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Industry 4.0: A Cost and Energy efficient Micro PLC for Smart Manufacturing

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Abstract

"Smart Factory" is the future of industries. Industry 4.0 is the backbone in realizing this new concept. Industry 4.0 is based on the latest new technologies viz. Internet Of Things (IOT) and Cloud computing. IOT provides the devices which communicate between themselves and with the servers. Machine to machine communication is the base for IOT. Whereas the cloud computing provides us the space to store all the data and the facility to compute without the need of complex hardware thus reducing the cost of IOT devices. It is inventively challenging to construct devices and develop the services to realize the vision of the Fourth generation in Industrial Revolution. But it's more challenging to get the existing Manufacturing setups and the Small scale industries in the realm of the Smart Factories. Thus a small cost effective MicroPLC is proposed which can be used in various configurations to enable the industrialist to enjoy the features of the Smart factories at optimal cost and energy.

Keywords: Cyber-Physical Systems, Industry 4.0, Smart Factory, Internet of Things, Smart Manufacturing

1. Introduction

Manufacturing process all started with the invention of steam engines which is referred to as the first industrial revolution. With the development of the conveyor belts and the single line flow manufacturing technique mass production of products started which marked the 2nd industrial revolution. After the invention of computers, and the use of computers in industries started the third revolution in the industry. At the end of the 20th century we could see the increasing usage of computers in almost all areas of the corporate world.

Within the first three industrial revolutions, humans have witnessed and created mechanical, electrical and information technology which were aimed at improving productivity of industrial processes. The first industrial revolution improved efficiency through the use of hydro-power, increased use of steam power and development of machine tools; the second industrial revolution brought electricity and mass production (assembly lines); the third industrial revolution further accelerated automation using electronics and information technology, and now the fourth industrial revolution is emerging which is led by CPS technology to integrate the real world with the information age for future industrial development[1] Figure 1 displays the four stages of the industrial revolution.

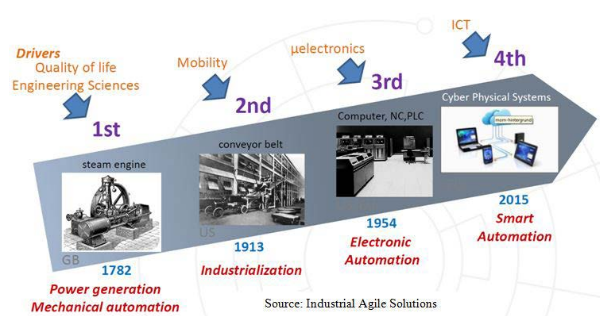

Figure 1. Stages of industrial revolution.

The concept of Industry 4.0 is based on the integration of information and communication technologies and

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industrial technology, and is mainly dependent on building a Cyber-Physical System (CPS) to realize a digital and intelligent factory, in order to promote manufacturing to become more digital, information-led, customized, and green. The purpose of Industry 4.0 is to build a highly flexible production model of personalized and digital products and services, with real-time interactions between people, products and devices during the production process. Industry 4.0 will affect not only German industry or even international industrial development but will become a driving force[4] which will change traditional methods of industrial production, and guide future manufacturing. Germany's electrical industry association has predicted that Industry 4.0 will increase industrial productivity by 30%[1].

The paper is structured as follows: section 2 presents the currently used technologies in the manufacturing Industries. The proposed solution product MicroPLC is described in section 3. A case study of bike manufacturing is explained in section IV. Thus the conclusions and future works are stated in section 4 and 5.

2. Existing Setup

Most of the production industry in present day deploys automation of various levels in order to increase productivity & gain profit by mass production. These automations are more of independent control panels or are monitored centrally with the used of SCADA. The biggest benefit of automation is that it saves labor; however, it is also used to save energy and materials and to improve quality, accuracy and precision.

Automation or automatic control is the use of various control systems for operating equipment such as machinery, processes in factories, boilers and heat treating ovens, switching in telephone networks, steering and stabilization of ships, aircraft and other applications with minimal or reduced human intervention. Some processes have been completely automated.

Even though automation has drastically changed the way industries work and its great impact on the production rates, there are some areas where this technology falls short to serve. The features like the real-time monitoring of the industry and adaptability of the manufacturing equipments with the changing demand cannot be achieved by the existing technology. Human centric and customer focused manufacturing are also important things to be achieved.

In recent year we have also seen the rapid research and development of a new technology whose vision is to interconnect millions of devices with each other and with enterprise systems. That is "Internet of Things" (IoT). The IoT is the network of physical objects- devices, vehicles, buildings and other items which are embedded with electronics, software, sensors, and network connectivity, which enables these objects to collect and exchange data[1]. The Internet of Things allows objects to be sensed and controlled remotely across existing network infrastructure[2] creating opportunities for more direct integration of the physical world into computer-based systems, and resulting in improved efficiency, accuracy and economic benefit.

IoT products are already into market which can monitor and control your house appliances and environment completely automatically without any human interventions. They communicate with each other and also analyze other user specific data from different sources, learning our needs and preferences. IoT Things do their work without the knowledge of the user. The user works are done before he realizes that he needs those works to be done. IT can be seen to what extent this technology has developed so far.

With the application of the IoT concepts in industry opened a whole new area of research. When IoT is augmented with sensors and actuators, the technology becomes an instance of the more general class of Cyber-Physical Systems (CPS). Cyber-Physical Production Systems (CPPS) is advanced version of production monitoring systems which uses IoT and CPS concepts. With the change to CPPS, data can be easily collected and stored onto cloud servers which can be anytime used for calculations and other needs. CPPS is a best example for the collaborative use of IoT and CPS concepts.

Various countries like the Germany, USA have already started to build the experimental models to try and prove Industry 4.0 concepts and features. This is evident that it won't be long that companies start using the Smart Manufacturing systems to produce products. Thus some add-on solutions have to be developed to avoid making the existing system absolute or to give industrialist a chance to taste the flavor of smart manufacturing without huge investments.

3. Proposed Product

As seen in the previous sections Industry 4.0 is basically information sharing between the management process and the production or manufacturing activities. As devices from many different sources will be used in the CPS, care must be taken for proper compatibility between the devices. Thus a standard protocol is to be laid for the CPS devices.

Thus the proposed product "MicroPLC" is not a novel or innovative idea it is the stepping stone in preparing the existing setup to enjoy the smart manufacturing concepts. The author describes the product "MicroPLC" that is developed to achieve the following objectives

- To provide a low cost CPS node for automation.
- To be able to connect the existing setup with the cyber world using any of the proposed connection scenarios.
- An independent Cyber-Physical System.
- To facilitate features like ease of programming, remote programming & configuration.
- Ambiguous reporting by real-time monitoring.

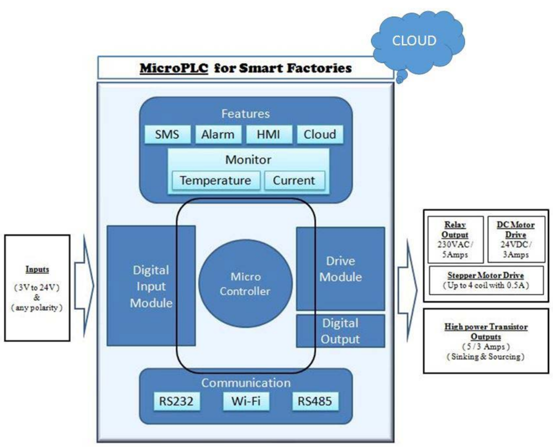

Figure 2. Block diagram of MicroPLC.

The block diagram of the MicroPLC is shown in Figure 2. It is typically a PLC with added inbuilt modules required for smart manufacturing. "MicroPLC" can be understood in two parts firstly the PLC (automation section) and the Cyber-Physical part.

3.1 MicroPLC – for Automation

The block diagram shows the input devices like the sensor, switches etc; Output devices like the relay, motor etc; and the Micro-PLC itself. The Input and output devices are connected to the Micro-PLC to form an automation system. Micro-PLC also consists some inbuilt features like the SMS, Alarm, HMI and Cloud. Micro-PLC also facilitates popular communications like the RS232 & RS485. The blocks are explained below.

- *Digital Input module:* This module is used to overcome the difference in the voltage levels. The industrial voltage levels are 12V DC or 24V DC. Input module is designed in such a way that it can accept both levels of voltages without any change in the circuit. This can work with PNP as well as NPN inputs without any change in the configurations. Opto-isolators are included in the design so that the MicroController is kept safe from the faults happened at the input side.
- *Digital Output module*: This module is used to control the output devices like the DC motor, Stepper motor, AC appliance and other DC elements like the solenoid coils. The outputs are grouped as drive control and digital output. The drive control unit takes care of controlling the Motors and high rating devices. DC motors can be directly connected to the module. It supports wide range of motor ratings as relay based H-Bridge is used. The Digital output unit provides digital DC output with a capacity of 3/5A.
- *Features:* Some key features are added to the Micro-PLC which makes it stand out from the remaining PLCs. All the errors and safely alarms can be conveyed with the buzzer as well as independent personalized SMS can be sent. An HMI – Human machine Interface will be built-in with the Micro-PLC allowing for easy access and monitoring of the working of the PLC. In order to be able to be used in the Smart factories Cloud connection capabilities will be added to the unit. It also will have a self health monitoring facility which will be monitoring the vital parameters like the temperature and current and also will smartly detect the device failures and intimate the maintenance team, thus aiding the reduction of the downtime.
- *Communication:* In order to have machine to machine communication industrial standard communication protocol RS485 is provided. For configurations and settings RS232 is also

included. The key communication protocol incorporated is the Wi-Fi module. This is required for the realization of the smart factories using Industrial Internet.

- *Microcontroller:* The brain of the Micro-PLC is the microcontroller which controls all I/Os and where the automation sequence and logic resides. The microcontroller used in the project is the CORTEX M0 based ARM microcontrollers from Nuvoton. The NU_LB_NUC140 learning board incorporating NUC140VE3AN microcontroller is used.
- *Programming the PLC:* Programmable Logic Controller (PLC) can be programmed using 5 languages. They are Ladder diagram, structured text, Sequential flow chart, Functional block diagram and Instruction List or Statement List. Ladder diagram is the most popular and widely preferred language for programming PLC. Instruction list programming is a text based language, used to describe PLC programs, and is one of five methods specified by international standard IEC 6113. Instruction list is sometimes claimed to be a 'low level language', reminiscent of assembly language, but 'slightly lower level' (than a graphical method) might be more accurate. The ladder diagram and the Instruction list go hand in hand. They can be easily converted from one to another. Also instruction list being text based coding it can be more conveniently used for remotely programming the PLC.

3.2 MicroPLC – Cyber Connect

This product can also be used along with the other control element. It can communicate to the existing system using any of RS232 or RS48 communication protocols. In this configuration the MicroPLC just acts as link to connect the system to the cyber (a server) over the Wi-Fi. The ESP8266 is a very cheap Wi-Fi module. It consists of the full version of TCP/IP stack and also a microcontroller is on board. The module can even be reprogrammed to act as a standalone Wi-Fi connected device--just add power!

The feature list of this module includes 802.11 b/g/n protocol Wi-Fi Direct (P2P), soft-AP and Integrated TCP/IP protocol stack. It can be used in station mode which can connect to already existing network and transfer data. Also it can be used in Access mode to act like a server so that other devices can connect to it. All the available packages of this module are shown in Fig 3.. ESP8266-01 is used in the proposed product.

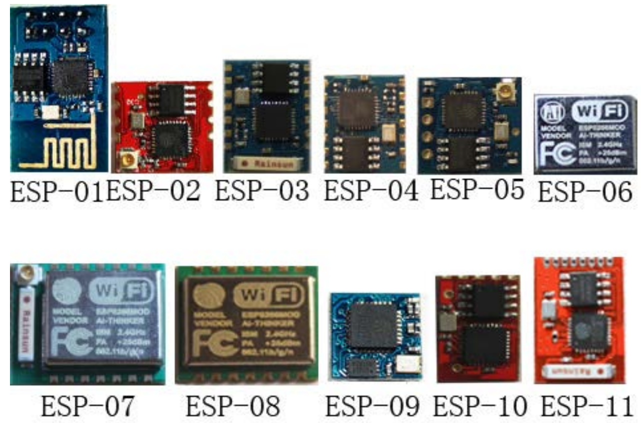

Figure 3. ESP 8266 Wi-Fi module family.

In this way the already available systems can be connected to make a smart manufacturing plant. Three connection (usage) configurations of the proposed product are explained below.

MicroPLC used as an independent automation controller.

In this scenario the machine operation sequence is controlled by the Micro-PLC (Figure 4). Thus the entire sensor mount on the machine are connected to the Micro-PLC. The Micro-PLC will take input and then based on the sequence programmed it drives the actuators automating the machine. The cloud connection can be used to configure the parameter or to monitor the setup. This can also be remotely programmed using the Wi-Fi network.

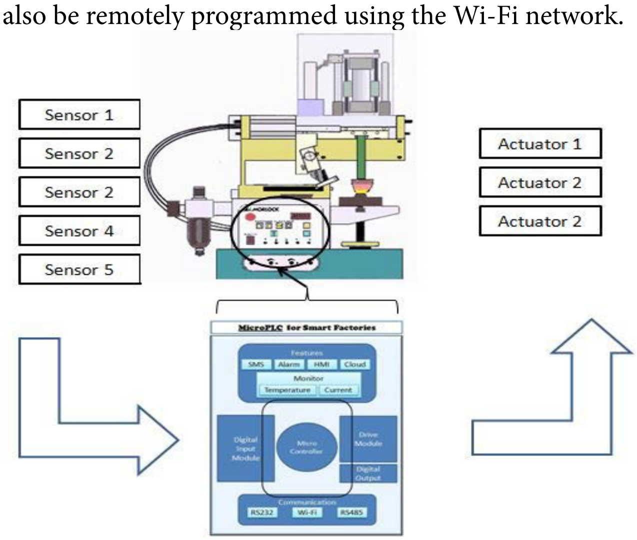

Figure 4. Independent automation controller.

4. MicroPLC used as CPS Link

MicroPLC can also act like just a Cyber Physical System (CPS) (Figure 5) connecting the machine to the virtual factory or the cloud. Please do make a note here that the machine is not controlled by the Micro-PLC. It only has a communication link with the other controller automating the machine.

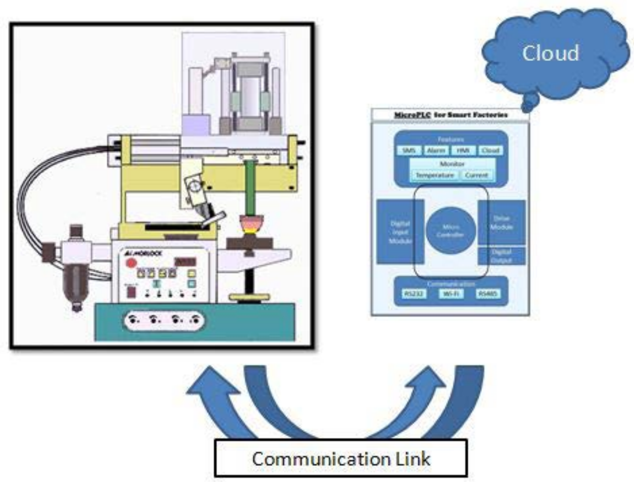

Figure 5. Cyber-Physical System link.

5. MicroPLC as a Master

The Figure 6 shows a long assembly line controlled by a decentralized control scheme. Here multiple controllers are automating a small part of the big line. Thus in order to connect this whole assembly line to the cloud the Micro-PLC is used. So the Micro-PLC communicates with all the nodes (small controllers) and gathers data and reports to the cloud.

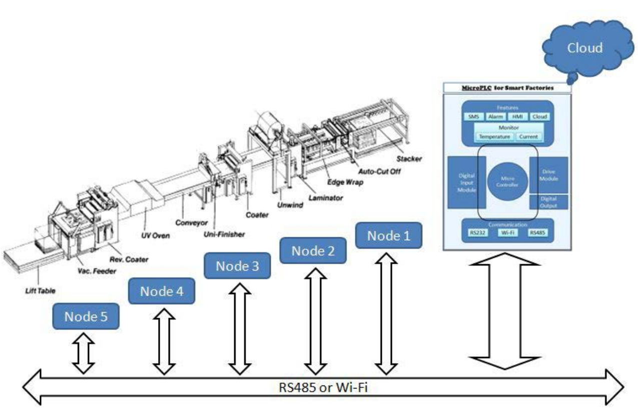

Figure 6. Cyber-physical system master

6. Case Study

This section explains about a production line scenario which intends to illustrate the features and benefits of using the proposed solution product. The scenario presented here is a semi-automated multi-stationed assembly line of 2 wheeler vehicle (bike). The bike is assembled in sequence over 10 different stages. At each stage a new part is added thus getting the completely assembled bike at the end of the 10 the stage (station). The parts that are added at each stage may a single part or that itself can be assembly of some more parts, they are called as sub-assembly. In most cases the parts and sub-assembly are outsourced i.e. they are supplied by the vendors.

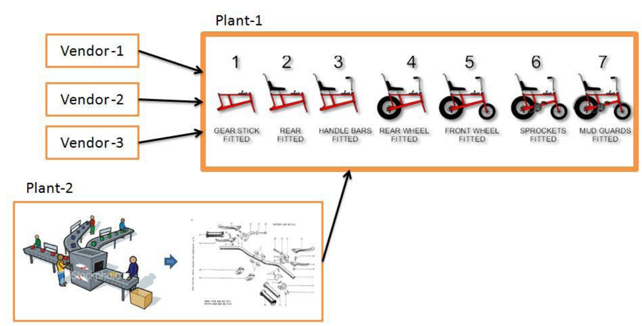

Figure 7. Bike manufacturing case study

The process and material flow followed to manufacture bikes is graphically shown in the Figure 7. The pant-1 is where the complete bike is assembled. Vendors are also shown from where the parts are supplied to the plant-1. Plant-2 manufactures the sub-assembly and then sends them to the pant-1. We can understand that is the production at plant-1 increases plant-2 will also have to produce more to meet the requirement. Thus a continual information exchange between the plant 1 and other vender is required so that the bike manufacturing goes smoothly.

Now consider that the MicroPLC is used at all the assembly lines stages. They will act as a CPS module and will always keep track of the data keep the cloud updated. Thus there is always a real-time data of the requirement and the actual parts produced at each stage. So if the target (requirement) of bikes is increased then the CPS will automatically communicate will other CPS in other plant and vendors thus updating their targets so as to meet the final bike orders.

The network formed by the use of the MicroPLC can also be beneficial for other departments like Maintenance, Quality etc. as well. Each equipments will perform self-diagnostics of their station parts and keep the maintenance log updated, Thus helping the maintenance to plan and perform Preventive Maintenance (PM). This also reduces the downtime as the breakdowns are avoided due to PM. On the quality front, the testing stations can initiate actions in when it observes any abnormalities in the product being manufactured. For instance if more than three products fail consecutives during testing it can analyze the module which is faulty and instruct that station or the vendor to double check or look into the matter. This way the product can be used to make the existing setup more intuitive and adaptive.

7. Conclusion

This paper explains a solution to make the existing system adaptable to the Industry 4.0. Thus the setup won't get absolute and the industry owners can enjoy the features of the upcoming era at nominal cost. The Automation section (PLC) of the product has been completed and tested to withstand the specified ratings. The cyber space and communication architecture as explained in the case study is yet to be implemented.

8. Future Work

We would like to take the product concept to the next level by utilizing the cloud computing facility. This will open doors to the true "On demand" manufacturing systems. We will also improve field variables architecture to reduce the network traffic. The use of Smart Tablets as the Human machine Interface to each MicroPLC to provide the local reporting and storable facility is also being studied.

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