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MIND COURSE SUPPORT

LECTURE 1
PLC BASED PROJECT ON MECHATRONICS SYSTEMS FOR INDUSTRY 4.0

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Contents

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1. OBJECTIVES OF THE LECTURE

This course aims to develop the general and specific skills of the students within the MIND project consortium. This course is one divided into two types of objectives, theoretical objectives as well as practical objectives. The theoretical objectives are addressing the challenge of reinventing and reconfiguring PLCs (Programmable Logic Controllers) as best option for industrial automation to fulfil requirements of Industry 4.0. Special focus is on PLC based projects on mechatronics systems for Industry 4.0. These theoretical objectives are related to the definition of innovated structure of PLCs and in the understanding of new roles that PLCs will have in the world of Industry 4.0. In addition, summarizing all new benefits of reconfigured PLCs will also be presented as outcome of theoretical part of this course.

Practical aspects focus on improving the practical skills of students and teachers by establishing networking of PLCs and communication on different levels using different hardware/software platforms and protocols such as PROFINET, Siemens Simatic S7-1200/TIA Portal/Web Server and MATLAB, in which students can practice and design different actions or models.

General objectives:

- Knowledge of PLCs as core of industrial automation,
- Principles of reinventing and reconfiguring PLCs as best option for industrial automation to fulfil requirements of Industry 4.0,
- Knowledge of communication between PLC and other devices in term of Industry 4.0,
- Knowledge of using PLCs of different PLCs' producers.

Specific objectives:

- Include the ability to analyze functional relationships in mechatronic systems,
- To provide fully integrated automation training, combining mechanics, pneumatics, electrical engineering, PLC control, and communication interfaces.
- To establish PLC communication using industrial network protocols and Internet
- Knowledge of the steps required to provide communication of PLCs via TIA portal

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- Knowledge of establishing communication and connection of PLC with simulation software such as MATLAB.

2. INTRODUCTION, PLC AS CORE COMPONENT OF INDUSTRIAL AUTOMATION

The development of information technologies has changed the way people live. These innovative technologies have allowed people to carry out different activities in innovative and different ways, increasing productivity, flexibility, comfort, etc. At the same time, these technologies have allowed the storage of large amounts of data, leading to the creation and access of information and knowledge in a much faster way. The access of more and more people to data, information and knowledge, has facilitated the increase of the standard of living of the people as well as the increase of the education level of the population. Education and even learning is greatly influenced by the motivation of individuals.

Nowadays, no plant can be found without any part of that plant being guided by an automatic process. Development of automation has resulted in rapid economic growth, reduction in human labor and an increase in productivity. Many processes are too fast or complex for a person to follow them with logical decisions and solutions. Many situations in production are life-threatening or harmful to health. The requirements for speed and precision are often unattainable for humans, so the introduction of automatic control is necessary to achieve the desired conditions. In addition to larger and more efficient production, automation increases product quality and reduces the risk of human error. The development of technology has enabled fully automated management of industrial production, where a person intervenes only in case of failures or major disturbances. The basic element for the realization of an automation system is a process computer. The most common form of process computer is PLC (Programmable Logic Controller). In the late 1960s, the PLC was conceived as a replacement for relay technology. The main drawback of relay technology was that any change in the control system must be done by changing the wiring or even inserting completely new circuits. These changes have caused high costs not only for equipment, but also long-term downtime required for modification and testing. Today's PLCs

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have a whole host of advanced functions and great processing power, and significantly outperform this elementary form of automation.

2.1 Development of PLCs

The invention of PLCs moved control logic from a hard-wired relay system to a software configuration executed by a microcontroller. Inputs and outputs were now wired into the PLC input and output boards, while engineers programmed the control logic directly into the Central Processing Unit (CPU). The result of the move from hardware to software-based solutions brought about a radical shift in flexibility and reliability of control systems. The flexibility came from the ability to make changes to the program in the CPU instead of rewiring an existing installation of relays. The reliability came from a substantial reduction in field hardware. Every relay used introduced the possibility of a dirty contact or coil failure; removing literally hundreds of relays and replacing them with a single CPU had a dramatic improvement on the robustness of the plant and equipment downtime. The PLC has thus rightly become known as the brains of the manufacturing plant. Early models of the PLC used a programming principle called ladder logic. The program effectively mimicked an electrical wiring diagram so that plant engineers could easily transition from the hard-wired relays to the software solution. However, the software became more sophisticated over time allowing for more complex control algorithms and higher levels of automation. Different companies each developed their own product range and protocols, making it necessary to introduce common standards for the industry. For example, the International Electrotechnical Commission issued the IEC 61131-3 standard [IEC13], which defines programming language constructs and rules for PLCs. These developments led to PLC systems becoming more open therefore increasing their interoperability.

During the 1980s and 1990s, PLCs developed to such an extent that they became standard installations for industrial and manufacturing facilities. Improvements in microprocessor capacity enabled a wider range of automation design. At the same time signal processing improved significantly, enabling PLCs to function in the severe factory environments where

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they are subject to electromagnetic interference. The requirements of the industrial environment are much more rigorous than a typical personal computer system. PLC installations are expected to last up to 15-20 years. Their electronic design must also be supplied for isolation from plant disturbances. Industrial users were looking for robust and consistent automation systems and PLCs met those requirements.

2.2 The challenge of PLC application in Industry 4.0

Industry 4.0 was never considered at the time PLCs were initially developed. However, in retrospect, they occupy a critical position in control systems architecture to enable Industry 4.0. As the brains of manufacturing and industrial plants, PLCs are the collection point for all plant data. They are also the implementer of instructions. They drive setpoints, operate motors and valves and change product models or types based on external inputs. Industry 4.0 enables these instructions to come from cloud-based applications based on data analysis, potentially without any human intervention.

Industry 4.0 offers significant benefits to manufacturers by enabling them to optimize their production systems. Access to data across enterprise and logistics systems makes it possible to adjust production plans in real time based on customer needs or bottlenecks. Plant information can also be used to assess equipment problems and plan repairs before failures occur. It is access to information and powerful applications that take automation to another level; this is the foundation and the promise of Industry 4.0.

Industry 4.0 requires the collection of much more data than industrial control systems used to collect previously. A single machine could literally have hundreds of sensors, continuously capturing information on its health and performance. Smart devices connect to PLCs using net- work architecture, each device sending potentially large volumes of data. Equipment data can be analyzed in the cloud to identify problems before they arise, for example a pump bearing running hot could automatically initiate a maintenance request. Industry 4.0 therefore advances the maintenance activity so that repairs are executed before the bearing fails completely. Human intervention in terms of monitoring pump performance

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and investigating potential problems are completely bypassed as long as sensors produce accurate information and software models diagnose problems correctly.

The output side of PLCs is also affected by Industry 4.0. Cloud-based applications develop new production plans based on customer needs and other external factors. Changing the plan on a production line consisting of multiple robots requires detailed instructions and updates to each unit on the line, which must happen in real time to provide uninterrupted production. PLCs have the power to control the whole production line as a single unit due to their processing and I/O capacity.

The benefits of Industry 4.0, in the form of optimization and equipment analysis, can only be achieved using the data collection and automation facilities offered by PLCs. Nevertheless, Industry 4.0 also creates some challenges for the manufacturing and industrial environment. Safety is one area of universal concern. Industrial and manufacturing sites are highly regulated with an onus placed on the employer to keep workers safe and prevent incidents that could affect neighboring communities. The introduction of internet-based technology that integrates with the physical plant raises cyber security concerns. It would be catastrophic for external parties to gain control of live operating plants with the aim of sabotaging the facility. Prior to Industry 4.0 the entire industrial automation system ran on a proprietary architecture that was isolated from the internet. With the benefits of Industry 4.0 come risks that weren't there before, which must be adequately managed in order for Industry 4.0 to gain a wider acceptance.

Robustness is also a perceived challenge in terms of implementing Industry 4.0. The ability of PLCs to handle the harsh environment of industrial settings has been critical to their acceptance and success to date. They have built-in barriers that limit the impact of electromagnetic disturbances to the integrity of sensor data and output accuracy. However, the increase in data throughput and the use of ethernet based networks for smart devices can cause industrial users to question the robustness of Industry 4.0 systems.

In that sense, industrial and manufacturing companies are caught between the clear benefits of Industry 4.0 and their concerns about cyber security and robustness.

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On the other hand, robotization of factories is continuing to grow. The international market for industrial robots is growing at a rate of more than 14 percent per year. This growth is driven by a reduction in the costs of manufacturing robots as the technology becomes more widely used, as well as a higher level of control over robot functionality that has opened new applications. Robot movement can now be controlled in up to 22 axes using individual motors.

Multiple sensors capture the status of the robot including position, speed, and even external influences. Cooperative robots, which work together with humans in the same workspace are equipped with arrays of safety sensors that pick up human movement in their danger zone. Sophisticated algorithms determine the safety risk based on position and movement. Motion control systems slow the robot and even stop it before a safety incident occurs. All these features require very fine control of robot movement, as well as high quality sensor information in real time. An industrial robot may have magnetic, pressure, radar and current sensors as well as torque, position and various safety sensors.

Development in PLC technology has helped facilitate advances in robotic control. Their robustness is particularly important in industrial settings using robots. Motors and electrical switching devices create large electromagnetic disturbances that can influence sensor signals. PLCs must take measures such as built-in barriers to prevent the sensitive control side from being impacted by disturbances from the I/O environment.

While early robotic systems were very vendor dependent and proprietary, current trends are towards more open systems and architectures. Converting a control algorithm from one proprietary vendor system to another was time consuming and expensive; interoperability problems that were resolved with open PLC systems. They make it possible to copy one robotic control system to another even when different vendors are involved, speeding up commissioning of new facilities.

As an example, a logistics bottleneck at a distribution warehouse may require switching the production line to a different model. This change could make the difference between continuing to run at full capacity and a complete production line shutdown. Cloud-based applications monitoring enterprise systems and factory information can identify problems and implement solutions using PLCs.

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Another key advantage of using PLCs for robotic control in Industry 4.0 applications is the collection of comparative information for analysis. Similar robots in similar service can be compared for performance and maintenance criteria. Thus, lessons learned from a robot failure in Germany can be applied to a robot in service in China. As the database of information grows from multiple sources all over the world, cloud-based applications get better at predicting failure. Industry 4.0 systems can initiate planned repairs resulting in a reduction of unplanned outages.

As industry embraces Industry 4.0 it is becoming clear that the number of potential applications for PLCs is also increasing. This is giving rise to new solutions that conform more closely to the end-application's requirements, but must still demonstrate the same levels of robustness, security and interoperability that have been established over decades of use. The technologies to enable this new breed of PLC are coming from reliable semiconductor manufacturers, who understand the demands and requirements involved.

Developing a PLC relies on access to components designed to meet the task. As PLC formats become more flexible it will be necessary to secure access to components that can fit those formats. Figure 1 shows a block diagram of a typical Micro PLC; a solution that is pared down to only the most essential components. At the heart of any PLC of any size is the microcontroller.

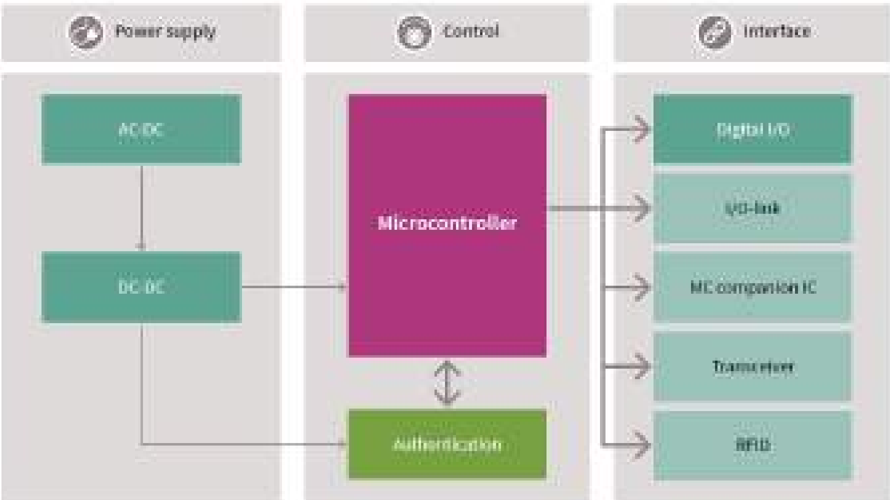

Figure 1: A conceptual system-level diagram of a Micro PLC [Wur19]

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2.3 Industry 4.0 requirements for PLCs

PLC controllers currently form an important technological basis for the automation of industrial processes. Even in the age of industry 4.0 (I40) and industrial internet, it can be assumed that these controllers will continue to be required to a considerable extent for the production of tomorrow. However, the controllers must fulfill a range of additional requirements, resulting from the new production conditions.

When applying Industry 4.0 principles [Kag13], high-quality networked production systems result, based on cyber physical systems (CPS), also referred to as cyber physical production systems (CPPS). A series of I40 requirements are placed on the future controllers used in these systems.

According to [Lan19], these include:

- Introduction of the service paradigm in production automation (production services);
- Autonomy, reconfigurability and agility (plug and work).
- Overcoming the strict information encapsulation of controllers.
- Networking in local and global networks.
- Interoperability between heterogeneous control systems.
- Dependencies are to be changeable dynamically at runtime.
- Use of models for the development of “higher-quality” control approaches.
- Orchestration of heterogeneous controllers.

Current PLC controllers cannot yet fulfill the majority of these requirements or can only do so on a rudimentary basis or at extremely high expense. The paper describes the concept and two prototype implementations for a new type of a PLC controller in which the controller functions (control programs) will be implemented as smart control services in a cloud. The programming of this new PLC occurs as is usual in industry, pursuant to the standard IEC 61131-3. [IEC13]

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Resulting from the historical development of PLC controllers, these have been developed as proprietary device systems that are operated locally under real-time conditions. If a networking of these controllers is necessary from a user viewpoint, proprietary TCP/IP protocols or those standardized in the automation sector (Modbus TCP, Profinet etc.) are used for this. The standard technologies widespread from the Internet and Web have so far played hardly any role for PLC controllers.

For several years, however, a transformation has been under way, with PLC manufacturers increasingly integrating ICT technologies from the web world in their systems, such as web server and HTML pages for diagnosis and configuration, in order to adapt the controllers incrementally to the new requirements.

Three different approaches to make PLC controllers I40 compatible can essentially be revealed from the state-of the-art. These include:

- the introducing of web technologies,
- the global networking and
- the introduction of service principles.

Most of the newer PLC controllers already contain a web server as well as special HTML pages on the device, these enabling a browser-based configuration and diagnosis of the controller. Process data or program variables form the control program and can also be read, and some-times also written, with restrictions. Access via a web browser is via the HTTP protocol and is hence query- based and relatively slow. Examples of this can be found in [Wag19]. The solutions are proprietary and adapted to the relevant controller. Open and consistent web interfaces are not available. The above I40 requirements cannot therefore be fulfilled.

For integration of the PLC controllers in supervisor, management and coordination systems (e.g., SCADA or MES systems), which are partly based on web technologies, additional modules are integrated in the PLC controllers, these enabling a bidirectional and event-based process data transmission between the controller and supervisor &management system. This includes, for example, solutions such as the use of Java-Applets on websites for access to Siemens's controllers [Soc09], the Web connector with MQTT broker in Bosch-Rexroth

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controllers [Col14] or also browser-based access to controllers that already contain an OPC UA server [Mic15].

These solutions also involve proprietary and closed control-integrated modules. Although the modules utilize web technologies, they cannot be transferred to other controllers. The global process data communication is used for HMIs (HMI - Human Machine Interface) and/or supervisor & coordination functions in the higher level of the automation hierarchy (e.g., plant management level). Authoritative statements regarding the time response of the process data transmission are not available. However, different statements result from the latency times greater than 100 to 300 milliseconds. Open and consistent web interfaces are not available. The above I40 requirements can only partly be fulfilled with some adaptation expense for integration in a CPPS.

Based on the I40 requirement for the service capability of an I40 controller, some projects [Pic13] [Gri15] are involved with the integration of service functions in PLC controllers. Thus, the Device Protocol for Web Services (DPWS) enables, as standardized protocol, service-based access to PLC controllers [Sch14] etc. also for reading/writing process data. The internal functional system of a PLC is to be equipped correspondingly for this with the support of the controller manufacturer.

An option for implementation of the DPSW independently of the manufacturer of a PLC is shown in [Cri18]. A service server is implemented here as a functional module based on the standard IEC 61131-3 programming language. This can then be used for the control programming.

However, the DPWS solutions have a principal disadvantage: Instead of reducing or removing the information encapsulation (I40 requirement), further functionalities (service functions) are encapsulated in the controller. Although the service paradigm can consequently be implemented, it significantly encumbers the implementation of other I40 requirements (e.g., Plug &Work, change of dependencies on the runtime). Moreover, DPSW uses the very heavy-duty and complex Microsoft web service protocols. The attainable transmission times of process data via a global network therefore tend to be in the upper range there too, hardly any definitive statements are available).

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In summary, it is to be estimated that there are various solutions and endeavors to provide PLC controllers with additional functions in order to network the controllers in an IP network as defined by Industry 4.0. However, there are considerable deficits in respect to the global networking :

- The process data communication between the controller as a device and a global web functional landscape is slow. Effective statements regarding transmission times and for guaranteeing their quality are not available.
- However, the controllers do not have any web interfaces or, if they do so, such interfaces are inadequately disclosed.
- Available I40 models and architectures have not yet been considered.
- Tools for the migration of classical PLC controllers to the new CPS-based production environment corresponding to Industry 4.0 are practically nonexistent.

2.4 PLC as IoT component

Industry 4.0 represents a high level of interdisciplinary interaction between IT, automation and communication requiring flexibility and excellence from the specialists. Therefore, professors, teachers and laboratories must be very well prepared regarding to that technology representing a challenge in the future engineering education.

The existence of laboratories to teach or training students on such technologies is nowadays quite limited and usually based on proprietary systems. However, some interesting realizations can be found in the literatures that are close to such technologies. A novel approach in hardware and software architecture for implementation of remote laboratories for automatic control is presented in [Kal15]. Here, the physical setup and communication principles of hardware architecture are based on two types of devices: the programmable logic controllers and industrial network routers; the user interface of client application is designed as a Web page, powered by optimized JavaScript, using the sophisticated on-the-fly content generation. An educational experience presented as a Cyber Physical Systems (CPS) challenge develops an Android-based remote-control system for teleoperating an educative

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mobile robot in [Gon14]. The design and implementation of an innovative IoT experimental platform using gateways and wireless network technologies is presented in that can contribute to have ore online laboratories is described in [Sal15] and [Dur15].

Security is also another important issue related to those subjects. Many companies still rely on management and production systems that are unconnected or closed. With the increased connectivity and use of standard communications protocols that come with Industry 4.0, the need to protect critical industrial systems and manufacturing lines from cyber security threats increases dramatically. As a result, secure, reliable communications as well as sophisticated identity and access management of machines and users are essential [Dur15]. Reference [SaHa15] is a good approach as an introduction on such concept and specific examples to improve security are given in [Mor13] and [Vav15].

Initial architecture and reference models have been available for the new CPS-based production structures since 2015. The Reference Architectural Model Industry 4.0 (RAMI 4.0) was developed in Germany and published in April 2015 by the ZVEI [Han15]. Two months later, the Industrial Internet Reference Architecture (IIRA) was published by the US organization IIC (Industrial Internet Consortium) [Iic15]. Both architecture models deal comprehensively with the future production process, to some extent from different viewpoints, but essentially remain very general and provide only limited information in respect to a practical implementation. RAMI 4.0 forms an exception in respect to the question of which structure an I40 component should exhibit.

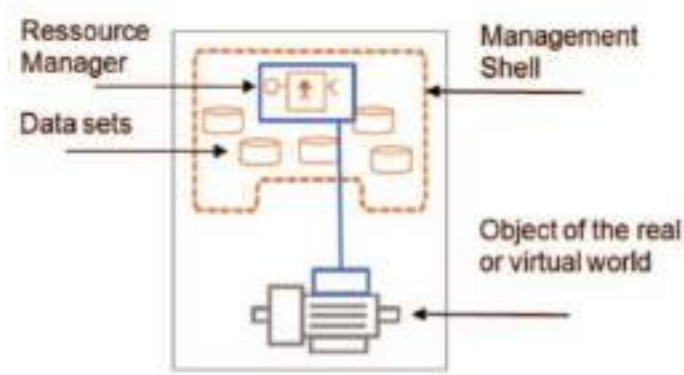

Figure 2. Component structure of an I40 component according specifiation RAMI 4.0 [LaRo16]

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According to RAMI 4.0, an I40 component comprises three essential components [LaRo16]:

- Physical object (device) or object of the information world (virtual object),
- Management shell and
- Resource manager.

Fig. 2 shows the structure of such an I40 component. RAMI 4.0 does not provide any further details regarding implementation of the structure according to Fig. 2, nor are any implementations known so far. For the present task of a PLC controller as an I40 component, nevertheless, Fig. 2 provides an initial basis that is to be outlined further below.

2.4.1 Virtual object

Virtual object is only considered generally in the RAMI model. A suitable connection to the IP network is presupposed without further discussion. However, this results in the problem that a normal PLC is only provided with a corresponding web-compatible interface to an inadequate extent. A Device Gateway is therefore introduced, which must be able to provide the process data of the PLC controller in the IP network and hence in the web world, rapidly, reliably and securely. The device gateway should be set up so that it can also be integrated in existing PLC controllers without intervention and, if possible, without additional device-technical expense. A “lean” and web-compatible protocol is required for communication with the IP network.

2.4.2 Management shell

According to RAMI 4.0, the management shell has the following features, amongst others:

- It manages the information belonging to the object in the system environment.
- The management is coherent and consistent in this system environment.
- It has precisely one resource manager.

The management shell is located outside the controller in the information world of the Internet/Web and must therefore also utilize the corresponding technologies from this environment in order to be able to establish a connection with web services, clouds and other objects in the Industrial Internet of Things. In relation to a PLC controller as a device, a Service Shell is defined as a functional interface with a management data set, which can be used in the above automation-technical context in a consistent manner (if possible for all devices, not only PLC controllers).

As a giving system environment is assumed for the present solution, the further RAMI property of various management shells does not have to be considered. But also other management shells res. service shells for different system environments are possible (if required).

2.4.3 Resource manager

The following RAMI properties of the resource manager are of particular interest in relation to a PLC controller as I40 component.

- It organizes the data exchange with the device in online mode.
- It organizes the internal information management.

According to the authors of this paper, the resource manager must also establish a virtual mapping of the de- vice in the selected system environment (Internet/Web) so that it can communicate with other IT objects in the IT world via the service shell. The resource manager is therefore modelled as a Virtual Device (VD) for the present solution.

The further RAMI properties of the resource manager such as participants in an I40 service system and organization of the external access to information in the management shell should preferably be assigned to the management shell, in the opinion of the authors.

Based on the above versions, the structure outlined in derived for the model of a PLC controller as an 40 component.

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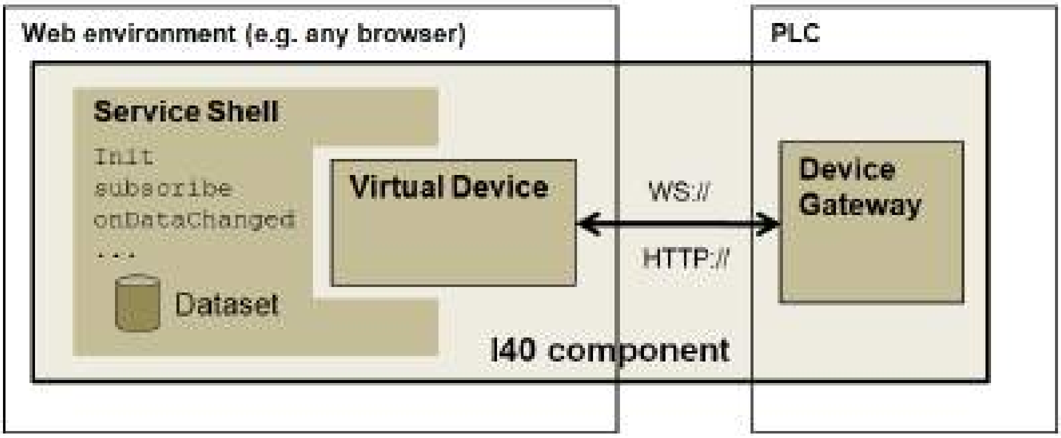

Figure 3. Model of a PLC as a I40 component

The communication between the virtual device and device gateway is realized for initialization and parameterization via the HTTP protocol. The websocket protocol is used for rapid bidirectional process data transmission. The pragmatic and “lean” WOAS Device Protocol developed in the WOAS project (WOAS = Web-Oriented Automa- tion System) [Lan13] and based on JSON functions is used as an application protocol.

The data set (or multiple data sets) integrated in the service shell contain requisite parameterization and management information for the I40 component. These data sets I40 component itself or outsourced to an external database (in a cloud).

The most remarkable advantage is that with this component the PLCs can be seamlessly integrating in Industry 4.0 product environments using the service paradigm. As a direct result, existing conventional PLC systems can be also integrated in a new CPS-based Industry 4.0 automation without any changes, just include the available library in the user program.

2.4.4. Demonstration example

In [LaRo16] the created concept was tested and evaluated within the framework of a prototypical implementation with Phoenix Contact controllers and the programming tool PC WORX. This resulted in a fastest transmission of process data from a PLC in an IP network. The use of the I40 component with the WOAS portal and the laboratory applications created

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shown the flexibility of the complete system as CPS test and training platform [LaRo16]. This practical example has been shown in Fig.4 and Fig.5.

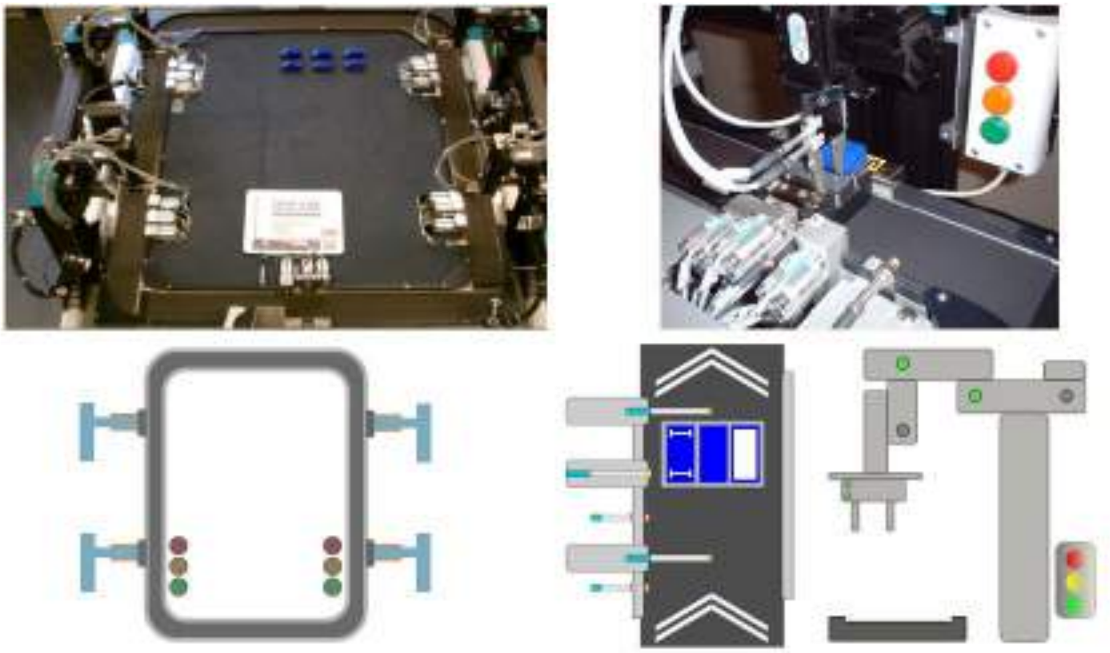

Figure 4. Laboratory installation and one of the stations (top). Section of the web page representing the above pictures (bottom)

Figure 5. The CPS Integration Platform WOAS

An available and open implementation to do and practice is the CPS Integration Platform WOAS (http://woas.ccad.eu), shown in Fig.5. The WOAS portal [Lan13] is a multi-client-

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enabled and role-based web portal, which can be used to connect services and devices to and among one another. On the client side (browser) the platform is completely implemented in HTML5 and JavaScript. No Plugin is required and the system is runnable in each existing browser and device.

In principle, every PLC can be integrated in this portal as an I40 component when using the described device gateway. Together with other automation services (operating services, visualization services etc.) requisite functional systems (SCADA and HMI systems, remote labs etc.) can easily be created and utilized in the web browser without additional software complexity.

Additionally, the complete software for the PLC as an I40 component including the documentation and example implementations are available free of charge for downloading and non-commercial use. The WOAS platform itself as well as some other remote laboratories are pro- vided via a cloud server in the Düsseldorf Telelaboratory. The PLC used in the demonstration example is currently integrated in the WOAS portal as an I40 component a publicly accessible website is available for test purposes.

In that sense, use of PLC controllers as an I40 component is also envisaged in order to outsource non-time-critical parts of control programs in a cloud as services and enable these to execute in the cloud itself and/or on a web client in a runtime machine.

2.5 Virtualization of PLC

Current R&D work deals with the virtualization of complete PLC controllers and their outsourcing into the cloud. A scalable control platform for cyber-physical systems in industrial productions is researched and realized in [Pic13]. In [Gri15], a cloud-based controller is presented, which also uses a virtual control system in an Infrastructure as a Service (IaaS) cloud. The work of [Sch14] also uses virtualized PLC controls in the cloud and connects these to OPC UA-based automation devices using web technologies. Problems with the virtualization of PLCs result especially from the fact that already available manufacturer-specific PLCs are

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virtualized. These controllers, however, are closed systems, which were originally not developed considering the aspects of web technologies.

Adjustments, modifications, or extensions of these controllers by third parties are hardly possible. Functionality cannot be resolved as services. The flexibility of virtualization is very limited. Reference [Cri18] proposed a methodology for converting an automation plant managed by PLCs onto an EFSM control module (EFSM—extended finite state machine) that is driven by single board computers or SoC (system-on-a-chip). The EFSM Control Module can use IoT devices, but in that solution, the functionality (control program) cannot be resolved as a service from the cloud.

In summary, it can be estimated that there are different solutions and efforts to equip PLC controllers with additional functions in order to be able to use the controllers in an Industry 4.0-type IP network. To this end, the known work already uses web technologies in part, in a manufacturer specific and/or limited way, and increasingly also tries to use the service principle and cloud structures as a new paradigm for the realization of control functions. However, there are still the following deficits that result in corresponding needs for research:

- Although web technologies are used, a flexible distribution of the structure and function of the control functionality is not used. The information encapsulation of industrial control programs in local or virtualized devices (PLCs) is not called into question.
- For smart control services using cloud technologies as an essential feature of a future networked industry, systematic investigations, architectures, interfaces and demonstration solutions are lacking.
- Available standard technologies from the world of IP networks for increasing flexibility and efficiency are not or insufficiently used in the control level.

3. COMMUNICATION PROTOCOLS

The short review of the most used communication protocol supported by the Siemens S7 PLC series has been presented.

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Since the need for communication in industrial systems, many communication protocols have been developed, from simple to extremely complex. Some did not come to life, proving inefficient or simply obsolete, and some are still in use today. Siemens, as one of the leading manufacturers of industrial automation components, implements various communication protocols that have proven to be good solutions for certain levels of communication over time. Siemens has participated in the creation of some of them (PROFIBUS, PROFINET, USS ...) independently or in cooperation with other leading companies.

Industrial systems are hierarchically organized in 5 levels (from the lowest to the highest):

- Sensor and actuator level,
- Machine level,
- Cell level,
- Level of production plant,
- Factory level.

At the lowest level of sensors and actuators, there are devices such as: sensors, valves, switches, motor starters, etc. At this level, small amounts of data are exchanged with controllers such as on / off signals and response times must be extremely low. There is no need for devices of this level to communicate with each other.

At the field or machine level, there are parts of production equipment, such as: conveyors, robots, automated tools (CNC machines), etc. Various sensors and actuators are connected to these devices to enable the operation of these devices. There is a somewhat more extensive data exchange here than at the level of sensors and actuators. Most often, this level does not require mutual communication, but only communication with neighboring levels.

The cell consists of a group of machines or devices and within it similar elements are processed and a new product is formed. Larger amounts of data are transferred here and a certain delay in the transfer of information is expected. At this level, there is already a need for mutual communication between the PLCs themselves.

Multiple cells make up one production plant in which the controller of the plant that manages the cells is located. At this level, it is necessary to collect a large amount of data, so

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that the application of a high-speed transmission protocol is required. Also, mutual communication of the drive controllers is necessary.

At the very top, there is the level of the factory, i.e. the company that supervises the work of the entire factory and manages certain tasks. It is clear that this is a matter of transferring a huge amount of data and that it is necessary to apply high-speed and reliable protocols, which are based on Ethernet and TCP / IP standards intended for computer networks.

3.1 PROFINET

PROFINet is an open Industrial Ethernet standard, developed by the PROFIBUS Organization. It is designed to meet all the needs of industrial automation. It is based on Ethernet (IEEE 802.3), which has been an unavoidable standard for communication at a higher level and at the factory level, for many years. Unlike Ethernet itself, PROFINet is also used at lower levels of industrial communication, in the transmission of analog and digital process quantities. Essentially, PROFINET is an integrated and enhanced PROFIBUS DP with Ethernet technology. Like PROFIBUS, PROFINet supports various profiles such as PROFIDrive, PROFISafe, etc. The convenience of the PROFINET protocol is also reflected in the possibility of connecting with other industrial protocols, such as PROFIBUS, MODBUS, AS-i, etc.

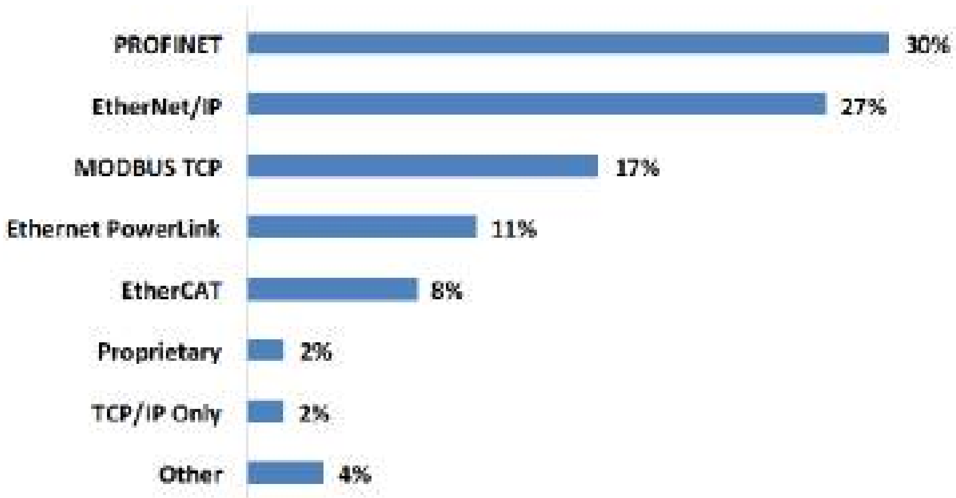

Figure 6. Industrial Ethernet market share

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Using TCP / IP and other IT standards, PROFINET communicates where real-time operation is not required (Downloading parameters, diagnostics, exchanging large amounts of information, etc.) and for real-time communication, it uses reserved Real-Time channels bypassing TCP. / IP protocol packet.

PROFINET finds its application in various areas of industry, such as:

- Production plants,
- Car industry,
- Food, tobacco and beverage industry,
- Product packaging lines.

There are two types of PROFINet standards:

• **PROFINet IO** - represented at lower levels of communication between the controller and input / output devices in the transfer of process variables. PROFINet IO uses the communication model and application layout of the already tested PROFIBUS DP and extends it to Ethernet as a communication medium. Among other benefits, it allows for higher bandwidth and many more stations on the network itself (participants in communication). PROFINET IO uses three different communication channels to exchange data with control systems and other devices. The standard TCP / IP channel is used for parameterization, configuration, and other acyclic read / write operations. The RT (Real Time) channel is used for cyclic data exchange and for various alarms. The third, IRT (Isochronous Real Time) channel, ie the channel for synchronous communication in real time, is a channel of high speed and response and finds application in robotics (Motion Control). All channels can be routed over the same network, without the risk of signal conflict.

• **PROFINet CBA (Component Based Automation)** - used for communication between network components at the controller level via TCP / IP protocol. The basic idea is to divide the entire automation system into several independent subsystems, in the form of system components that will exchange large amounts of information with each other. PROFINet CBA is based on DCOM (Distributed Component Object Model), developed by Microsoft.

PROFINet IO devices can be connected and considered as one PROFINET CBA component. With the help of the PROFINET CBA concept, networking of several such components results in machine-machine communication.

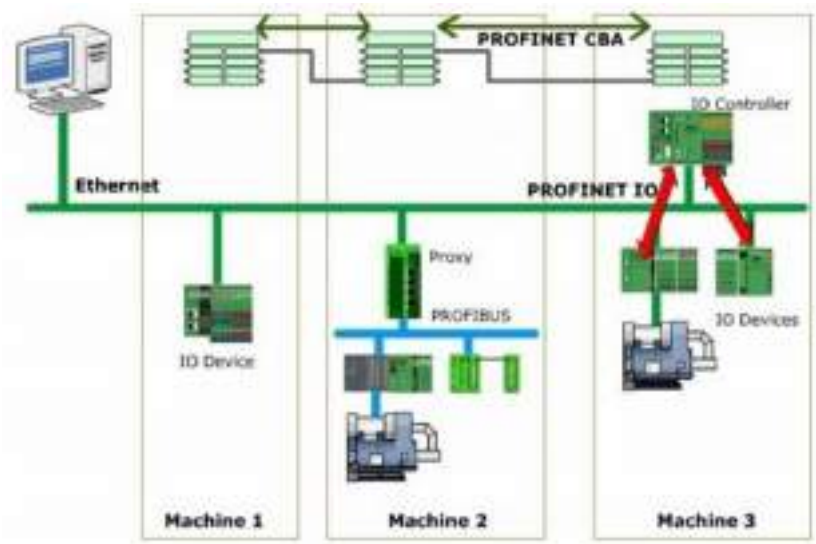

Figure 7. Example of simultaneous implementation of PROFINET IO and PROFINET CBA protocols

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4. CYBER PLC

4.1. Introduction

Manufacturing Control System (MCS) is widely applied in various enterprises [Lei09] [Dot18]. However, as the automated equipment with various standards or protocols is popularly applied in the manufacturing system, the associated MCS will have a problem to keep up with the standards or protocols. In addition, traditional manufacturing control architectures are mostly limited in monitoring, i.e., providing information of the shop floor status only. Control is a problem because traditional MCSs are developed based on rigid control architectures that do not respond effectively to dynamic changes. How to develop an MCS that is intelligent, robust, and adaptive to environmental disturbances is an issue.

To conquer the above issue to develop an intelligent MCS (iMCS), in [Lin19] Cyber PLC (Programmable Logic Control) based on today's IoT (Internet of Things) technologies has been proposed. Cyber PLC is in contrast with traditional PLC. Traditional PLC has the limitation in applying in a large and distributed system [Del17], in spite of reliability and robustness. Hence, to develop a large and distributed system needs an MCS architecture with various protocols for integration. Cyber PLC takes the advantages of IoT and cloud/fog computing to develop a virtual PLC that is not limited by the geographical distance and protocols. Cyber PLC maintains the advantages of traditional PLC, but it is more extensible and flexible without relying on industrial protocols and do not need to consider the compatibility of equipment equipped with various industrial standards or protocols.

The originality of Cyber PLC in [Lin19] is to virtualize the physical PLC. Cyber PLC unifies the signal and data of control. By using Cyber PLC, there will be no need of industrial protocols, e.g., Modbus, CC-Link, OPC- UA, etc.

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4.2 The principles of Cyber PLC

The traditional sequential programming, although suitable for most of the production systems, is an unsuitable method in a distributed collaborative environment. The environment requires programs supporting inherent multi- level and distributed yet collaborative tasks. It is not only a broad appreciation of mechatronics, manufacturing decision making, planning and operations, but also a deep integration of communications, information and advanced control functions. As it has been already stated, due to the robustness of the PLC, PLC is still widely used in today's industrial control. The program logic contained in the PLC dominates the operation of the system. However, in a highly complex industrial production environment, any system component failure or adjustment could result in an abnormality on the rigid PLC program logic and hence results a breakdown of the manufacturing system. The rigid PLC, applying in most production automation systems is inflexible and unable to respond to the reconfigure, scalable, and adaptive system requirements.

The proposed Cyber PLC in [Lin19] is similar to SCADA in manufacturing control system. But, Cyber PLC has a virtual program logic control with anti-jamming and non-rigid logic control features. Cyber PLC could be the central manager of many distributed physical PLCs. The I/O module transfers data from physical PLCs to the Cyber PLC. Cyber PLC has the function of control. However, because it receives data from equipment, its function can also include data analytics. With data analytics, Cyber PLC is empowered with predictive and preventive functions. From the perspective of computing, Cyber PLC's position in the manufacturing system is at the fog level [Shi16] and is the same as SCADA (see Fig. 8).

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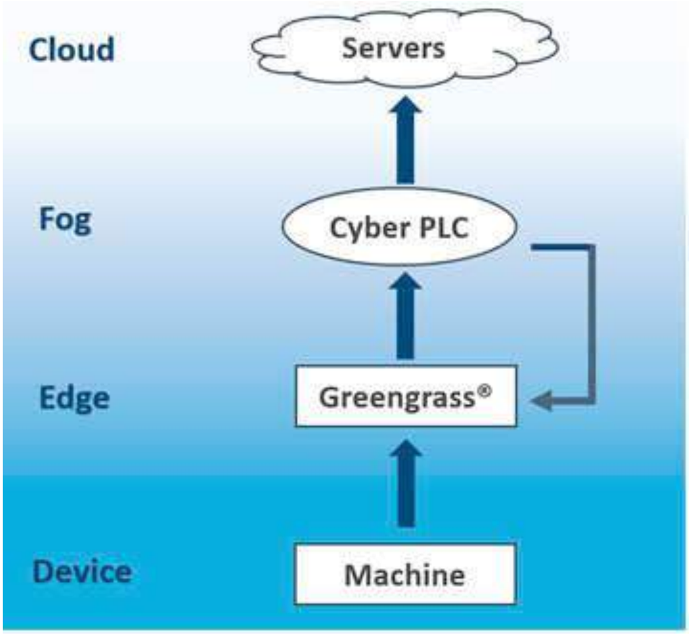

Figure 8. The position of the Cyber PLC in the manufacturing system [Lin19]

4.3 No need for industrial communication protocols

With the maturity of today's IoT technology, the realization of Cyber PLC is feasible. However, for this automation technology application, a highly reliable and usable communication system is essential. Due to the unfavorable characteristics of the PLC transmission channel, it is difficult to ensure the reliability and availability of the communication system especially for long-distance transmission. It can be challenge if neither a standardized data format nor exact amount of data is available for transmission [Bau09]. That is why when uploading data to SCADA, a traditional PLC requires communication protocols. It is difficult to implement M2M in an IoT environment due to the large number of pair-to-pair communication of different devices in the automation process. Different communication protocols cause data transmission barriers in data sharing. In the past, multiple signal converters and gateways were needed as intervening stations for signals. The advantage of Cyber PLC is to let each device transfer data to the fog level for further control and analytical purposes.

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4.4 Deployed techniques

MQTT (Message Queue Telemetry Transport) is a protocol that is a lightweight messaging protocol designed to connect physical devices to applications for web development as the best choice for IoT and M2M connectivity protocols. MQTT is based on publish/subscribe messaging and is suitable for one-to-many messaging. In MQTT, the data published by the publisher is distributed by the agent to the subscriber. MQTT's job specification simply collects data from the device and reliably transmits the data back to the collection server, so it has few configuration options and does not require any configuration options [Esl15].

AWS IoT Greengrass seamlessly extends AWS to node appliances to manipulate the data it generates on the machine while continuing to use the cloud for management, analysis, and persistent storage. With AWS IoT Greengrass, the connectivity device can perform AWS Lambda functions, perform predictions based on machine learning models, keep device data synchronized, and securely communicate with other devices even when not connected to the Internet. When using AWS IoT Greengrass, we can build and test device software in the cloud using familiar language and programming models, and then deploy the software to the device [AWSG20].

AWS IoT Greengrass uses MQTT to synchronize the Micro Control Unit (MCU) with the cloud and connect the data to the cloud unimpeded. However, AWS IoT Greengrass simply connects the MCU to the cloud, but it lacks the idea of industrial control. Since AWS IoT cloud is conceived as the Cyber PLC, the AWS Lambda function is regarded as a vehicle, so that the device can be controlled instantly.

4.5. System architecture and deployment

Based on the above technologies, in [Lin19] Cyber PLC architecture has been proposed as it is shown in Fig. 9. On the device side, the sensors and devices can be integrated by the MCUs. The device is controlled by the local lambda function built by Greengrass. It is intended that all devices and sensors transmit data to the MCU first. Then, the MCU integrated by

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Greengrass transmits data to the Cyber PLC. With Greengrass the MCU data can be completely uploaded to the AWS IoT function through the MQTT protocol.

On the Cyber PLC side (right side of Fig. 9), Cyber PLC has a virtual logic control environment. Cyber PLC receives data uploaded by Greengrass and stores it on AWS IoT. Cyber PLC, realized in AWS Lambda, analyzes.

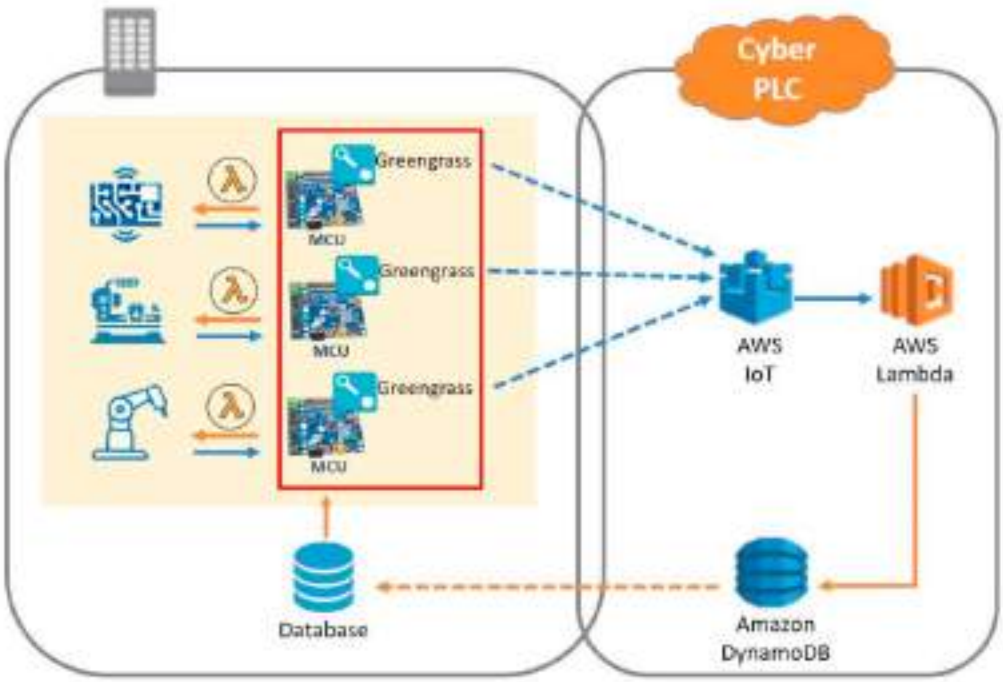

Figure 9. Cyber PLC architecture [Lin19]

Following the architecture shown in Fig. 2, deployment procedure has been developed [Lin19]:

Step 1: Using MCU and Greegrass to link with the I/O of the machines or sensors. Arduino and LinkIt by Mediatek [Med16] are typical MCUs.

Step 2: Using AWS IoT to stream the data in MCU with the data in AWS IoT component in the cloud [AWSS20].

Step 3: Designing the control logic (rules) with Python in AWS Lambda to convert the inputs from the MCU to the outputs.

Step 4: The outputs in Step 3 are synchronized with AWS DynamoDB.

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Data in AWS DynamoDB are further synchronized with the data in the local database. Note, Steps 2-4 are all deployed in AWS.

Step 5: The data in the local database is inputted to the MCUs to control the equipment through Greengrass.

According to [Lin19], in Step 2, how to convert the traditional program logic in PLC to the rules with Python in AWS Lambda is a challenge and is still under development.

5. PLC - I4.0 TRAINING EXAMPLES

In order to fulfill targeted specific objectives of this course and to provide sufficient practice for developing modern Mechatronics skills related to Industry 4.0 different scenarios for different automation processes will be defined and realized related to PLC control. For that purpose, FESTO didactic center will be used. In that sense, full practices of integrated automation training, combining mechanics, pneumatics, electrical engineering, PLC control, and communication interfaces will be provided. As extension, industrial robot Mitsubishi RV-2SDB will be used for some of demonstrations related to PLC control.

As it states in the theoretical chapters of this course material, communication between PLCs and other devices is one of the key elements of Industry 4.0. In order to provide practical skills in establishing PLCs' networking different examples with different industrial network protocols, different PLCs, and communication and remote control via Internet will be practiced.

Especially, knowledge of the steps required to provide communication of PLCs via TIA portal will be presented and different scenarios will be realized. The same scenarios will be realized with other open platforms and portals related to provide cloud-based devices.

Finally, knowledge of establishing communication and connection of PLC with simulation software such as MATLAB will be presented, and numerous examples will be shown and realized.

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5.1 FESTO Didactic center

Festo didactic center was developed and manufactured exclusively for professional and additional training in the field process automation. It consists of four parts:

- Filtration station
- Mixing station
- Reactor station
- Bottling station (filling)

Filtering station - The purpose of using this station and all its parts is to give answer to certain questions of technical practice, i.e., how aquariums, vacuum cleaners work, filters, and the like.

Mixing station-Food products, paints, construction materials and pharmaceuticals funds are an example of using more resources in proportional quantities to get final product. Each of them requires constant measurement and mixing with careful selection ingredients and apparatus used to combine them. This station provides the ability to improvise mixing and measuring processes, thanks to exceptional equipment which it possesses, such as high-quality control components and controllers and precision.

Reactor station-In order to extend the shelf life of food products, improved the solubility or miscibility of liquids, it is necessary to know and then include a lot of efficient chemical processes in their production. This station provides an opportunity improvisation of change and control temperature, thanks to the equipment it possesses.

Bottling station (filling) - It is of great importance to every beverage manufacturer that it is prominent the quantity on the packaging equal to that inside. Therefore, it is important that the bottling process, i.e., charging, be constant in terms of precision. This station shows the real industrial system where they can see and learn all aspects of a quality and efficient bottling process. The core is monitoring and managing the packaging that is needed to recharge.

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Figure 10. Festo Didactic Learning system and Mitsubishi RV-2SDB

5.2 Industrial robot Mitsubishi RV-2SDB

The Mitsubishi RV-2SDB robot is an industrial robot suitable for assembly and material handling and wide a range of other tasks.

This robot has six degrees of freedom of movement and is powered by AC servo motors. Length and shape of the arm they are designed for optimal performance and maximum reach by providing the possibility of a position close to the base robot.

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6. CONCLUSION

PLCs continue to define the smart factory and improve the efficiency, safety and reliability of industrial automation. Without higher levels of automation, the advancements society has come to expect and rely on will slow down and, eventually, stall.

Industry 4.0 is heavily dependent on the evolution of PLCs, as they need to be more connected, more competent, and increasingly more secure. The move to software-defined functionality and control was the first step towards achieving that, but many industries are now dependent on that evolution continuing and, if possible, accelerating. With robust and secure solutions to meet this demand, Infineon is well placed to provide the technologies needed to realize the promise of Industry 4.0.

PLCs will consistently always remain the fundamental processor for real-time manufacturing processes but will also help communication with input sensors through Industrial IoT. This will also enable PLCs to collect refined data and transmit it to machine learning programs. PLCs and the facilities that utilise them need to be prepared for the rapidly changing global climate and environment surrounding us. Unprecedented climatic events such as heat waves, floods, or even cold waves are becoming increasingly common and severe at the same time, which can negatively impact the functioning of electronic equipment such as PLCs.

PLCs in the future should be developed and designed to be more robust and sturdier in order to withstand the harsh and hostile climate. They will be manufactured with different materials, such as fiber signals which are significantly more durable than electronic signals, especially in hostile environments like plant floors. Due to the IIoT technology, the PLC can also be operated remotely from another location and be stored in isolation far away from harsh conditions where there's little to no interference. This is especially critical if there are sensitive & delicate sensors and processes that mandate the need for precise regulation and actions.

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1 7. REFERENCES

[IEC13] IEC 61131-3:2013 Programmable controllers - Part 3: Programming languages

[Wur19] Würcher M., *The evolution of PLCs driving Industry 4.0 forward*, Published by Infineon Tech ologies AG 81726 Munich, Germany

[Lan13] R. Langmann, L. Meyer, "*Architecture of a web-oriented automation system*", 18th IEEE Int. Conf.on Emerging Technologies & Factory Auto 10.-13.09.2013, Cagliari, Italy, Proceedings.

[LaJe16] R. Langmann, H. Jacques, "*Generic remote labs in automation Global Engineering Education ference* (EDUCON 2016), Abu Dhabi, April 2016.

[LaRo16] Langmann R., Rojas R., *PLCs as Industry 4.0 Components in Laboratory Applications*, iJOE – Volume 12, Issue 7, 2016, pp.37-44 http://dx.doi.org/10.3991/ijoe.v12i07.5828

[Lan19] Langmann R., Stiller M., *The PLC as a Smart Service in Industry 4.0 Production Systems*, Applied Science, 2019

[Kag13] Kagermann H., Wahlster W., Helbig, J. *Recommendations for Implementing the Strategic Initiative INDUSTRIE 4.0*; Research union: Business-Science; National Academy of Science and Engineering: Munich, Germany April 2013.

[Wag19] WAGO Kontakttechnik GmbH: Effective Upgrade: *A Plug-In Makes WAGO Controllers IoT-Ready*. Available online: https:/www.wago.com/us/plc-mqtt-iot (accessed on 23 April 2019).

[Col14] Colombo, A.W.; Bangemann, T.; Karnouskos, S.; Delsing, J.; Stluka, P.; Harrison, R.; Jammes, F.; Lastra, J.L. *Industrial Cloud-Based Cyber-Physical Systems*; Springer International Publishing: Zug, Swiss, 2014.

[Soc09] EU Project: *SOCRADES*. 2006–2009. Available online: http://www.socrades.net

[Mic15] Microsoft: *Introducing DPWS*. 2015. Available online: https://msdn.microsoft.com/en-us/library/dd170125.aspx .

This project has been funded with support from the European Commission. This publication [communication] reflects the views only of the authors, and the Commission cannot be held responsible for any use which may be made of the information contained therein.

[Pic13] ISW of the University Stuttgart: *Industrial Cloud-Based Control Platform for the Production with Cyber-Physical Systems (piCASSO-in German)*—BMBF-Verbundprojekt, Stuttgart. 2013. Available online: http://www.projekt-picasso.de/index

[Gri15] Grischan, E.; Stahl, C.; Greiner, T.; Barth, M.; Gorecky, D. *Cloud-Based Automation*. atp ed. 2015, 3, pp.38–47.

[Sch14] Schmitt, J.; Goldschmidt, T.; Vorst, P. *Cloud-Enabled Automation Systems Using OPC UA*. atp ed. 2014, 7, pp.34–40.

[Kal15] M. Kalúz, J. García-Zubía, M. Fikar and L. Cirka, "A flexible and configurable architecture for automatic control remote laborato- ries", IEEE Transactions on Learning Technologies, Volume 8, Issue 3 - 310, January 2015. http://dx.doi.org/10.1109/TLT.015.2389251

[Gon14] P. González-Nalda, et al., "*Building a CPS as an educational challenge*", International Journal of Online Engineering (iJOE), 8, Vol 10, No 4, 2014. http://dx.doi.org/10.3991/ijoe.v10i4.3765

[Sal15] C. Salzmann, S. Govaerts, W. Halimi and D. Gillet, "*The smart device specification for remote labs*", 12th International Conference on Remote Engineering and Virtual on (REV2015), pp. 199 - 208, Bangkok, Feb. 2015.

[Dur15] NM. Durakbasa, G. Bas, D. Riepl and JM. Bauer, "*An innovative educational concept of teleworking in the high precision metrology laboratory to develop a model of implementation in the advanced manufacturing industry*", pp. 242 - 248, 12th International Conference on Remote Engineering and Virtual Instrumentation (REV 2015), Bangkok, Feb. 2015.

[SaHa15] K.Salah, M. Hammoud, S.Zeadally, "*Teaching cyber security Learning Technologies* Vol.8, Iss. 4 pp. 383 - 392, April 2015. http://dx.doi.org/10.1109/TLT.2015.2424692

This project has been funded with support from the European Commission. This publication [communication] reflects the views only of the authors, and the Commission cannot be held responsible for any use which may be made of the information contained therein.

[Mor13] D. Moritz, C. Willems, M. Goderbauer, P. Moeller and C. Meinel, "*Enhancing a virtual security lab with a private cloud framework*", ent and Learning for Engineering (TALE 2013), p. 314 - 320. Bali, Aug. 2013.

[Vav15] J. Vávra, M. Hromada, R. Jasek, "*Specification of the current state vulnerabilities related to industrial control systems*", International Journal of Online Engineering (iJOE), pp. 64, No 5, 2015 http://dx.doi.org/10.3991/ijoe.v11i5.4981

[Han15] M. Hankel, *Reference architectural model Industrie 4.0 (RAMI 4.0)*", ZVEI, April 2015.

[Cri18] Cristani, M.; Demrozi, F.; Tomazzoli, C. ONTO-PLC: An ontology-driven methodology for converting PLC industrial plants to IoT. Proced. Comput. Sci. 2018, 126, 527–536.

[Lei09] P. Leitao, *Agent-based distributed manufacturing control: A state-of-the-art survey*, Engineering Applications of Artificial Intelligence, 22 (2009) 979–991.

[Dot18] M. Dotoli, A. Fay, M. Miśkowicz, C. Seatzu, An overview of current technologies and emerging trends in factory automation, International Journal of Production Research, 56 (2018) 1-21.

[Del17] J. Delsing, *IoT Automation: Arrowhead Framework*, CRC Press, (2017).

[Shi16] W. Shi, J. Cao, Q. Zhang, Y. Li, L. Xu, Edge Computing: Vision and Challenges, IEEE Internet of Things Journal, 3(5) (2016) 637 – 646.

[Bau09] M. Bauer, W. Plappert, C. Wang, K. Dostert, Packet-oriented communication protocols for smart grid services over low-speed PLC. In 2009 IEEE International Symposium on Power Line Communications and Its Applications (pp. 89-94). IEEE. (2009, March)

[Esl15] H. Eslava, L. A. Rojas, R. Pereira, Implementation of machine-to-machine solutions using mqtt protocol in internet of things (iot) environment to improve automation process for electrical distribution substations in Colombia. Journal of Power and Energy Engineering, 3(04), 92 (2015).

[Lin19] Y.J. Lin, Y.X. Lin, C.Y. Huang, Using Cyber PLC to Link Physical Operations with Cyber Control Decisions 25th International Conference on Production Research Manufacturing Innovation: Cyber Physical Manufacturing, August 9-14, 2019 | Chicago, Illinois (US)

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