INDUSTRY 4.0 for VET

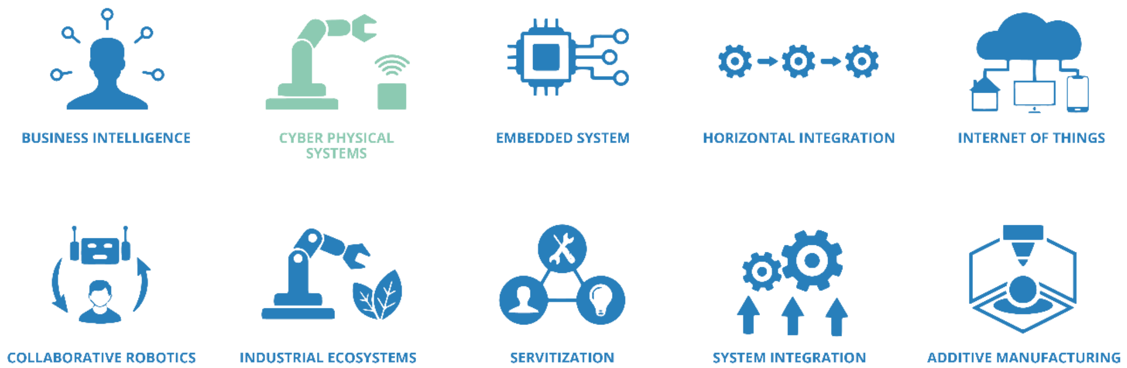
6. CYBER PHYSICAL SYSTEMS

6.1 The topic

The first introduction

Big Data is the oil of the future - data is both the most important resource and the lubricant in the digitalised industry 4.0, in which the physical world is to be connected with the digital world. This sounds a bit like science fiction - but it is already present!

Because the most important building block of Industry 4.0 is already in use: Cyber Physical Systems are precisely the technical marvels that can connect the world you can see with the virtual world of data and information.



Cyber Physical Systems are essentially the sensory organs of information technology, attached to future-proof machines and products. They collect impressions and processes of their environment and subsequently provide exactly the data that makes the production process ever more efficient and better.

If Industry 4.0 is the future of the manufacturing industry, then Cyber Physical Systems are the cornerstone. This chapter will introduce you to exactly this basic building block.

The practical relevance - for this you will need the knowledge and skills

Cyber Physical Systems is one of the most important function carriers of Industry 4.0, with an enormous field of application. The knowledge you learn here can help you in industrial production and logistics, but also in medical, traffic, defence or environmental technology and many other fields - in principle, wherever Industry 4.0 is applicable.

Learning objectives and competences at a glance

In this chapter you will learn to understand Cyber Physical Systems and how to classify them in Industry 4.0. For this purpose, you will first be introduced to the terms and general functions. Furthermore, the technological basics are discussed and the areas of application and some concrete examples in industrial use are introduced. A reference to current problem areas will round off your basic knowledge of the topic.

Learning Objectives
Cyber Physical Systems (CPS) as part of Industry 4.0 can be perceived and understood.
Know the technological requirements and components of CPS and be able to link them together.
Get to know the application areas of CPS in industry, society and individual use.
Know and be able to weigh up the opportunities and risks of CPS.

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6.2 Cyber Physical Systems in Industry 4.0

In the modern world everything wants to be networked. The smartphone with the car, the coffee machine with the alarm clock, the blinds with the sunrise, the smartwatch with the health app and best of all, the refrigerator with the digital shopping list. Why is that? To make life more comfortable, better and a little bit more efficient.

Everyday devices exchange information with each other, send data and information back and forth and thus control each other in real time - a kind of "automation" of everyday life is to be achieved in this way, which automatically adapts to external needs.

These processes are essentially called the "Internet of Things" (IoT). Devices are interconnected, exchange and control each other.

Definition

Internet of Things

… REFA (the German Association for Work Design, Business Organisation and Corporate Development) defines the term Internet of Things as
"the increasing networking of devices, sensors and other equipment using an IP network. The aim is to ensure that physical things that have their own status information provide their data for further processing in the network."

This is exactly what Industry 4.0 wants to achieve - especially in the manufacturing and logistics industry, true wonders of efficiency and cost savings can be achieved with a properly implemented Internet of Things.

Industry 4.0 simply means that all units involved in a production environment are connected in a constant exchange via a network in real time. This includes production plants and logistic systems, but also the products to be manufactured (or their components) as well as people.

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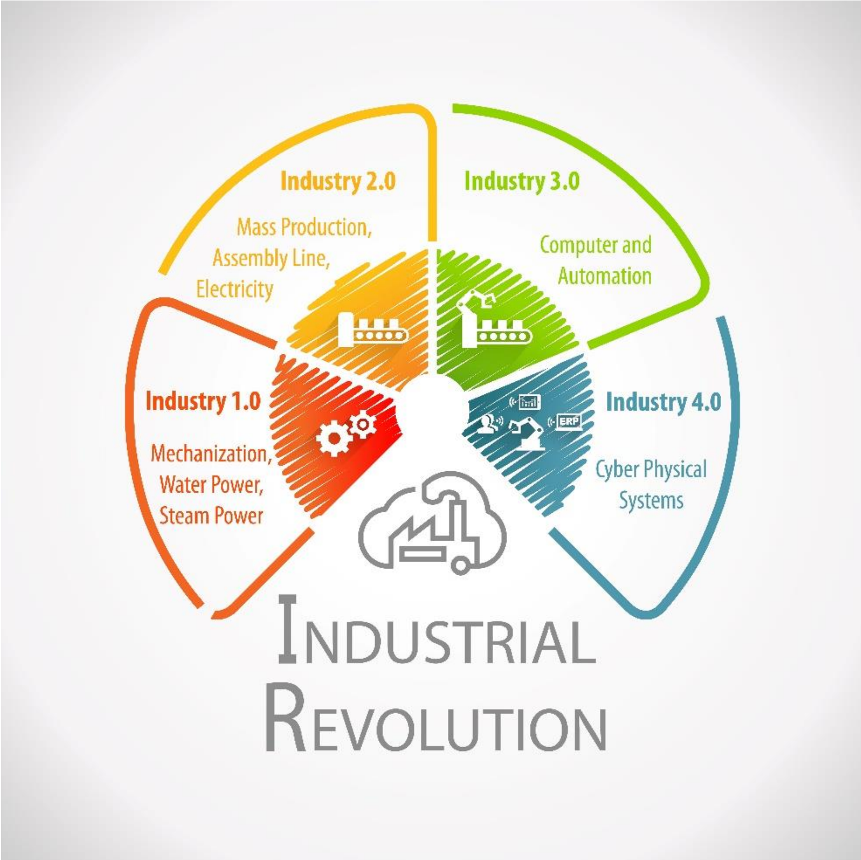

For this exchange three things are needed, first and foremost: data, data and again data. And this brings you back to the main topic of this chapter: Cyber Physical Systems (abbreviation: CPS) - are nothing less than the foundation of Industry 4.0. Because CPS deliver, you guessed it: data.

Excursus

Data, information and knowledge - the world of CPS

Data is good, but actually useless - if it is not processed in a meaningful way. In a networked (industrial) world, data is the raw material, but the actual usable resource is actually the knowledge gained from the data. Since CPS is much about data, it is important that you understand the differences.

Data are **simple signs**, symbols and numbers generated by a system, for example a machine: "1992" - not much can be done with that yet.

Information arises when this **data is assigned to a context**. Knowledge about a possible situation arises in the process. For example, an industrial scale outputs one unit: "1.992 grams" - so you can do much more with the value. However, the information still has very little value, because you do not know where to put it.

Now you still need the **facts or the product** to which you can assign the information: "1.992 grams of adhesive are needed to join two electronic components. This way, you first know what is needed for what, and can make an informed decision or solve a problem.

For Industry 4.0 to work, the physical world (i.e. the production environment with all machines and products) must be connected to the digital world (network and software). This is exactly the task of CPS.

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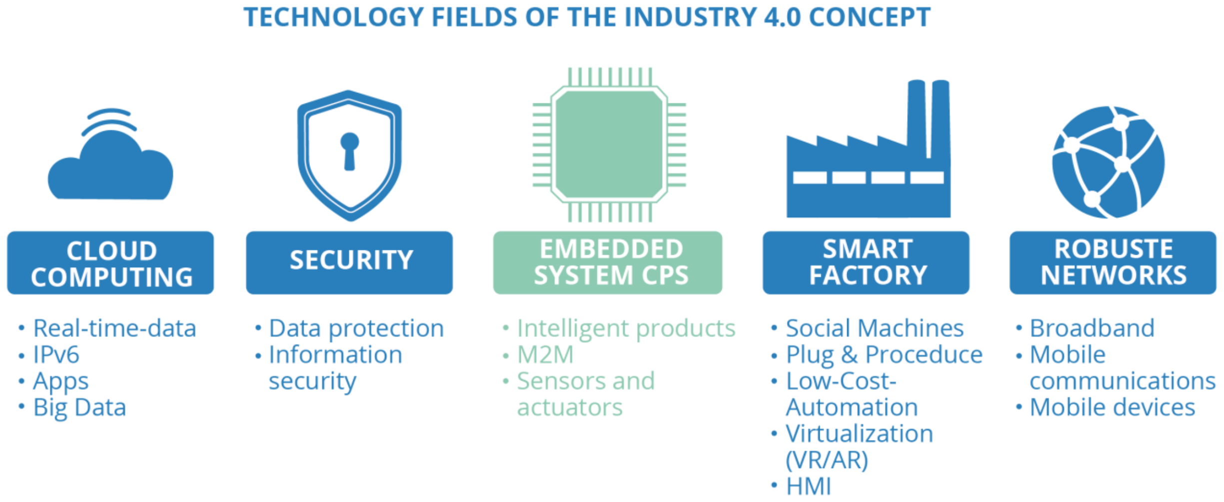

This is done by **combining mechanical and electronic components with information and software components**. These then communicate via a data infrastructure (e.g. Internet). Two basic tasks are processed in particular:

- Generation and exchange of data
- Monitoring and control of infrastructure

Important

"Embedded Systems" and CPS

The attentive reader will have noticed it in the diagram above. Embedded Systems are mentioned in the same breath as CPS. What is going on there?

Embedded systems are the technological predecessor of CPS and comprise classic measurement and control technologies. Here, too, the digital ("cyber") world is connected with the mechanical ("physical") world - but each unit remains on its own. CPS are now a whole group of such devices, connected to a network and in constant exchange ("systems" - hence the name Cyber Physical Systems).

However, the essence of CPS is not that it takes on these tasks, but HOW FAST. Because in an Industry 4.0 production environment (also called "Smart Factory") there is only one credo and that is: Full speed ahead. For a completely networked production environment to benefit from this network, the data must be read out in real time, processed into information and knowledge and then the production process must be adapted accordingly.

Static and mobile devices, equipment and machines (such as conveyor belts or robots) and thus networked objects are then controlled in real time. This can lead to an immense increase in production efficiency, reduce costs and optimise complex procedures and processes in their handling time.

Remember

Cyber Physical Systems (CPS) are the technological basis of Industry 4.0 or the Internet of Things. This is about:

- the generation and evaluation of data in the production and further processing
- and the management and control of the infrastructure in a production environment

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in real time.

For this purpose, the physical world (production facilities, logistics systems, machines etc.) is combined with the digital world (software) via a data network (Internet). This is done by connecting mechanical or electronic components with software or information technology components. These connections are CPS.

6.3 The technologies behind CPS

CPS are a network of many different technologies that serve to connect the real world with the virtual world. In more professional technical terms, this refers to a network of mechanical systems that are controlled and monitored by a computer-based process.

The various technologies are used to **perceive measure** and **name context-dependent processes** - and to derive and implement the appropriate approach from these. This is done across machines via a network.

Of course, the right technology has to be found - the good thing is that it has already been invented and is in use! CPS are the backbone of Industry 4.0, especially because their developments made a networked production environment theoretically conceivable in the first place.

Now things are getting a little complicated: The technologies in use actually form systems themselves. The "embedded systems" discussed above as part of CPS, for example, are not called this way for no reason - CPS can therefore be seen more as a kind of a "super-system" of smaller subsystems.

The following example should explain this better:

Example

A system of systems

An office building has installed a separate system for fire protection in each of its rooms. Each of these systems consists of a sensor that detects an outbreak of fire, an alarm that sounds in case of fire and a fire extinguishing system on the ceiling.

Suppose the dust bin starts to burn in room A - the sensor detects this, the alarm sounds and the fire extinguishing system starts to spray water. Room B on the next floor, however, does not yet notice this.

But if the systems in room A and room B are now connected to each other, sensor A can report to sensor B: "We're on fire!" Sensor B can now promptly decide to trigger the alarm so that this room is also evacuated, but not to activate the fire extinguishing system - because there is no fire in room B (yet).

Thus, a context-dependent decision was automated across the system and executed in real time.

The required technologies can be divided into three core technologies:

- Control
- Communication
- Computation.

The following diagram shows how these are connected:

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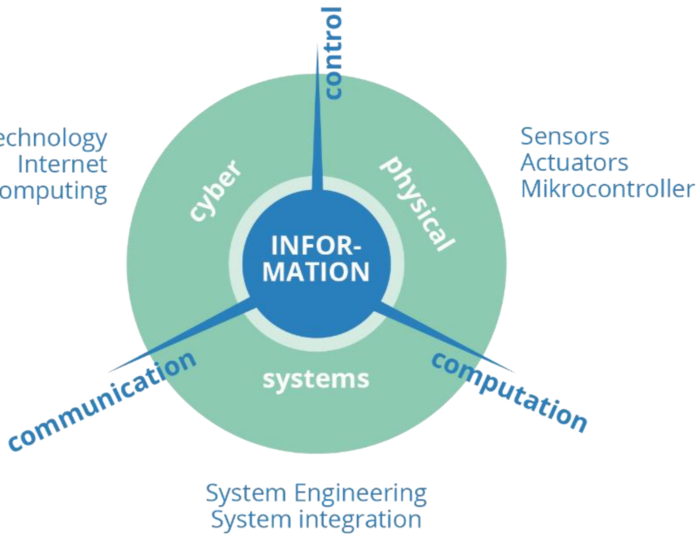

Of course, such a model is of very little use if you do not understand the individual components:

Physical elements - between control and processing

These are essentially the embedded systems, i.e. subsystems, mentioned above. These consist of:

- **Actuators:** These are mostly components of drive technology - this does not necessarily mean that something is moving, but that at least something is being moved. For example, a robot arm that turns a component over needs a motor to move it. It is essential that such an actuator can be controlled by an electrical signal.

- **Sensors:** These are the counterparts of the actuators - they "sense" their environment according to physical or chemical properties (e.g. pressure, heat, brightness, etc.) and represent these by means of a measured variable (e.g.: temperature of the work piece = 10 degrees Celsius). This measured variable can be further processed as an electrical signal.

- **Microcontroller:** The brain of an embedded system - also called a "chip" - the microcontroller performs computing tasks like a computer. It monitors, controls and transfers processes automatically, depending on its programming.

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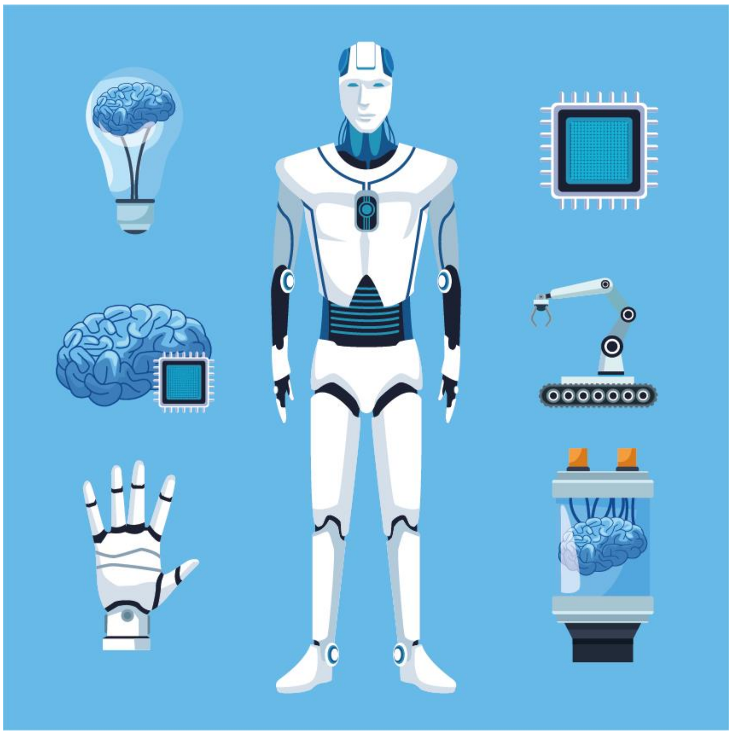

Behold: actually, the combination of physical elements is nothing more than a robot! It senses its environment with its sensors, moves and acts accordingly with its actuators, and it acts exactly as dictated by its microcontroller. It is important that it can react dynamically to its environment and that actions and measurements can be carried out simultaneously.

Cyber elements – between control and communication

The cyber elements serve the virtual world of data transfer and data processing. Here, data becomes information and information becomes knowledge. One thing above all is needed for this
- a proper network technology!

- **Internet:** With such amounts of data in real time, a super-fast broadband Internet must be available. But new mobile phone standards such as 5G can also help with data transfer.

- **Address space:** Each element also needs its own Internet address. New, more comprehensive Internet protocols such as IPv6, which allow many more different Internet addresses, can ensure that each element has its own unique, unambiguous address.

- **Cloud-Computing:** In order to process the amounts of data quickly, you need a lot of computer power - you can access external servers, which take over computing power and provide additional storage space for databases.

Data must arrive, be calculated and put into context in real time. Based on this knowledge, a decision must now be made on how to proceed in the production environment (remember the fire alarm example) and this must be forwarded to the appropriate subsystems. These then implement - and then everything starts all over again.

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Systemic elements - between communication and processing

After all, this is about the connection and application of a large system - that is rather theoretical. In this respect the discipline of so-called "systems engineering" is helpful. This is where the demands on the CPS are defined and appropriate measures are taken:

- **Request:** What is to be done anyway? Which machines have to be set up in relation to each other so that they can work together (e.g. in a production line).

- **System integration:** Which interfaces do the individual systems need to be integrated into the larger one? Which software is used?

- **Quality assurance:** How are errors analysed? How are they repaired? What is the fault tolerance of a single subsystem compared to the whole system?

Remember
CPS generate data, information and knowledge from physical processes. These are processed in real time, dynamically control processes and are connected via a network. This requires three core technologies: Control, Computation and Communication. These are fulfilled by the following technological modules and concepts: -Physical elements: actuators, sensors and microcontrollers -Cyber elements: Network technologies like the Internet -Systemic elements: A conceptualisation of the overall system in accordance with the requirements with "systems engineering CPS are nothing more than super systems of different subsystems with these technological building blocks.

6.4 Application areas of CPS

The fields of application of CPS are actually boundless - apart from purely industrial (but rather future-oriented) fields of application such as intelligent manufacturing and production environments in various industries ("smart factories"), CPS are already being used in other fields. These include intelligent power grids ("smart grids"), electronic health, age-appropriate assistance systems, but also intelligent traffic monitoring systems or automatic early warning systems in disaster control.

Some examples should make you aware of the integration of CPS already taking place in the world:

Industry 4.0 – Smart Factory

Imagine that there is a production environment that controls itself autonomously, knows what to do depending on the product and component, and also independently makes its processes more efficient. That would be something! At the same time, this would be called the "final level of Industry 4.0", so to speak.

In fact, some companies are already busy trying to integrate CPS in their industrial production. The automotive industry, in particular, is already using CPS in some cases to automate work steps. However, the industry is still far away from complete networking, as not all the necessary technologies have been sufficiently researched yet.

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Smart Factory is already a big topic in the automotive industry, as you can see in the graphic above. So, if you want to make a name for yourself in the automotive industry, you know what you or your company have to deal with!

Example

Maintenance of machines

One of the biggest cost items in industrial companies is the maintenance of the machines. CPS already help industrial companies to save costs here. Take a look at the following comparison:

Maintenance without CPS

Here, either reactive or preventive maintenance is carried out.

Reactive maintenance: Production simply continues until the machine stops working - this has extremely low maintenance costs at the beginning, but you risk long downtimes and high replacement costs.

Preventive maintenance: Regardless of the actual failures, maintenance is carried out at regular intervals, i.e. parts or entire machines are replaced - this is quite safe, but expensive in the long run.

Maintenance with CPS

The machines can determine themselves when maintenance would be due via their sensors. As a result, wearouts can be detected very quickly and maintenance can be carried out more efficiently.

In addition, possible failures can be "predicted" and reacted to or prevented accordingly.

Smart Grid - the Internet of Energy

Even a power grid can become "intelligent" with CPS. Why is this even necessary? Nowadays, electricity is being generated in an increasingly decentralized manner. This means that in most cases (especially in rural areas) there is no longer a single, central source where the electricity comes from, but many smaller sources such as wind turbines, photovoltaic systems, biogas plants, etc..

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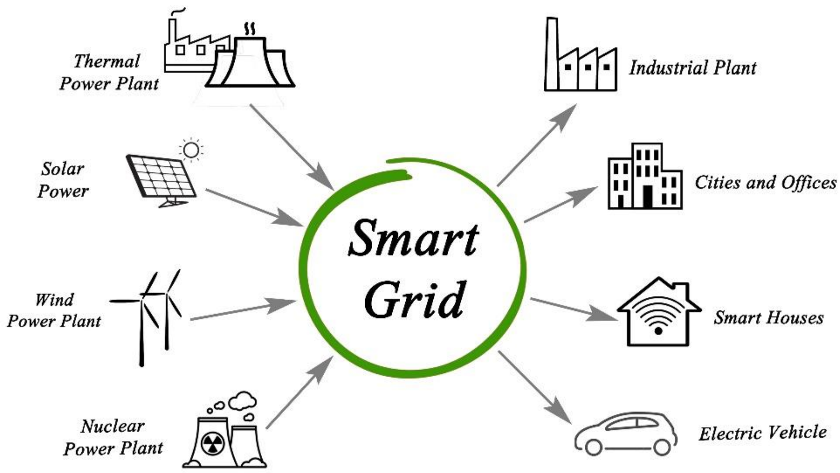

This is complex and requires a system - especially in the area of load control (i.e. which device is currently using how much power). It's a good thing that CPS exists. It allows all players in the electricity grid (generation, storage, supply and consumption) to exchange information with each other fully automatically and in real time.

As a result, devices communicate to the power grid how much power must be generated and made available. These devices react, can select the source accordingly and, in the event of an overload, can also block the current.

Civil protection, military defence and transport

CPS can also be real life savers. CPSs, which can detect and warn of natural disasters such as tornadoes or earthquakes days in advance using appropriate sensors, have become indispensable in evacuation situations. CPS can also provide assistance in environmental issues - for example, they can automatically detect soil conditions and draw conclusions about plants and animals in the vicinity based on changes in these conditions.

This is not so different from industrial applications: After all, here too, efficiency is to be increased and the time and costs required reduced.

But CPS are also used militarily. Modern air defence systems and military drones are networked with each other using such systems in order to be able to react quickly and in a coordinated manner.

Traffic also benefits from CPS and is actually an obvious example of real-time system regulation. Traffic jams, accidents and road damage are registered in real time and appropriate diversion measures or road closures are implemented - thus relieving traffic and preventing further congestion or accidents. Even completely autonomous vehicles are conceivable in this way. However, this is still a dream of the future, as the corresponding road infrastructure has to be built first.

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E-Health

In addition to public and corporate applications, every single person can also benefit from CPS on an individual basis. One example is the keyword e-health (electronic health, i.e. the electronic processing of health data).

Prevention, monitoring, diagnosis, treatment and management can be linked electronically. The electronic health file in Austria (also called ELGA) is part of e-health, as are online pharmacies or smartwatches and fitness trackers (devices worn on the wrist that detect health data such as pulse rate or register falls).

Example
A patient is diagnosed with diabetes. He is given a digital blood collection device to monitor his blood sugar regularly. This is linked to his smartwatch, which uses the data transmitted to make recommendations for action with regard to sport, nutrition and medication. In an emergency, the smartwatch reacts and can autonomously alert the rescue. When the rescue arrives, the paramedic is informed via the smartwatch that the patient is a diabetic. The paramedic can then take the appropriate measures quickly.

Another area of application is (age-appropriate) technological support - Ambient Assisted Living

This is essentially about people who need support in some way for a self-determined life - whether due to age-related problems or physical limitations.

CPS are used here to create technologies that can respond to people's specific needs. Support is not only provided to them, but also to nursing staff and relatives for example.

For example, homes can be designed in such a way that voice can be used to control heating, operate blinds or activate lighting. This could also be done automatically, e.g. by switching off the lights and the stove whenever the person leaves the apartment. This would save some manual steps for older people. In the event of a fire hazard, the fire brigade can be automatically notified in addition to the alarm.

A point of criticism: The operation of such systems must, however, be relearned beforehand - e.g. which voice commands must be used. This can be difficult for disabled or elderly people. So, special attention must be paid to the simplicity and user-friendliness of these systems.

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Remember
CPS offers a number of application areas, some of which have already been implemented, others are planned for the future. Some examples are: Industry 4.0 • Smart factories and fully automated production environments • Maintenance and logistics systems Social areas of application • Smart grid • Civil Protection • Environmental protection • Military defence • Traffic Individual • E-Health • Ambient Assisted Living

6.5 Opportunities and threats of CPS

As you have already learned, CPS is primarily there to make complex systems faster and more efficient. There are various advantages and disadvantages.

What about the **advantages**? Some of them you probably already know from the previous chapter:

a. Increased efficiency and cost savings

Systems can run much more efficiently. Due to constant self-control and readjustment, issues such as maintenance, wearouts, resource consumption and production downtime are minimised, perceived in real time and reacted to accordingly.

For example, logistic systems can automatically determine stock levels and demand and place orders accordingly.

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b. **Adaptability**

CPS enable the networked environment to react extremely quickly, adapt and control processes itself. For example, the same production environment can be used for mass production as well as for working on individual prototypes. This is usually not possible in conventional factories without high additional costs.

Different systems can be combined under one large system. In this way, future concepts such as self-driving cars and networked road systems become possible in the first place.

c. **Industrial safety**

In many dangerous situations, people are no longer needed on the spot. Disaster control, military operations or even manufacturing processes are carried out by CPS units. The human being only has a monitoring and control function.

And the downside?
Well, that's where it gets harder. But there are actually some dangers that have to be considered and currently still raise big question marks:

d. **Complex technology**

You have already recognised it - there is a lot of technology in CPS. It has to work, not only on its own but above all together. If a subsystem is defective, the whole system may be affected. Because of the many technical elements that are all connected to each other, CPS are considered to be quite susceptible to failures. The more complex the technology, the more possibilities there are for faults.

This can result in individual small errors that paralyse the entire system. Troubleshooting is then correspondingly lengthy and difficult.

e. **Programmed decisions**

CPSs should act as autonomously as possible. A "wrong" decision can be made due to a software error or an unforeseen event. A machine can only "think" as far as it has been programmed. For some situations this might be too little, especially in the case of operating errors by humans.

f. **Hacking and security**

As you have learned, CPS will also experience a great deal of integration in social issues. However, technical systems could also be hacked and thus sabotaged or manipulated. This is particularly critical in areas such as energy supply or military applications.

Absolutely high safety regulations have to be fulfilled constantly. This is one of the biggest disadvantages of networked systems.

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g. Privacy and personal rights

We live in a world in which many things are connected with each other and innumerable information is available on the net. Here, of course, the question also arises what data is sent where and by whom it is used.

This ranges from company data to highly private data. The use of energy in one's own household can shed light on living habits, health data can bring disadvantages in insurance matters or companies can lose important data to competitors.

Here, too, it is necessary to clarify not only information technology but also legal issues and to introduce new standards.

Remember
CPS have a number of advantages and disadvantages. Advantages: • Increased efficiency and cost savings • Adaptability • Occupational safety Disadvantages: • Vulnerable technique • Wrong decisions • Hacking • Data protection

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6.6 Summary

Cyber Physical Systems (CPS) are the technological basis of Industry 4.0 or the Internet of Things. This involves the **generation and evaluation of data in order to control and adapt processes in real time**.

For this purpose, the **physical world is combined with the digital world via a data network**. This is done by connecting mechanical or electronic components with software or information technology components.

CPS is a supersystem of various subsystems. These subsystems include embedded systems, mechatronic concepts such as robots and network systems such as the Internet and cloud computing.

The most important technological building blocks and concepts for this are **actuators, sensors, microcontrollers, modern data networks and system engineering.**

CPS offers a range of modern application possibilities. These are of industrial (e.g. through smart factory concepts), social (e.g. in civil protection, defence, smart grid or transport) and individual benefit (e.g. through e-health or ambient assisted living).

The advantages of CPS are high efficiency, adaptability, work safety and cost savings. Disadvantages are susceptible technology, possible wrong decisions of the systems, the danger of hacking and the challenge to meet the data protection requirements in connection with such systems.

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