Industry 4.0). The insertion of this embedded system to the outside world will take place through the Central Processing Unit of protocol converter (CPU). This CPU is a device that has more than one central microcontroller and works concatenously with the PROFIBUS and ETHERNET networks. To do so, it has connections to both networks and the data flow is always bidirectional in the MASTER to PROFIBUS converter CPU configuration. The converting CPU will then be the master of the PROFIBUS network and the other CPUs of the PLCs of its slave stations. Thus, in your connection to ETHERNET, you can connect a Router "N" G and gain Internet access with initial data on a cloud host. The summary of this description is illustrated in Figure 6 shown below.

Figure 6 - Regardless of equipment brands, the proposed connectivity of the I 3.0 manufacturing plant to the Web network and access to the I 4.0 concept.



Source: Adapted by the authors with data from the MPS 500 FESTO didactic Manual, June 2018.

4.1 - Application of C.P.U. conversationalist.

The converter CPU is a device that converts PROFIBUS communication protocols to ETHERNET, in order to provide bidirectional data packets from the process, generated and or to be inserted in the manufacturing plant.

The interface of the mathematical model that the microprocessor uses for communication is a matrix where the bits are inserted and indexed to the memory mask of the PLC monitor program used. Table 2 lists the main manufacturers of converter CPUs.

In order to perform the technology upgrade to I 4.0, each workstation must have an / IP address (ETHERNET) to index the converting CPU in its data matrix and allow the construction of site elements indexed to addresses.

Table 2 - Top Converting CPU Manufacturers, March 2018

MANUFACTURER	MODEL
SIEMENS	IE\PB LINK
PHOENIX-CONTACT	AXC 1050
MITSUBISHI	QJ71MES96
ADFWeb	MN67575
BECKHHOFF	CX8030 | Embedded PC for PROFIBUS
FESTO	CPX-CEC-C1/S1/M1-V3

Source: The authors.

Thus, through the generated GSD file, the IP number of each station can be indexed to a database or to an array of characters in forms of language PHP or HTML5 characteristic of website construction on the Internet (COMER, 2016; OPC FOUNDATION, 2017).

To collect data and work with the various devices in I 4.0, Table 3 shows the conversion software for interfacing between I 3.0 and I 4.0 systems. It is important to note that the number of components and their respective IP addresses must come from the station format in I 3.0.

4.2 - Cost Spreadsheets: C.P.U. , Router, Communication Protocols.

In the first of a series of renovations aimed at future prospects, a survey of leading converting CPU manufacturers was prepared to provide an overview of the costs of a basic conversion kit for Industry 4.0. Table 4 lists the prices of converter CPUs and table 5 lists the manufacturers of different generation (“N” G) routers.

The software market is booming and new business models and opportunities are emerging. Some computer applications have still been found to be paid, but all tend to be free of cost with open protocols and interfaces. Table 6 lists the available software searched from major manufacturers.

Table 4 - Price comparison Converter CPUs - * quote 03/15/2018.

Manufacturer	Model	Connections	Price $
Siemens	Ie/Pb Link	RS232; RS 485 (PROFIBUS;	1.730,00*
Phoenix - Contact	AXC 1050	ETHERNET) RS 485 (PROFIBUS – ETHERNET)	746,96*
Mitsubishi	QJ71MES96	MODBUS; ETHERNET RS 485 (PROFIBUS);	4.420,00*
ADFWeb	MN67575	ETHERNET RS485 (PROFIBUS);	342,79*
Beckhhoff	CX8030 |	ETHERNET	753,75*
Festo	CPX-CEC-C1/S1/M1-V3	RS 485 (PROFIBUS; ETHERNET)	914,75*

Source: Data collected by the authors.

Table 5 - Price Comparison Routers.

Manufacture	Model	Connections	Price $
PHOENIX CONTACT	TC RS2000 4G VPN	ETHERNET / VPN 4G	1.590,00
WEIDMULLER	EG 2ET LAN FN	ETHERNET / VPN 2G	866,55
WEIDMULLER	UMTS/3G IE-SR2GT	ETHERNET / VPN 3G	1.137,81
SIEMENS	R.R.FOR-.M876-3 3G-	ETHERNET / VPN 3G	1.225,19

Source: Data collected by the authors.

Table 6 - Comparison of communication software protocols between CPU converters concatenated with table 4 and Web - Internet. Accessed March 2018.

MANUFACTURE	MODEL	PRICE IN U$
MITSUBISHI	MX-MESIF-STD-C1	420,75
SIEMENS	SIMATIC OPC UA S7-1500	0,00 dowload free
BEKCHOFF	Twin-CAT3	0,00 dowload free
FESTO	CODESYS	0,00 dowload free
PHOENIX CONTACT	PC WORX BASIC-PRO LIC	1.503,35

Source: Data collected by the authors.

Describing the cost of various manufacturers and their technology solutions applied to minor upgrades and renovations in the right places, they collaborate with the mission of integrating Information Technology and Industrial Automation.

In an advanced refurbishment (Renewal) of machines or systems, a lower cost is always presented compared to purchasing new equipment.

The advantages of Industry Renewal 3.0 for Industry 4.0 are:

• Represented by rapid interconnectivity of systems and agility in decision making in manufacturing processes.

• Meeting the demand for a product tailored to the customer's personal taste characteristics makes it prone to shell out slightly more value added in the final product, which confirms the economic aspect observed by Kagermann, *et al.* (2013).

• The initial time spent in technical training tends to be compensated by the anthropocentric character developed by the operator with the equipment, proving the quote of Leitão (1997), and still consolidates the thought of Leão *et al.* (2007): *"learning from experience involves the components of doing and thinking".* The challenges brought by the new teaching / learning methodologies in learning by doing cited by Kolb (1984), lead to involve more students and teachers in the process of knowledge acquisition.

• The appreciation of the intellectual work of the operation makes the employee strongly linked to the development and improvement of the work seeking to improve more. Unconsciously the contributor himself provides the most from his Man-Hour as put by Matsusaki, (1998).

• With the implementation of the new CPU in the plant network, the set of IoT (internet of things, such as RFID readers), according to Cassotti (2016) can be indexed to a single domain on the Internet, using the IPv62 protocol.

Disadvantages may be expressed in Disadvantages, these may be:

• Cost-benefit turnaround time for the process where this renewal may be inserted;

• Training time and investment in data protection and security equipment and software should be considered in small and medium enterprise (SME) applications.

• What is the big challenge of I 4.0 lot of a highly customized part at a price close to a thousand parts lot without customization.

• If the plant needs to be heavily restructured, you must first arrive at I 3.0 and then interconnectively into I 4.0. Precise and orderly sequences are required in a timeline followed to the letter so that there is no capital loss, citing for example the comparative table between I 3.0 and I 4.0 (chapter 2 of this article) proposed by Kargermann, (2013).

Thus, renewal should not provide the increase in average consumer price (PMC) and imply greater competition and loss of market coverage. The impact generated by this digital transformation, with the insertion of the new converter CPU in the case study, should add value to the final product with better flow in the production process, increased efficiency, reduced defects and lost time, and increased customer satisfaction. customer connectivity throughout the production chain.

5. CONCLUSIONS

To conclude the considerations developed in this paper, we mention a situation that occurred in 1998, when Kodak had a staff of 170 thousand and sold 85% of all photographic paper sold in the world, however, due to the digital technological advancement in the area. photography has built a new trend, which in the course of a few years Kodak's business model has disappeared and the company has gone bankrupt. This same phenomenon is happening to several other companies.

The integration between a manufacturing plant, composed of several productive cells, with the worldwide computer network (Internet), the initial objective of this article, was achieved, besides the demand of how the market produces new CPUs combined with intelligent software capable of integrate Automation Technology (TA) with Information Technology (IT). This reality demonstrates how new business models quickly and synergistically activate new emerging technologies, avoiding what happened to Kodak.

In light of the observations presented, seeking to contribute to this new manufacturing methodology, this paper describes the central idea that automated manufacturing cells, including educational equipment produced in the 1990s and 2000s, can be adapted to work in the applications of new technologies. Industry 4.0 cutting-edge technologies through the establishment of a renovation.

The scientific contributions of this study are based on the object of communication between PROFIBUS-ETHERNET converter CPU protocols and PROFIBUS master CPU, and inherent in these protocols the correct data filling via its bit matrix, contributes to the real state of the art. in the evolution of the theme.

For future work, the RFID network configuration with product-attached tags and readers throughout the manufacturing plant is placed, interacting with the production stations, and machine-to-machine (M2M) communication as a complement.

From the vocational training point of view, it can be seen that these new concepts exposed in this article were very well accepted by the trainers and students, highlighting a high form of interactivity between those involved with the advanced manufacturing plant MPS 500 connected to the network. Ethernet / IP, state of the art in the scientific case study of this article.

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