Industry 4.0 and Cyber-Physical Systems – Classification and Practical Example

Format Change in Machine Building

Jens Amberg, Managing Director of halstrup-walcher GmbH

1. Classification of CPS in Context of "Industry 4.0"

Seldom does a term from the diverse nomenclature of "Industry 4.0" produce such astonishment and incomprehension when first encountered as "cyber-physical system" or CPS for short. Before we look more closely at this term and its meaning, we will firstly consider its embedding in the context of Industry 4.0.

The basic aim of Industry 4.0 is to make Europe as a production location in general and especially the particular production facilities in Germany as flexible as possible. Ultimately, this should result in global competitiveness being maintained. This competitiveness is being called into question in view of low-wage countries and emerging economies. The basic idea is simple. A manufacturing unit should be able to be adapted to changed customer requirements within the shortest possible time. At the same time, this efficient adaptation produces resource efficiency by integrating all upstream and downstream stages of production, and only preliminary products that are definitely needed are produced. And because only an optimal integration of people with their (particular) skills makes the desired adaptable manufacturing system possible, further humanisation of the working environment should occur at the same time.

How should this individualisation and flexibilisation now be achieved? A pivotal approach involves networking machines, equipment, tools, storage systems and the emerging products together. This networking is also described as the "Internet of Things", and a factory networked in such a way is termed a "smart factory".

But how can objects be networked? For better understanding, the concept of the "virtual image" must be explained. All non-human participants in manufacture such as machines exist not only in the real world of production that can be grasped with our five senses. They exist beyond that in Industry 4.0 in a "virtual image" that reflects the real world and is supplemented by information. This virtual image can be found in the world of information technology (IT) and depicts all the possibilities and abilities of the production participants as well as their current states.

Based on the information of the virtual image, it is possible for an individual decentralised participant in manufacture to make independent decisions and also communicate these directly to the neighbouring production participants. So an intelligent transport container makes a request to the machine in question with reference to workpieces for supplies if it discovers that the corresponding bin is empty.

Every participant in production that has a virtual image of this kind and can be networked for interaction with other production participants is called a "cyber-physical system". "Cyber" refers to the virtual image here, while "physical" on the other hand refers to the object in the manufacturing reality that can be perceived with our five senses.

As shown in Figure 1, not only is the interaction of cyber-physical systems among each other included, but also the provision of information and integration of high-level recipients and decision makers, from local machine operators and the control system or Manufacturing Execution System (MES) to external customers and suppliers.

So for example, a tool itself notices the first signs of wear and tear and orders its own replacement at the external tool suppliers.

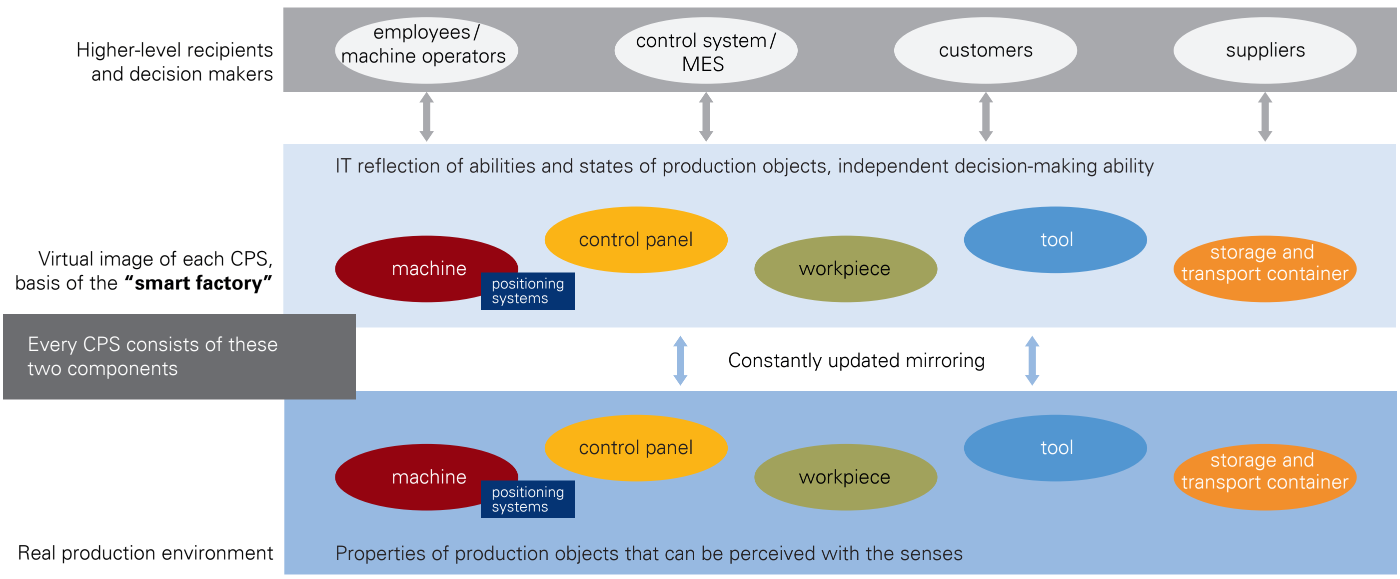

Fig. 1: The cyber-physical system is a real component of production and at the same time an image of the same thing in the "smart factory".

2. Basic Functions and Uses of CPS

The approach is revolutionary: Because these cyber-physical systems have the required decentralised intelligence, they are themselves able to assess situations, make decisions and prompt other cyber-physical systems to perform actions when necessary. These behaviours were programmed and are ideally even able to change and adapt themselves. The hierarchical and vertical decision path, a hallmark of everyday manufacturing for decades, is thus cancelled or at least largely replaced.

A brief recollection: How did this hierarchical decision path work? Components (especially sensors) recorded the actual state of the process and reported all relevant information to the central control unit. The actual state of the process was then analysed at the control unit level or also at the higher-ranking control system level, decisions were made and the process intervened in with the aid of actuators or manual actions.

This hierarchical and vertical communication is not meant to be replaced with the aid of CPS, but sensibly supplemented. At the same time, three subsystems enable the cyber-physical system to successfully assume its new role: sensors, actuators and embedded systems, a microprocessor-based and decentralised intelligence. The CPS can record its current situation in the environment itself with the aid of integrated sensors. So a machine's optical sensors for instance can supply comprehensive information about the type and state of the workpieces to be processed. Actuators are used to execute actions. For example, a grappler that picks the selected workpieces is extended. At the same time, the decentralised intelligence evaluates the sensor information as well as information flowing in from other CPSs. Based on this, it makes its decisions and passes these on in turn to its own actuators. At the same time, it contacts other CPSs and prompts these to actions.

The virtual image of the cyber-physical systems should not only be understood as a snapshot of the current status and current links. In fact, the virtual image also includes information about the entire life cycle of the CPS. Already in their design phase, data emerges that includes information about geometry, mechanical properties, logical connections and sets of parameters. All other life cycle phases like engineering, start-up and operation with maintenance and service provide additional information. Based on all this information, a cyber-physical system is able to react to situations independently.

Ideally, the past information available to it can also be used for this purpose in order to be able to adapt decision rules to the new situation each time.

Based on this, each CPS can now also have knowledge about its integration into the entire production facility. That can be used by the CPS to configure itself during start-up, automatically establish communication with its production partners (the other CPSs) and thus greatly reduce the costly start-up time. The optimisation phase then can be performed during the day-to-day production. In the process, the CPSs can also optimise themselves due to their intelligence. In the simplest case, that can be an independent discovery of the optimum operating point. In more complex cases, this can be a choice between predefined or even newly determined procedure scenarios. If problems occur at one time in the production sequence, for instance because a machine has malfunctioned or required material is missing, alternative strategies that "heal" the process itself and keep it running can be developed.

However, such problems are ideally avoided or at least visible with good lead time by the CPSs generating early warning information and thus making preventive maintenance possible. They thus ideally support what is known as "condition monitoring". In decentralised communication between the various CPSs, it is not absolutely necessary for this to be directly between one CPS and another. The expectation is rather that a multitude of communicative CPS platforms will emerge in just a short time. These platforms then use their services and applications to network people, external systems and CPSs with each other. Both communication channels, direct CPS exchange and the path via CPS platforms, exist next to each other and optimally complement each other. An example should explain it. A CPS transport container can immediately enter into a communication exchange at some stages of production, because these are technically able to do this. By contrast, all other stages of production that do not have CPS functionality themselves are controlled via a CPS platform. The CPS transport container can thus make decentralised requests for supplies in all production areas relevant to it (so also without the detour via the control level) and locally trigger operations.

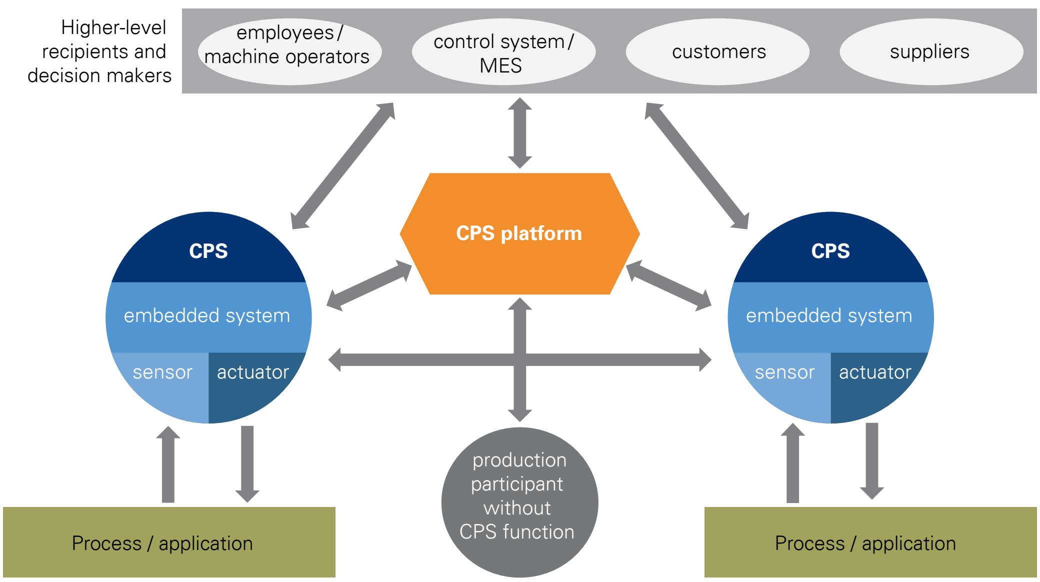

Fig. 2: CPS platforms link individual CPSs, external systems and the operator together and supplement their direct communication.

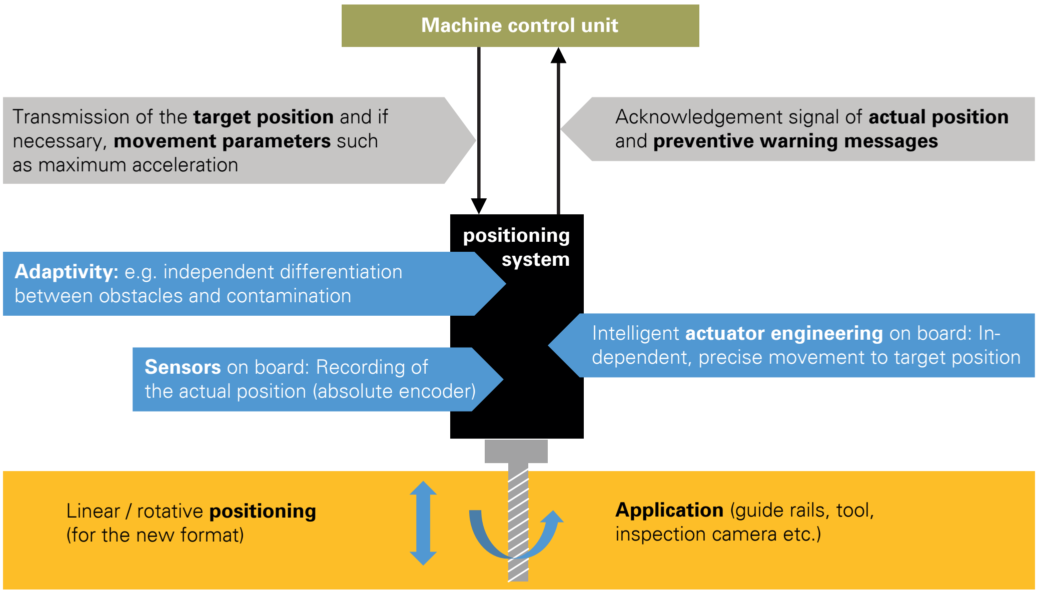

Fig. 3: Conventional hierarchical integration of a positioning system into a machine that itself acts as a CPS.

should instead better focus in future on optimally supporting the machine's role as a CPS as it establishes contact with the in-house transport systems, the nearby machines and the parts supplier.

As shown in Figure 4, the positioning system as a CPS can alternatively also be embedded by breaking through the hierarchical structures of the machine control unit. Instead of just a vertical exchange with the machine control, the CPS positioning system enters into a direct exchange with decentralised components.

3. Practical Example of a Cyber-Physical System: The Self-Modifying Machine

In the example of positioning systems, it should now be explained that the machines of the future, which will act as cyber-physical systems themselves, can ideally be a combination of cyber-physical subsystems. With their sensors (absolute encoders for positioning) and actuators (gearbox, motor, engine control) for moving positioning objects, the positioning systems for format change have all the components to represent an independent CPS together with the decentralised intelligence on board (embedded system).

The CPS positioning system can naturally be conventionally integrated into the machine procedures as shown in Figure 3. At this juncture, the positioning system automatically navigates to the new position according to the specification of the next target position (thanks to the machine control) and in doing so, independently minimises so-called "drag errors" (deviation from the designated position during the navigation process). If drag errors are too large, high-quality positioning systems will decide for themselves whether the situation is a "block movement" (obstacles) they should brake for or whether the positioning movement should be accelerated due to detected dirt and sluggishness in order to overcome the contamination. The positioning task is optimally executed in this manner – but it is requested from above by the machine control unit. In terms of Industry 4.0, this

A simple example shown here is of a new format being detected by a sensor. So for instance, an optical sensor in a packaging line can detect that a shift must be made to a new packaging size due to a new product format. The sensor gives the positioning system a direct decentralised specification of the new target positions, whereupon these move the guide rail, packaging tools and if necessary the inspection camera to the new position. In the course of this, the higher-level machine control and also the operator at his panel are continuously informed of the actual position or when target positions are reached. This information is accompanied by reports that make preventive maintenance possible. Another example is the independent coordination of two synchronously running positioning systems without it being necessary to incorporate the control unit for that.

As a result of this decentralised embedding of the positioning system as an independent CPS, adaptability and responsiveness are increased. The central machine con-

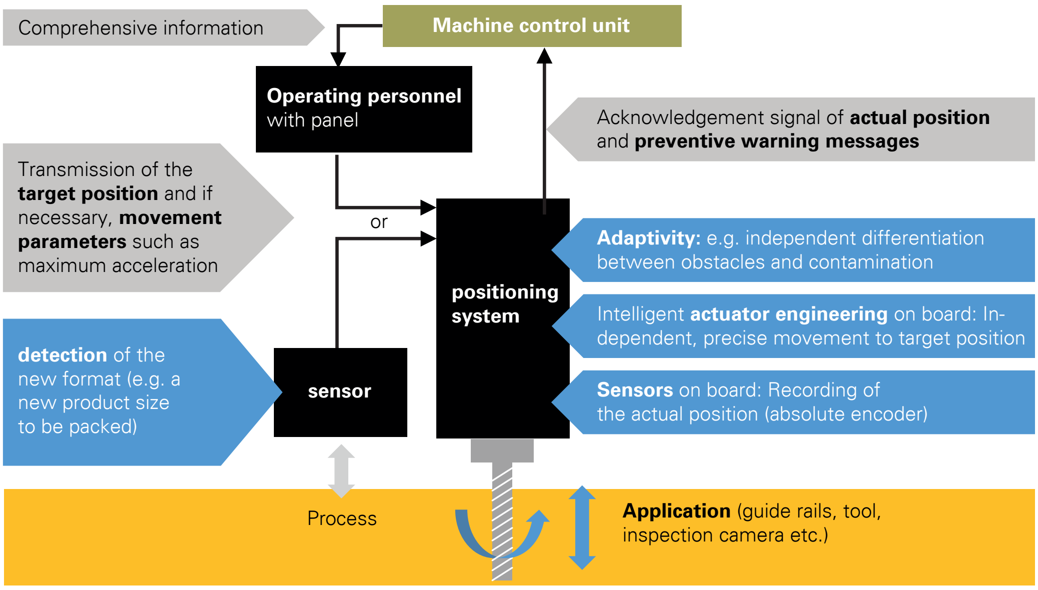

Fig. 4: The positioning system as independent CPS within the machine

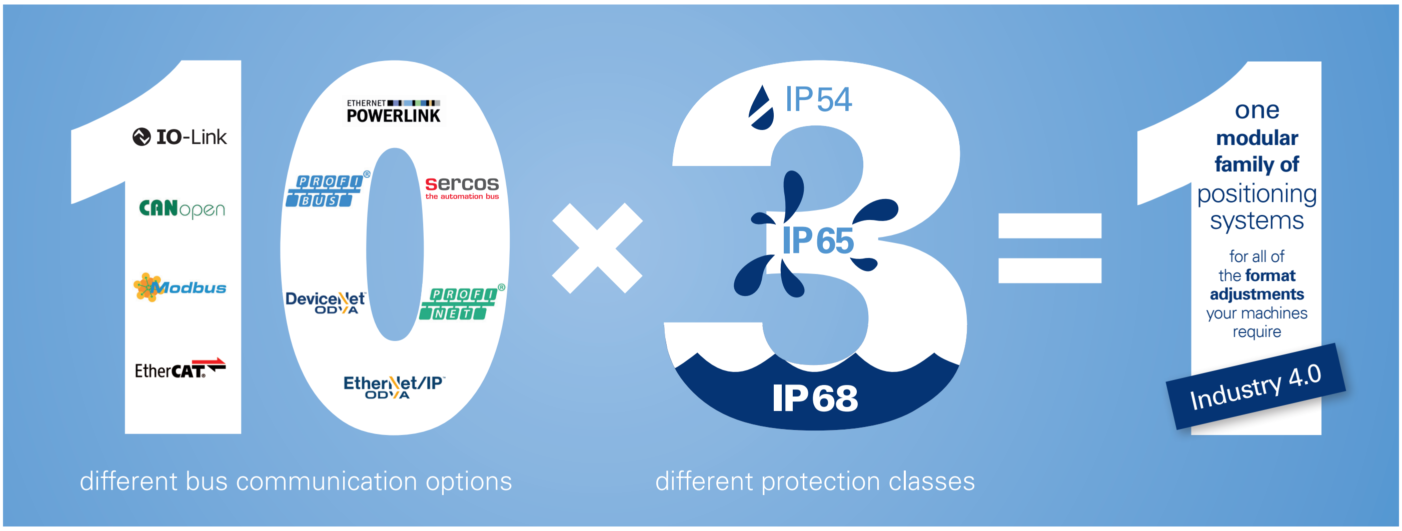

Fig. 5: Positioning systems of the PSx-3 series support mechanical engineers in implementing Industry 4.0 by a modular design that offers high flexibility in machine design.

trol unit can focus on its own CPS tasks and on the machine's integration into the overall production process. The person in charge can intervene via control panel if necessary or concentrate on optimisation of the production process instead of having to trigger simple and regular processes like format changeovers.

The ability to manage format changes at both levels described above, i.e. modification of the machine user's production as well as modification during machine design, will be a crucial factor in the next few years that decides the competitiveness of mechanical engineers.

What mostly only concerned the industry's major groups yesterday is nowadays also the emphatic focus of medium-sized mechanical engineering companies. The future of CPS thus began long ago not only where machines are concerned, but also components, and everyone involved needs to keep up. To paraphrase Albert Einstein: "Life is like riding a bicycle. If you stop moving, you will fall off."

Fig. 6: Example of a halstrup-walcher positioning system (here: PSW with IP 68)

halstrup-walcher GmbH
Stegener Straße 10
D-79199 Kirchzarten
Germany

halstrup walcher

www.halstrup-walcher.com
info@halstrup-walcher.de
Fax +49 (0) 76 61-39 63 99
Tel. +49 (0) 76 61-39 63 0