Cyber Physical Systems in the Context of Industry 4.0

N. Jazdi (IEEE member)
Institute of Industrial Automation and Software Engineering
University of Stuttgart
Stuttgart, Germany
Nasser.Jazdi@ias.uni-stuttgart.de

We are currently experiencing the fourth Industrial Revolution in terms of cyber physical systems. These systems are industrial automation systems that enable many innovative functionalities through their networking and their access to the cyber world, thus changing our everyday lives significantly. In this context, new business models, work processes and development methods that are currently unimaginable will arise. These changes will also strongly influence the society and people. Family life, globalization, markets, etc. will have to be redefined. However, the Industry 4.0 simultaneously shows characteristics that represent the challenges regarding the development of cyber-physical systems, reliability, security and data protection. Following a brief introduction to Industry 4.0, this paper presents a prototypical application that demonstrates the essential aspects.

Keywords—CPS, Industry 4.0, Cloud Technology, Internet of Things

I. Introduction

Cyber Physical Systems (CPS) are automated systems that enable connection of the operations of the physical reality with computing and communication infrastructures [1], [2], [3]. Unlike traditional embedded systems, which are designed as stand-alone devices, the focus in CPS is on networking several devices [3]. CPS goes with the trend of having information and services everywhere at hand, and it is inevitable in the highly networked world of today.

Embedded systems, such as smartphones, cars and household appliances are the inseparable part of modern life. Nevertheless, it is possible to control only a few of them remotely. It is very desirable if we could turn on the heating system on the way back home, so that the house is already warm upon arrival. Coffee machines can start brewing the coffee in the morning while still in bed, in order to shorten the waiting time. This remote access to process data can also be used for the maintenance of these systems. The information from the remote diagnostics helps the service personnel bring the right tool and spare part. The system can order its spare parts by itself with the help of a corresponding communication infrastructure.

Even today, there are many fields of applications for CPS, such as medical equipment, driving safety and driver assistance systems for automobiles, industrial process control and automation systems, assistance systems for controlling the power supply in terms of optimized use of renewable energies.

A CPS consists of a control unit, usually one or more microcontroller(s), which control(s) the sensors and actuators that are necessary to interact with the real world, and processes the data obtained. These embedded systems also require a communication interface to exchange data with other embedded systems or a cloud. The data exchange is the most important feature of a CPS, since the data can be linked and evaluated centrally, for instance. In other words, a CPS is an embedded system that is able to send and receive data over a network. The CPS connected to the Internet is often referred to as the "Internet of things".

II. Industry 4.0

The term Industry 4.0 was manifested for the first time at the Hannover Fair with the presentation of the "Industry 4.0" initiative [4]. Following the first Industrial Revolution "Mechanization" as a result of the invention of the steam engine, the second "Mass production" with the help of electricity and the third "Digitization" by the use of Electronics and IT, this marks the dawn of the fourth Industrial Revolution through the use of cyber physical systems (CPS) and the Internet of Things and Services. In the field CPS, Germany has a leading role and can draw on almost 20 years of experience. The integration of cyber technologies that make the products Internet-enabled facilitates innovative services to achieve, among other things, Internet-based diagnostics, maintenance, operation, etc. in a cost-effective and efficient manner. Moreover, it helps realization of new business models, operating concepts and smart controls, and focusing on the user and his or her individual needs. The goal of the Industry 4.0 is the emergence of digital factories that are to be characterized by the following features [5]:

A. Smart networking

Automated systems and equipment, internal logistics systems and operating supplies are consistently intermeshed with help of cyber technology, such as wireless and wireline communication services, smart actuators and sensors and telecommunication technologies. This gives them a direct access to the higher-level processes and services. This gives rise to completely new innovations with added value and

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business models that support optimal resource utilization and smart control.

B. Mobility

Mobile devices such as smartphones and tablets have already made inroads in industrial automation. They provide a temporally and spatially independent access to processes and services of the automated systems. This creates a new dimension in the diagnostics, maintenance and operation of these systems.

C. Flexibility

Industry 4.0 allows a high flexibility both in the development, diagnostics and maintenance as well as in the operation of automated systems. In the development of these systems, you can select the best offer from a large pool of suppliers of components, modules and services. The diagnosis can be carried out partly by the user. Here, the access to "Big Data" helps the automation. The information can be retrieved on-demand, intelligently used and linked so that an automated diagnosis can be achieved. Spare parts can be ordered automatically at the cheapest manufacturers, thus counteracting the problem of skills shortage.

D. Integration of customers

With industry 4.0 it will be possible to customize the products to the specific and individual needs of customers. Automated systems of the 21st Century adapt to the needs and abilities of users of all age groups. A modern ticket vending machine provides, for example, various options for operation, so as to allow its use by people with different disabilities. Automated systems will support people in all situations and assist them in different stages of life, so that they remains sustainable, healthy and mobile.

E. New innovative business models

Production in the future will be distributed and flexible. New development processes, infrastructure and services will arise. The products will become modular and configurable so that the product can be adapted to the specific requirements.

Industry 4.0 brings many challenges that need to be extensively studied in the research. Many questions arise: How can the reliability and safety of these products, whose development is distributed, be determined and how are they certified? Another important task is the subject of data protection and security. It must be ensured that one's own know-how and privacy are protected and remain unaffected. To this end, new concepts and technologies that allow a trustworthy cooperation of many groups and units are needed. Furthermore, ethical, legal and social issues will have to be redefined.

III. COMPATIBILITY OF CPS WITH INDUSTRY 4.0

An interface to the Internet or a similar network is necessary to extend an embedded system, which is usually made of control units, sensors and actuators, to a CPS. In order to achieve this, there are various approaches that have been investigated in the context of this development and will be briefly presented below:

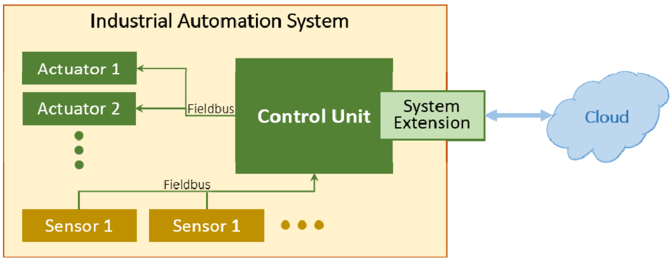

Fig. 1. Direct system control

A. Direct system extension

In this individualized solution variant, the embedded system, if not available yet, is extended by a communication interface to access the Internet and the software is changed accordingly to enable communication over the internet, e.g. with the cloud. To this end, all the sensor signals of the system must be transmitted by the control unit to the cloud. Methods should be implemented to control the actuators via Internet. Figure 1 shows the arrangement of this solution variant.

B. System expansion by microcontroller board:

In this solution variant, a microcontroller board that has the various communication interfaces such as CAN, UART, WLAN, Ethernet, etc. is developed. This is connected to the embedded system and takes over the communication to the Internet or a cloud. However, this requires uniform interfaces, over which the board can be connected to the embedded system. The software of the board must be adjusted separately to each system. However, the entire code need not to be rewritten every time, but only the mapping is to be reworked accordingly so that it is relatively easy to transfer this variant to other systems. This arrangement is demonstrated by the following figure:

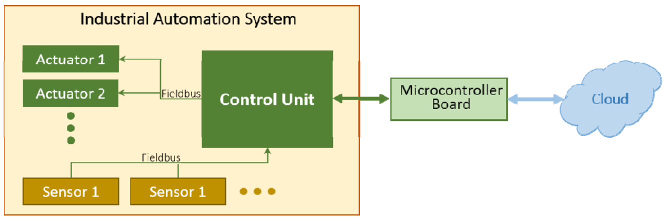

Fig. 2. System extension by microcontroller board

C. Extension by smart actuators and sensors:

Traditional embedded systems usually consist of a control unit, several sensors and actuators, which are connected to the control unit via field buses. The control unit assumes the signal processing function in such systems. Should smart sensors and actuators be used now, the sensors take over even the processing of the signal and the actuators independently check their current status, and correct it, if necessary. These sensors transmit their data to a central control unit, e.g. via field buses. In order to extend such a system to a CPS, it would be conceivable to also send data from the sensors and actuators, which are sent via the field bus, to a cloud, and process it there. However, a high data volume is the result here and the cost of smart sensors and actuators must not be underestimated. Figure 3 shows the extension.

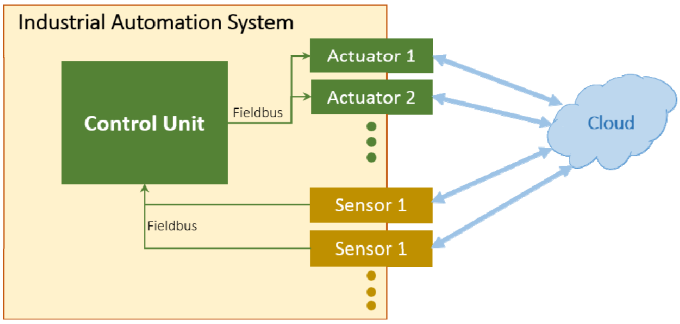

Fig. 3. Usage of intelligent actuators and sensors

IV. Prototypical Implementation of an Industry 4.0 Application for an Industrial Coffee Machine

A scenario for the development of CPS has been developed at the Institute of Industrial Automation and Software Engineering (IAS) of the University of Stuttgart. In the process, the industrial coffee machine at the IAS, an embedded system, was extended to a CPS. A microcontroller board was used as a gateway to the cloud for the extension. The coffee machine was connected to the cyber world with the help of hardware add-ons. Various services such as remote diagnostics or a software update can be realized via the cloud now.

The variant "extension by a microcontroller board" is selected for the implementation of the prototype. This variant has the advantage that it is transferable and does not require rework of the whole system. The infrastructure had to be designed and implemented for the cloud via which the communication should take place. This requires an access point, with the help of which the microcontroller board could dial into a network. A database was used on a local computer as a cloud and tables were set up for the storage of the communication.

A website and a prototypical Android app were created for operation of the CPS. These user applications are able to exchange data with the industrial coffee machines. To this end, you can access the tables of the cloud. Figure 4 shows the system configuration.

The microcontroller board is now capable of intercepting the CAN communication that is also used internally by the coffee machine, and saving all messages in the cloud. Moreover, data can be stored in the cloud messages to be sent to the coffee machine and forwarded from there to the system with the help of the board.

Benefits of the transformation of a coffee machine to a CPS arise during maintenance. Thus, it is possible to remotely determine which component is defective or which ingredient has been used up, so as to bring the appropriate spare parts or ingredients for maintenance. The configurations can also be changed remotely in this way. Products can also be customized. Thus, for example, the temperature and the strength of the coffee are automatically customized to the needs and preferences of the user when ordering via an app.

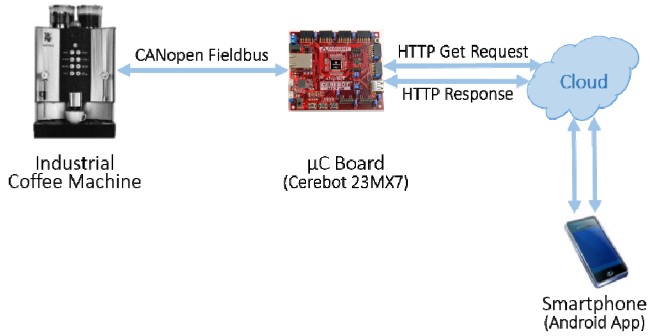

Fig. 4. System architecture

There will also be a Facebook page for the coffee machine and others of its kind in the future, so as to network the coffee machine with the cyber world even better. In this way, it will be possible to find the nearest coffee machine, which can deliver the desired product.

V. Summary and Outlook

This article described the significance of Internet of Things and Services and their important role in our future professional and everyday life. It illustrated that Industry 4.0 has already been started und will affect our life and the future business model expressly. It demonstrated the importance of Industry 4.0 within an application which is realized for an industrial coffee machine at the Institute of Industrial Automation and Software Engineering.

The future works concentrate on realization of a distributed remote application based on software agents. This application will be executed on different industrial automation systems in Germany, Brazil and Ukraine. On this way a distributed production line should be demonstrated.

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