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Development Trends in Cost Oriented Production Automation

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Abstract: The field of manufacturing automation is one of the fastest growing in technology not only because of the rapid developments of IT hard- and software as well as micro-, nano- and femto-technologies for the development of new materials. Therefore in production automation we have the new headlines new materials, smart products, smart factories, Internet of things (IoT), production 4.0.

This requires Multi Robot Systems or Multi Agent Systems (MAS) consisting of cooperative industrial, mobile and probably in the future humanoid intelligent robots acting as a team for solving common tasks. In addition they have to be cooperative. The tasks of the robots must perform the mechanism of cooperation and the system performance. Production 4.0 requires the replacement of the Central Control Computer by a distributed, networked Computer System.

From the side of Automation in this paper the latest trends in manufacturing automation will be presented. Concerning the problems of SME`s to introduce Production 4.0 first ideas on "Cost Oriented Production 4.0 – Production 4.5" will be discussed.

From the side of TECIS both disciplines will raise some new social and ethical questions related to humans.

Keywords: Intelligent Systems and Automation, Production, Digitalization, Smart Production, Ethics, Social aspects

1. INTRODUCTION

Currently the main manufacturing systems evolution drivers are:

- Global growth & competition,
- Knowledge Economy,
- Environmental pressures,
- Molecular manufacture,
- Conflict over resources,
- Ideology, & culture, ICT- ambient & networked,
- Global competition in services,
- Human need,
- Physical Product

This yields, in the past, to the development of Computer Integrated Manufacturing (CIM), Intelligent Manufacturing Systems (ims), Agile Manufacturing Systems (AMS). At that time the hard- and software possibilities were very limited and therefore industrial applications of AMS not economic.

Agile manufacturing systems are now in realization based on "Cyber Physical Systems (CPS)". CPS comprises smart machines, storage systems and production facilities capable of autonomously exchanging information, triggering actions and controlling each other independently. Based on the new Internet protocol IPv62 introduced in 2012 sufficient addresses are available to enable universal direct networking of smart objects via the Internet. Now is possible to network resources, information, objects and people to create the "Internet of Things and Services" (Fig.1)

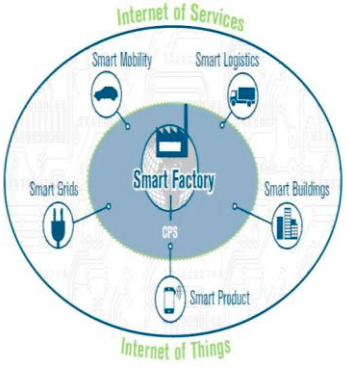

Fig.1 The "Internet of Things" (acatech, 2013)

One of the headlines of production automation is currently Production 4.0. This approach is definitely not new. We had it under the headline "Agile Manufacturing" in the late Nineties. The idea beyond was to produce different products on one production line economically. At that time it was not realizable because of the missing IT hard- and software.

The basic ideas of Production 4.0 are**:**

Products, machines and robots will be equipped with processors, sensors and wireless communication facilities

They are able to communicate with each other and with other production machines, and are self-organizing as well as partially even self-optimizing.

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2. PRODUCTION AUTOMATION

A manufacturing process consists of processing operations which transforms a work material from one state of completion to a more advanced state that is closer to the final desired product by means of shaping operations, property enhancing operations, surface processing operations.

Assembly operations joins two or more components to create a new entity, called an assembly by means of permanently (welding, brazing, soldering, and adhesive bonding) or semi-permanently (screws, bolts or rivets, press fitting, and expansion fits) (Kop, 2015).

In addition micro-, nano- femto- and in the future ato-technologies are and will be offering in the future additional possibilities for the development of new materials which will influence dramatically the production automation.

3. PRODUCTION 4.0

The Industry 4.0 vision is not limited to automation of a single production facility. It incorporates integration across core functions, from production, materials sourcing, supply chain, and warehousing all the way to sale of the final product. This high level of integration and visibility across business processes will enable greater operational efficiency, responsive manufacturing, and improved product design.

3.1 "Components"

One of the pillars of Production 4.0 are Cyber Physical Systems (CPS) comprising smart machines, storage systems and production facilities capable of autonomously exchanging information, triggering actions and controlling each other independently.

Now is possible to network resources, information, objects and people to create the Internet of Things and Services.

The Internet of Things (IoT) presents the networking capability that allows information to be sent to and received from objects and devices using the Internet network.

Therefore Production 4.0

- Will involve the technical integration of Cyber Physical Systems (CPS) into manufacturing and logistics.
- The use of the Internet of Things (IoT) and Services in industrial processes.
- This will have implications for value creation, business models, downstream services and work organisation.

The basic principle of Industry 4.0 is that by connecting machines, work pieces and systems creating intelligent networks along the entire value chain that can control each other autonomously.

Some *examples* for Industry 4.0 are machines that predict failures and trigger maintenance processes autonomously or self-organized logistics that react to unexpected changes in the production.

3.2 Smart factories

As a logical consequence "Smart" factories beginning to appear. These employ a completely new approach to production allowing individual customer requirements. Furthermore dynamic business and engineering processes enable last-minute changes to the production.

The result are "Smart" products which

are unique identifiable,
may be located at all times,
know their own history and the current status,
are able to create alternative routes to achieving their target state.

The main goal of a smart factory is to produce "lot size One" in an economic way. This yield to

a higher number of variants,
a high flexible production based on market needs,
an "on demand" production,
preventive maintenance planning in production,
"smart" robots communication.

3.3 Robots in Production 4.0

One important component in production automation are different types of robots. In the following some selected examples are described and shortly discussed which will be used in the very near future in production 4.0 or in daily life of humans.

Dual arm robots

Dual arm industrial robots are known since more than 5 years. They have usually only an upper body with two arms and a gripping unit. Because of their 60 – 70 degrees of freedom (DOF`s) industrial applications are for complex handling and assembly tasks.

Cooperative robots

Robots can accomplish different tasks in different environments, tasks that are tedious, difficult or even impossible for a human operator. If several robots are combined in order to create a multi- robot system, the range of tasks they can perform increases even more, as these systems can carry out actions that no single robot could since they are always spatially limited, no matter how capable they are.

A multi-robot system is a distributed system that consists of a collection of autonomous robots, connected through a network and distribution middleware which enables them to coordinate their activities and to share the resources of the system so that user perceives the system as a single, integrated computing facility. Nevertheless, multiple robot systems are different from any other distributed systems because of their implicit "real world" environment, which is more difficult to model.

Collaborative robots – COBOTS

In order to perform collaborative tasks Cobots are designed to be safe around humans (using sensors, force limiting and rounder geometries than traditional robots), to be lightweight (for them to be moved from task to task) and to be easy to implement and use without skills in programming. Above all,

a collaborative robot is not a replacement robot; it assists workers rather than replaces them.

As detailed by the international ISO10218 standard, robots can have four types of collaborative features. These are Safety Monitored Stop, Hand Guiding, Speed and Separation Monitoring and Power and Force Limiting.

Safety Monitored Stop is implemented in environments where the robots operate mostly alone, with occasional human interference. The feature will cause the robot to pause (though not shutdown) when the safety zone is violated (i.e. a human enters its workspace).

The speed and separation monitoring feature is an extension of Safety Monitored Stop. Instead of adopting a single behaviour throughout the robot's entire workspace, the latter is gradated into several safety zones.

Hand Guiding enables the robot to move while the worker is in its workspace (as is possible with Speed and Separation Monitoring). Using an end-of-arm device capable of detecting applied forces, the robot can be guided by a worker for hand guiding and rapid path teaching.

Power and Force Limiting feature is probably the safest of them all as these type of robots are purposefully designed to operate around humans rather than adapted to do so. As the name suggests, the forces and energy applied to a human are limited so as to avoid any inflicted harm.

Micro-, Nano-, Femtorobots

Microbots (or microrobots) are usually mobile robots with characteristic dimensions less than 1 mm or robots capable of handling micrometer (10^{-6} m) size components.

Nanorobot dimensions at or below 1 micrometer (10^{-6} m), manipulate components on the 1 nm (10^{-9} m) to 1000 nm (10^{-6} m) size range. Femto robots for manipulating objects in the 1 fm (10^{-15} m) size are currently more or less a dream and in reality not necessary – because we have currently nearly no components in this small size.

Nano and femto (sub-atomic particle size) robots may revolutionise medicine and enable a wide range of conditions, such as heart disease and cancer, including currently untreatable serious and life-threatening illnesses to be cured. They will be very important in the future.

Driverless mobile robots

Mobile robots have the ability to move around the environment and are not fixed to one physical location. Mobile robots can be "autonomous" (AMR - autonomous mobile robot) which means they are capable of navigating an uncontrolled environment without the need for physical or electro-mechanical guidance devices. Alternatively, mobile robots can rely on guidance devices that allow them to travel a pre-defined navigation route in relatively controlled space (AGV - autonomous guided vehicle). By contrast, industrial robots are usually more-or-less stationary, consisting of a jointed arm (multi-linked manipulator) and gripper assembly (or end effector), attached to a fixed surface."

In addition humanoid robots will be introduced not only because of social aspects. The main advantage is mobility and the ability to work on a "human" workplace.

4. COST ORIENTED PRODUCTION 4.0 (4.5)

There are currently no real numbers about the costs of installation and maintenance of Production 4.0 and therefore also only estimations for the "Return of Investment – ROI".

The challenge for small and medium-size companies within supply chains will be to make the kinds of investments such that it provides a return on investment. For very small and also medium enterprises it is unlikely they will be able to make such investments. One of the reasons is that nearly 70% of the value that we estimate will flow from the Internet of Things (IoT) in the next 10 years.

Reasons are:

- Transfer large amounts of data in real-time and with minimum delay
- Connect a large number of individual devices in a very reliable manner and with the highest standards of data security
- Utilize more and more wireless technologies, both within the plant and for remote connectivity
- Operate in an energy-efficient manner

Important facts for SME`s are resources efficiency and End of Life (EoL) management. By collecting energy consumption data from shop floor (e.g. at production line, machine, processes level etc.), and by providing them to decision makers in real time at any place (e.g. using mobile device) and eventually integrating energy data in production management practices energy efficiency can be improved, through find and reduce the wastes and enable energy-aware decision-making at production management level (e.g. production scheduling, and maintenance management, etc.).

Resource efficiency will be necessary to calculate the trade-offs between the additional resources that will need to be invested in smart factories and the potential savings generated

For the Internet of things (IoT) a Cost Oriented IT infrastructure which is easy to maintain will be necessary.

Cost oriented (humanoid) robot - CO(H)R - can be conceived by using industrial components with a robust simple mechanical design, easy operation through flexible programming. The use of such kind of components may decrease the complexity of design.

Therefore, low-cost components are a very good expedient for reducing the cost and time of designing humanoid robots.

Nevertheless, such a low-cost design will yield to a robot with limited capability both in mechanical versatility and programming flexibility. But in general, it can be thought a low-cost robot can have still interesting performances for mobility, manipulation, and autonomous operation that are useful in many applications. (Byagowi et.al, 2011).

One "cost oriented" example is Baxter an industrial android (humanoid robot) that can work right next to line employees on the factory floor, often working on highly repetitive tasks such as precision picking. This robot is very easy to program (intelligent manual teach in), can perform a wide range of simple tasks, can adapt automatically to changes in the work environment and is definitely safe.

5. SOCIAL AND ETHICAL ASPECTS

The process of engineering is the process of creating solutions that can simultaneously achieve the goals of the problem and remain within certain constraints. These goals and constraints are referred to as "design drivers". The three most common "design drivers" are

the cost of the solution,
the schedule of the project and
the features of the solution.

These drivers can act as either goals or constraints, depending on the situation.

5.1 Social aspects

In smart factories the role of employees will change significantly. Increasingly real-time oriented control will transform work content, work processes and the working environment.

Industry 4.0 yields to dramatic changes like:

- New skills and structures in the workforce.
- More collaboration required across all functions within the company, with its customers, and with its suppliers (especially tool vendors and IT).
- Need for advanced cyber security increasing exponentially.
- Investment requirements increasing.

Industry 4.0 will radically transform workers' job and competence profiles. It will therefore be necessary to implement appropriate training possibilities.

Another aspect is that in most industrialized countries, more managers than ever - along with their wealth of experience - are retiring every day, just when a solid knowledge base is increasingly important for production. The group of 50- to 64-year-olds makes up about 20 percent of the population in the European Union today. This results in a "Loss of know-how". In the past they served e.g. as "Senior Consultants".

To realize these new tasks especially education is absolutely necessary.

Production 4.0 is bringing lasting changes in the workplace and is thus the key to the success of industrial enterprises. The technologies that connect things, data and processes are placing new demands on employees and management, especially in industry. Workplace training for Production 4.0 implementation of the digital transformation processes are particular challenges for SMEs.

At the same time, however, Production 4.0 is making new, digital continuing professional development formats available that allow training content to be precisely tailored to the knowledge and needs of staff and management.

The constantly changing list of skills required for Production 4.0 must be regularly updated so that the relevant adjustments in the education system can be made. In the future, the focus will be on interdisciplinary thinking and acting, cross-functional process know-how, and IT skills involving both specialized and more general application knowledge

The goal should be to prevent a twofold digital divide between large and small industrial enterprises and between high-skilled and low-skilled workers. SMEs should receive special support to help them develop the skills needed for Production 4.0 (Acatech, 2016).

Summary: What about the workers – in the future, will people vanish from the factories with machines taking over?

Well educated employees will play a much larger role because of the progress in AI and the enormous volumes of data. People have to managing unforeseeable events and deriving new and creative ideas from experience (Kopacek,2017).

5.2. Ethical Aspects (Roboethics).

Ethical considerations can similarly be viewed as "design drivers", constraints or goals. Ethical behaviour is either something to be sought or something used to limit the design space. The technical features are analogous to the moral issues at stake in an ethical case.

Until now robotics is a discipline based on: Mechanics, Physics, Mathematics, Automation and Control, Electronics, Computer Science, Cybernetics, Artificial Intelligence… Therefore robots are frequently used as examples for Mechatronic Systems. For Roboethics nontechnical fields e.g. Philosophy, Ethics, Theology, Biology, Physiology, Neurosciences, Law… have to add (Kopacek, Hersh,2015).

Robotics unifies two cultures: Science and Humanities. The effort to design Roboethics should make the unity of these two cultures a primary assumption. This means that experts shall view Robotics as a whole - in spite of the current early stage which recalls a melting pot.

Table 1 Examples for ethic recommendations; adapted from (Kopacek, 2015)

Robots	Benefits (examples)	Problems	Ethic Recommendations
Industrial	Increase productivity, speed, endurance	Loss of "low tech" workplaces	Education Programs to create new skills
Mobile Robots	Increased safety and security	Safety, security, privacy	Update safety and security standards
Humanoid robots	Increased efficiency in performing complex tasks	Currently partially unpredictability of robots' behavior	Safety. Mechatronic Systems for the control of robots autonomy

So they can achieve the vision of the Robotics' future. Robotics scientists, researchers, and the general public have about robots different evaluations:

- Robots are nothing but machines
- Robots have ethical dimensions
- Robots as moral agents

Robots, evolution of a new specie

Currently the following definition is used:
"Roboethics is an applied ethics whose objective is to develop scientific/cultural/technical tools that can be shared by different social groups and believes. These tools aim to promote and encourage the development of Robotics for the advancement of human society and individuals, and to help preventing its misuse against humankind." (Veruggio, 2008).
Selected examples for robots and their applications concerning ethical issues are given in Tab.1.

The main goals of Roboethics are:
Avoid conflicts
Work for a safe future
Protect the environment by

-Select materials that require minimum energy to produce,
-Select processes that minimize waste of materials and energy,
-Design parts that can be recycled or reused,
-Design products that can be readily disassembled to recover the parts,
-Design products that minimize the use of hazardous and toxic materials,
- Give attention to how the product will be disposed of at the end of its useful life.

5. SUMMARY AND OUTLOOK

After a short introduction the basic ideas of production 4.0 are presented. The role of robots in form of cooperative robots (Multi- agent systems) is shortly outlined. One of the main goals of production 4.0 is to create "Smart Factories". They beginning to appear and employ a completely new approach to production. Smart Factories allow to fulfill individual customer requirements and the dynamic business and engineering processes enable last-minute changes to production.
Clearly this new automation philosophy requires highly cooperative industrial, mobile and probably in the future humanoid robots – a so called multi-robot system. For this cooperative and collaborative robots are necessary. These are shortly described as well as some others used or probably will be used in the future not only in agile manufacturing.
Concerning the problems of SME`s to introduce Production 4.0 first ideas on "Cost Oriented Production 4.0 – Production 4.5" will be presented and discussed.
Open questions are social and ethical aspects of this new production philosophy called "Production 4.5".
Meanwhile Production 5.0 is knocking on the door. Let`s have a look.

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