Making existing production systems Industry 4.0-ready

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Making Existing Production Systems Industry 4.0-Ready

Holistic approach to the integration of existing production systems in Industry 4.0 environments

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Abstract This paper presents an approach to how existing production systems that are not Industry 4.0-ready can be expanded to participate in an Industry 4.0 factory. Within this paper, a concept is presented how production systems can be discovered and included into an Industry 4.0 (I4.0) environment, even though they did not have I4.0-interfaces when they have been manufactured. The concept is based on a communication gateway and an information server. Besides the concept itself, this paper presents a validation that demonstrates applicability of the developed concept.

Keywords Cyber Physical Production Systems · Cloud Gateway · Information Server

1 Introduction

Industrial production has reached the edge of a new industrial revolution. In the foresight study of *Kagermann et al.* the factory of the future has been pictured [1]. Future production systems have to be developed considering the need for strong product individualization and, therefore, the necessity for high flexible production processes. To accomplish this challenge, Cyber Physical Production Systems (CPPSs) [2] should be integrated into the production sites in order to create 'smart factories'. A machine tool that provides data from the overall system and from each of its components (maybe even from the actual work piece) and that permits easy access for data acquisition and command execution could be a CPPS in the context described above.

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Even though more and more CPPSs are worldwide installed in shop floors every year, aged production systems are still existing. Following estimations of DMG Mori Seiki (DMG) [3] or the survey of the organization of German Machine Tool Builders' Association (VDW) [4], the life span of machine tools average out between 15 and 20 years. However, "smart factories will be realized much faster if the already existing stock of production systems can also be transformed into CPPSs.

This paper presents a holistic approach to the transformation of existing production systems into CPPSs based on a CPPS Enabler. Section two outlines the current state of the art, followed by the third section that describes the concept of the CPPS Enabler. This section includes the strategies to discover and connect to existing production systems, a method to communicate the existence of the production system to other production systems and, at last, methods for data acquisition and transmission. In the fourth section of the paper, a validation of the CPPS Enabler is presented. The paper concludes with a summary.

2 State of the art

Today, most production sites - from the information viewpoint - are still structured hierarchically from the shop floor level up to the enterprise resource planning level. One reference architecture to describe this structure is the information pyramid of automation (Fig. 1). The information pyramid leads to a communication infrastructure (stack) in which only members of adjoining segments can exchange information. The cycle time of data transformation decreases from top to bottom of the pyramid just as the amount of data transferred.

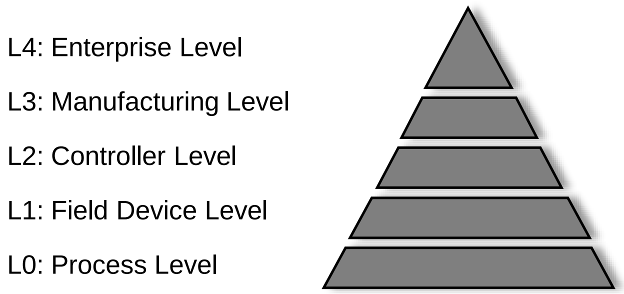

Fig. 1 Information pyramid of automation

But influenced by the concept of CPPSs, the information pyramid of automation will be transformed over the next few years. *Vogel-Heuser et al.* state, as illustrated in Fig. 2, that the information pyramid will resolve and be replaced by a mesh architecture [5]. Information clients and servers represent nodes of this mesh to exchange data based on a common information model. The architecture requires communication interfaces for the transformation or reception of data in a mesh.

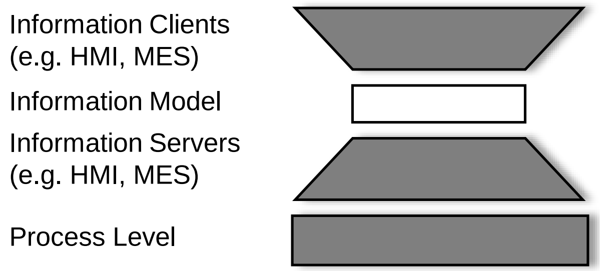

Fig. 2 Information model-based automation structure, based on [2]

2.1 Communication interfaces of production systems

Production systems today have different interfaces which can be distinguished between internal and external interfaces [6]. Internal interfaces are generally used to expand a production system control with additional process and control functionality. They are not further considered within this paper. External interfaces are used to connect the production system with the surrounding production site, mainly with systems for user interaction as human machine interfaces (HMI), machine and production data acquisition or production management as machine execution systems (MES).

Currently, external interfaces of production systems are various. Each interface defines its own communication mechanisms and profiles, even though some of them are used vendor-independent and others in a proprietary way. However, most of today's interfaces are Ethernet-based and can be accessed - in most cases - over an IP network. That applies for interfaces in the field device level (e.g. EthernetIP or Sercos with SIP to access common drive unit interfaces) [7] as well as in the control level. Regarding the control level, common industrial communication protocols that exist are, e.g. OLE for Process Control (OPC), ModbusTCP, Dynamic Data Exchange (DDE) or MTConnect. These industrial communication protocols can be used for the communication in each level of the information pyramid of automation. However, these protocols do not satisfy the requirements regarding communication interfaces for CPPS: All presented protocols are statically configured during the commissioning of the production system. A mechanism to automatically discover and to connect to other production systems does not exist today.

2.2 Mechanism for automatic discovery and connection establishment

In the consumer industry different protocols have been developed to discover communication partners and to establish a connection between them. As one example of them, Bluetooth defines a discovery mechanism to detect communication partners through inquiry messages [8]. Inquiry messages are broadcasted on different hopping frequencies until a partner is detected. The inquiry message is followed by a paging message that is used to establish the connection between partners. If partners have implemented the same Bluetooth profile, they can interact with a standardized interface (e.g. play audio).

New industrial communication protocols like OPC Unified Architecture (OPC UA) provide discovery functionality [9]. With OPC UA it is possible to discover different OPC UA servers and to connect to them, if the address of the discovery server is known. An automatic mechanism to detect an OPC UA discovery server by the OPC UA client does not exist today. The only known approach to automatically detect interfaces is implemented in the trojan 'Havex' which has the capability to actively search for OPC servers [10].

3 CPPS-Enabler

Production sites are an assemblage of different production systems that are not necessarily prepared to be part of an Industry 4.0 factory. The transformation of production systems into CPPSs requires concepts and solutions for the integration of these systems. That implies mechanisms for detecting and connecting to these systems as well for accessing and distributing data and command interfaces. The concept of the CPPS-Enabler, as described below, is illustrated in Fig. 3.

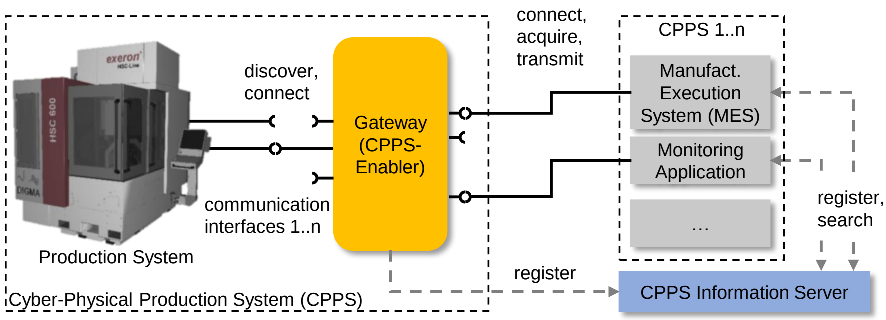

Fig. 3 Concept of the CPPS-Enabler

3.1 Connectivity

Being part of an Industry 4.0 factory assumes the possibility to easily discover and to connect to a CPPS. That implies the detection of available communication interfaces of the appropriate production system. The communication protocol OPC UA can serve as an example regarding this aspect. OPC UA offers a mechanism called UA Discovery that allows to detect available OPC UA server connection points and its associated security configuration. The discovery server provides all registered connection points. However, it is presumed to know the address of the discovery server. Hence, a complete autonomous discovering of communication interfaces is not possible. To extend the discovery approach, the discovery functionality has to be integrated in an overlying function. That overlying function searches in a defined IP range for commonly used ports in the automation area to detect available discovery servers.

Regarding the discovery functionality it has furthermore to be considered that communication interfaces in the area of production systems are various. The variety arises mainly out of the long life cycles of production systems and the need to support every of these communication mechanisms as long as these production systems are in use. Hence the discovery function needs to be adopted for different communication interfaces commonly used in the automation area.

Having detected the available communication interfaces of a production system, a gateway (CPPS Enabler) that is responsible for accessing and transmitting data of the production system can connect to the most applicable communication interface.

Identification of the most applicable communication interface depends on the following criteria:

- Performance: In case of the necessity to access a big amount of data or data in short cycle times, performance issues have to be considered. Even though most of the communication interfaces are IP-based, there are differences in the transmission behavior.
- Security: Applications that have to ensure data integrity and security require the establishment of a secure connection and, therefore, choose a communication interface with the strongest security configuration.
- Functionality: Communication interfaces are offering different levels of functionality. Functionality ranges from simple data access over data change notifications up to method execution. An application can choose a communication interface providing the amount of functionality that is matching the applications requirements.

One idea of Industry 4.0 is that all participants can connect and exchange data and information with each other. However, that assumes that all participants know about the existence of other CPPSs and their communication mechanisms. For this reason, the concept of a CPPS Information Server as an overall control center is suggested.

First of all, it has to be considered that CPPSs differ in their functionality as well as in their communication channel. A communication channel is the combination of a communication interface and, additionally, of the semantical definition, i.e. how data and functionality can be accessed via the given communication interface. If this precondition is not fulfilled, CPPSs are not able to access data and functionality of each other, although they are connected over the same network.

To encounter this problem, the CPPS Information Server provides information about the communication channel as well as the available functionality of each connected CPPS Enabler. The information provided by the CPPS Information Server can be classified in the following categories:

– Required parameters are the minimal set that is necessary to establish a connection to the CPPS Enabler, e.g. the address and protocol of the available communication points
– Optional parameters can individually adjust the characteristics of a connection (e.g. add encryption mechanisms).
– Client-specific parameters contain information which functionality is accessible by the CPPS Enabler that can be used by other CPPSs.

Based on the suggestion of the CPPS Information Server, a basic sequence to illustrate the relation between CPPS Information Server and CPPS Enabler is shown in Fig. 4.

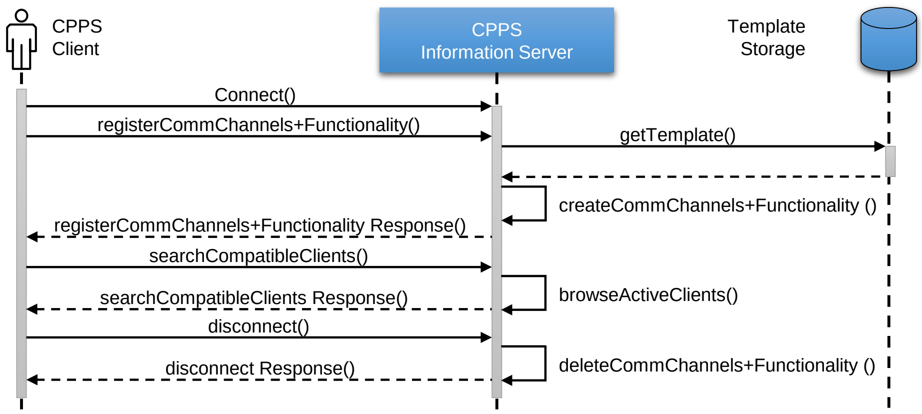

Fig. 4 Announcement of CPPS Enabler to CPPS Information Server (sequence diagram)

After the CPPS Enabler has established a connection with the CPPS Information Server, it registers its communication channel and functionality to the CPPS Information Server.

The available communication channels and functionality of the CPPS Enabler are specified by pre-defined templates. The pre-defined templates include the above mentioned required, optional and client-specific parameters. By calling the method 'registerCommChannels+Functionality' through the CPPS Enabler, the CPPS Information Server retrieves the desired templates from the storage and creates and deposits an information set including available communication channels and functionality for this client.

Knowing the set of templates, any CPPS is able to search in the CPPS Information Server for other compatible CPPSs. Compatibility refers to the set of registered functionality and the accordance of at least one communication channel that can be used to establish a connection.

Whenever a CPPS Enabler disconnects from the CPPS Information Server, the server deletes the deposited information set. Consequently, the CPPS Enabler is not available anymore and will re-register its functionality at its next connection.

In conclusion, the concept of a CPPS Information Server can be compared to a dynamic telephone book whose entries appear and disappear depending on the opening hours of the listed shops. What type of services the listed shops provide is defined through templates and will be dicussed in the next subsection.

3.2 Functionality Templates and Applications

Most functionality in the area of production systems can be distinguished between two groups. The first group includes all kinds of functionalities that are connected to data acquisition. The acquired data can be used for quality assurance applications, production analysis applications, applications for error detection and many more use cases. The second group includes functionality that is actively influencing the production system. Applications that use this functionality, e.g. HMI systems, are able to configure or command a production system.

The template for each functionality is pre-defined to assure a standardized semantic. The templates can be used for developing a CPPS Enabler to attach the existing production system to the Industry 4.0 factory. After having discovered and connected to the production system in the CPPS Enabler the functionality has to be selected which should be provided to the CPPS Information Server. The required data of the functionality and the existing data extracted from the production system through the open communication channel have to be merged. Based on this, two applications can communicate over communication channels and defined functionality with each other.

4 Validation

The concept of the CPPS Enabler has not been realized as a whole yet. So far only parts have been validated in different projects as described in the following sub-sections.

4.1 Discovery and Connection

The discovery and connection functionality of the CPPS Enabler is implemented in the 'Evergreen' project. 'Evergreen' is a framework for the development of vendor-independent graphical user interfaces. The 'Evergreen' application realized by the 'Evergreen' framework is divided into two parts: the graphical user interface, called 'Evergreen' GUI, and a communication gateway, called 'Evergreen' Server that implements different communication mechanism subordinated to an abstraction layer to connect to different control and automation systems in a standardized manner. 'Evergreen' implements the described concept of discovery functionality. Discovery is once realized for the communication protocol OPC UA that is used for the communication between the 'Evergreen' Server and the production system control and, additionally, for a SOAP communication interface that is used for the communication between the user interface and the 'Evergreen' Server. The discovery functionality for OPC UA is based on the UA Discovery functionality but extended by the automatic search for the discovery server communication point by scanning a given IP range and commonly used ports in the automation area. The discovery functionality for the SOAP interface is an autonomous mechanism: while scanning the given IP range and ports like the OPC UA discovery functionality, the SOAP discovery function sends out SOAP requests knowing possible responses. When detecting a response that is unique for the 'Evergreen' Server, it identifies this scanned station as a regular communication point of an 'Evergreen' Server.

4.2 Gateway (CPPS Enabler)

The concept of the gateway is a main part of the CPPS Enabler as it is the key module to enable production systems to be part of an Industry 4.0 factory, even though they are not prepared to be a CPPS. A sophisticated gateway in addition to the 'Evergreen' Server has been realized in the project 'Cloudplug' [11]. A 'Cloudplug' is a gateway realized on a standard hardware platform, which can be used in the production environment. Its main task is the transmission of production system data into the cloud. The cloud gateway implements an OPC UA Client for accessing the production system control and a mechanism to push the accessed data into the cloud target.

4.3 CPPS Information Server

The concept of the CPPS Information Server of the CPS Enabler is realized in the 'pICASSO' project [12]. The realization is based on an OPC UA Server whose address space can both be accessed via an OPC UA Client and a scripting interface.

To connect to the CPPS Information Server, the OPC UA Client needs to have certain information concerning this process. Based on secure connections, there is an authentication method (e.g. by certificate) to grant access. The credentials for authentication have to be recognized or even created by the server which is going to generate a namespace for a new client at this moment. The structure of this namespace is defined by the concept of the CPPS Information Server and is identical for each client. It provides nodes to store values for basic configuration information as well as the range of functionality of one client. Based on templates the CPPS Information Server is able to expand the client-specific namespace by client registered functionality. Than the client can use this up–dated namespace to publish the data of its functionality. This expansion of the client namespace with functionality templates by the server is realized over the scripting interface. These scripts started event-triggered when a new client connects to the CPPS Information Server.

The behavior is used in the 'pICASSO' project not only to dynamically register and unregister the functionality and communication channels of one client but to exchange data directly within the OPC UA Server that is used as CPPS Information Server. The templates of the CPPS Information Server created for the 'pICASSO' project are known to all project partners. Therefore each client which is developed by a partner knows how to access the functionality of a certain client of another partner that publishes compatible data.

4.4 Functionality Templates and Applications

The project 'Cloudplug' uses a template to define which communication interface has been selected to connect to the production system. Further the template defines which kind of communication channel is used to communicate with the production system and how the communication channel characteristics towards the data-consuming application are configured. As shown in Fig. 5 one goal of the project is to always provide a communication channel to the user of the 'Cloudplug' that meets his requirements at its best.

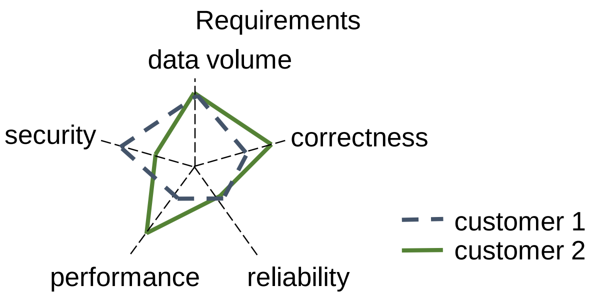

Fig. 5 Requirements of different customer

Further, the template used by the 'Cloudplug' specifies which data is exchanged between the production system over the 'Cloudplug' and the data-consuming application. With the information provided in the template, the sink of the data can dynamically create the received data structure and save the data in a data base for analysis.

5 Conclusion

An Industry 4.0 factory is an environment in which all participants are interconnected and sharing information with each other. Herefrom arises the advantage that needed information is fast accessible and any operations and demands can be invoked right away. This approach is known in the automation area as Cyber Physical Production System (CPPS). In a CPPS environment intelligent production systems are linked with each other for easy and fast data exchange. However, it can be stated that only a small percentage of the installed production systems are CPPSs, thus are cross-linked systems.

For this reason this paper presents a holistic approach to how the stock of non-capable production systems can be enabled to be part of an Industry 4.0 factory. The approach consists mainly of three parts (discovery of and connection to production systems, data provision of production systems, connection between production systems): First of all, a holistic discovery functionality is proposed that allows detecting available production systems and their communication interfaces. The extended discovery functionality is depicted at the example of two communication protocols, SOAP and OPC UA. Next, the main CPPS Enabler is a gateway which adopts the above mentioned discovery functionality and, therefore, allows discovering and connecting to available production systems. Additionally, the CPPS Enabler allows pushing data to a connected application. The concept of the CPPS Enabler has been validated with the standardized communication protocol OPC UA. Finally, a CPPS Information Server is proposed which serves as a base for informing about existent connection points to available CPPSs. Only a global information center is capable to inform about the existence of CPPSs. The CPPS Information Server is illustrated as an the example of an OPC UA based architecture.

This approach allows the assemby of consistent data links within production systems and associated software applications. Data consumers or inquirers can be systems such as cloud applications, HMIs or MES.

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