Collaborative Networks and ICT Trends for Future CPPS and Beyond

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Abstract. Enterprises are forced to implement continuously new ICT architectures, devices and technologies to react in time to the demands of the market for high quality, individualized products. These demands can be fulfilled only by well-organized and operated networked production systems. Cyber Physical Production Systems (CPPS) represent this type of networks connecting their different components through collaborative networks (CN), using emerging technologies in a very flexible and efficient way. The paper gives a short overview on the trends of CN and CPPS as systems, than the Brain Computer Interface (BCI) is introduced as a new technology to control devices in CPPS. As a next step a new paradigm for future production systems, beyond the CPPS is presented; the biological transformation in manufacturing (BTM), where biology, IC and manufacturing technologies are merged. There are many open questions in reference to BTM that need to be answered by the manufacturing community.

Keywords: Cyber Physical Systems · Brain Computer Interface · Collaborative Networks · Biological Manufacturing Systems

1 Introduction

The fast evolution of information and communication technologies (ICT) have resulted a new digital economy that has reached a point from where this process can be called as the "fourth industrial revolution". In this environment Cyber Physical Systems (CPS) are interlinked through real and virtual objects and processes. This phase can be characterized with deep interdisciplinary integration of technologies in digital, physical and biological world [1]. Manufacturing industry also belongs to those sectors that are basically changing in most of their component systems as new paradigms are involved into the production.

Today Artificial Intelligent (AI) technologies are the most dominant technologies for most sectors of economies, Gartner states that AI will become the biggest megatrend of the next decade [2]. The key AI technologies, e.g. deep learning, deep reinforcement learning, artificial general intelligence, machine learning, and conversational user interfaces appear not only as single applications but in many cases in an embedded, integrated form with other emerging technologies (e.g. AI+IoT, AI+BigData, AI+5/6G).

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AI research got a big push and it seems that the level of AI applications will define the overall technological level of a country, as AI appears in most sectors of the economy. USA is traditionally dominant in this market, but China is raising radically its investment level (both states invest billions of USD into research founds) [3]. These AI based technologies can be applied in CPPS as well.

The paper gives a short overview on the trends of CN and CPPS as systems, than the Brain Computer Interface (BCI) is introduced as a new technology to control devices in CPPS. New human-machine communication technologies are in the first line of emerging technologies.

In the next section a new paradigm for future production systems, beyond the CPPS is presented; the biological transformation in manufacturing (BTM), where biology, IC and manufacturing technologies are merged, and the goal is to explore the application possibilities of the knowledge of biological principles in manufacturing processes. According to the predictions of different institutions the realization of highest (third) level of biological manufacturing will be in real industrial use only about after 2030 [4].

The paper discuss the above technologies only from technical viewpoints, but it is important to mention that there are non- technical fields (e.g. society acceptation, ethical questions) too, that are influenced by these technologies in a great extent and have back-reaction on these technologies as well. The focus of the paper is on human centric technologies and the biologisaton of manufacturing, so some critical questions of these fields can be discussed for future developments:

- What are the main gaps between BTM and traditional manufacturing?
- In which fields of manufacturing could be involved additional biological methods, processes?
- What can be the main negative factors in the introduction of BTM?

2 Collaborative Networks and CPPS

2.1 Collaborative Networks and Their Challenges for Future Production

In this section the trends of Collaborative Networks and CPPS as a whole system will be presented in connection with Industry 4.0 concept based production systems.

The different collaboration issues in production systems based on the Industry 4.0 concept are analyzed, compared and summarized in a structured way in [5]. Based on this evaluation 13 main group of challenges have been defined for further research. The importance of humans in the systems (in group 4) and the application of nature related disciplines (in group 7) in CNs are defined as well.

In order to give a proper answer to these challenges emerging technologies should be applied: extensive application of AI in decision making and in organization of CNs, collaborative censor fusion, collaborative robot–human work (corobots), and new interfaces are needed (e.g. BCI).

2.2 Cyber-Physical Production Systems (CPPS)

CPSs can be applied in many fields of economy, in healthcare, different fields of industry, agriculture. In the field of production/manufacturing the specialized CPS is called CPPS and focus on operating highly effective, flexible production system. Cyber-Physical Production Systems (CPPS), relying on the newest and foreseeable further developments of computer science (CS), information and communication technologies (ICT), and manufacturing science and technology (MST) [6]. CPPS can be characterized by strong collaboration of systems both among machine and human agents that results intensive communication.

There are numerous surveys, studies and whitepapers published on the challenges, trends of future manufacturing systems and CPPS. In the most important fields the predictions are overlapping each other, only the accents are put in different points. A few word summaries of the results of two studies are introduced especially only those points of the works that can be connected to the topic of this position paper.

In the whitepaper of [7] the following main Research Priorities for Cyber-Physical Manufacturing have been defined (2 points are selected from 14 on the list): RP2. Worker at the center in manufacturing systems; RP7. Cyber Native Factories.

The Report of the ManuFUTURE – EU High-Level Group [8], contains 10 groups of trends for future manufacturing systems in Europe, in four of them are reference on humans and biology: “AI will support all human’s activity in manufacturing”, “Biotech transformation of products and processes”, “Collaboration and integration between humans and technology”, “New interfaces between humans and machines will enable new levels of collaboration”.

In the “Implementation Roadmap” chapter the bio based eco-systems are mentioned that although biotechnology has already significant developments these concepts call for a significant R&D effort and the mass implementation of the results will be a mid to long term target (2030–2040 for the 3rd level biologisation).

3 Human Machine Cooperation and Interfaces (BCI)

In the operation of highly digitalized production systems humans have a central role. Besides the conventional interfaces (e.g. keyboard and touch-screen, voice and gesture based techniques) BCI can be applied as well. In the literature many experts define the human machine interfaces (HMI) as critical technology and BCI is the interface that is handled with great expectations [9]. In the past years BCI is used in a growing extend in applications for healthy people (e.g. gamers, AR/VR applications) and now it appeared in the manufacturing world too.

3.1 Definition, Main Characteristics

BCI is a technology that allows the direct communication between the brain and an external device. A BCI can be described on a lower technical level as an artificial intelligence system (pattern recognition, machine learning) that can recognize a certain set of patterns in brain signals following five consecutive stages; signal acquisition, preprocessing or signal enhancement, feature extraction, classification, and the control interface. The controlled device can then send feedback to the user either via normal sensory pathways (screens, sounds) or directly through brain stimulation, thereby establishing a closed control loop.

BCI systems can be divided into three groups according to the placement of the electrodes used to detect and measure neurons firing in the brain; invasive-, semi-invasive and non-invasive techniques. The most sophisticated BCIs are bi-directional that can both record signal from the device and stimulate the nervous system.

There are also new and potentially dangerous situations in connection with BCI security. In BCI a hacker is no longer limited in access to machines and systems, but rather has the potential, to access partially the minds of living individuals [10]. New methods, processes have to develop to avoid these critical and dangerous situations.

3.2 BCI Applications in Manufacturing

There are examples of BCI applications in the field of manufacturing control as well. In the field of human-robot collaborative assembly has been applied BCI described in [11]. The human thought is realized as the desired robot movement to assist the human. This solution is an extension of multimodal communications (e.g. voice, gesture, haptic) and can realize more effective assembly.

In the paper [12] two classification algorithms are proposed by the authors for Brain Computer interfaces. The two algorithms are the Restricted Boltzmann Machines and the Long Short time Memory. The classification accuracy obtained from the two proposed methods showed similar accuracy than for the common Artificial Neural Network, opening the possibility to be used in manufacturing systems.

3.3 Manufacturing Related Advantages, Disadvantages and Trends of BCI

The advantages of BCI in manufacturing are: (1) BCIs can create direct communication between a human brain and any external devices; (2) EEG technique and neurochips make easier building BCI applications; (3) BCI stimulates researchers by generating new challenges.

The following features can be listed as disadvantages: (1) EEG technique needs extensive training for the users, (2) BCI techniques are slow and high costs, (3) Security/privacy problems are unsolved, (4) Ethical issues can be raised that can prevent further intensive BCI development.

The trends of BCI represent the raising of the theme. Intensive researches have been started in BCI field in the last years that resulted new HW elements as well, e.g. a BCI chip specially designed for decoding brainwave information.

Taking into consideration the research trends industrial application of BCI is predicted by the Gartner in more than 10 years [2].

4 Beyond CPPS; Biologisation in Manufacturing

4.1 Biologisation

There are significant improvements in the digitalization of manufacturing, both in the field of products and production in all phases of their life cycles. But taking into consideration the problems in connection with the limited resources of energy and material, new solutions have to be found for the industry. In this way the increased usage of practical solutions generated by the nature, e.g. from the biology came to light and can be handled as templates. The new solutions require the convergence of advanced technologies; require the knowledge of biologically inspired processes and aspects of sustainability. Inter- and trans-disciplinarity will be the defining features of future economy and production systems and these can create in this way a new age, a new paradigm.

4.2 Definition of Biologicalisation

The basic term for involving biology to the production is "biological transformation" ("Biological Transformation in Manufacturing"-BTM) but there are several other terms for the same concept. The authors in [4] apply the expression "biologicalisation" and define "biologicalisation in manufacturing" as "The use and integration of biological and bio-inspired principles, materials, functions, structures and resources for intelligent and sustainable manufacturing technologies and systems with the aim of achieving their full potential." According to a simplified definition it can be given as "the systematic application of the knowledge of biological processes aiming at optimizing a production“ [13].

4.3 Main Characteristics of Biologicalisation

Three levels of biological transformation can be distinguished starting with the inspiration-level which is followed by the integration-level and finally the level of interaction, [13]. The levels are defined according to the merge- rate of biological- and technological paradigms.

On the inspiration-level biological concepts are transferred to value creation networks, called bio - inspired manufacturing. Bio inspired concepts are well known in technology and have been applied for years (e.g. swarm/ant algorithms). The integration-level is the next layer, given as bio-integrated manufacturing. In this level biological systems are actually integrated into manufacturing systems, e.g. the substitution of chemical processes by biological processes [13]. The level of interaction is the last level towards a huge leap to biological transformation of manufacturing systems. This layer represents the final step towards a fully bio-intelligent value creation network (bio intelligent manufacturing) which is the result of a completely new production paradigm. On the interaction-level technological, biological and information systems converge and collaborate.

4.4 Examples of Biologicalisation in Manufacturing

Cyber-Physical Production Systems (CPPS) are a good example for the inspiration-level biological system as they have a similar structure to natural ecosystems with their sub-elements/systems with the connected specific tasks and system behavior and interconnection (complex communication, flexible exchange of resources) [14]. By an abstraction the characteristic of natural systems can be transferred to CPPSs to make use of their optimized way of performance.

The use of microorganisms in machining processes is a good example for the integration-level. In [15] and [16] possible utilizations of microorganisms for micro-machining has been introduced. A bacterium has been used that metabolize metal for their energy production. Another example is when microorganisms can be integrated into the metal working fluids (MWF) to replace mineral-oil-containing MWFs and thus reduce the pollution of the environment [17]. In the field of product development the virus-built batteries, protein-based water filters, cancer-detecting nanoparticles can be listed as examples [18].

An example on interaction-level is the EVOLOPRO project [19]. The goals of the project are to develop methods for increased productivity, more robust processes and the improvement of products by using biological principles of diversity of variants and the theory of facilitated variation for complex self-adapting technological processes.

4.5 Main Advantages of Disadvantages of Biological Manufacturing Systems

The advantages of BTM are as follows: environment friendly, energy saving, lower cost, more efficient.

The following characteristics can be listed as disadvantages: research/experiments have to be done, longer installation time, risk of introducing a system/process, alternative technologies exist, not the best solution is offered but a better one than the previous.

4.6 Future Trends for Biological Manufacturing Systems

Future trends cannot define exactly for Biological Manufacturing Systems as they are very complex systems, very diverse disciplines are involved. The trends of component technologies can be estimated and as a second step can be predicted the introduction of a BMS. Machine learning (ML) and artificial intelligence (AI) are fundamental techniques in many fields of BMSs.

Selecting some AI related technologies their estimated industrial application time by the Gartner are as follows: Deep Neural Nets – Deep Learning, 5G between 2–5 years, Digital twin, Quantum computing, Smart Fabric, IoT Platform, Edge AI - between 5–10 years, BCI, Smart Dust, Biotech - more than 10 years [2].

5 Conclusions

The CPPS will remain dominant production system type in the future as well. The IC technologies applied in CPPS operation will develop quickly and this can modify the structure, the architecture, the way of communication, their collaboration in a great extent. As human beings have central role in these production systems the communication between humans and different devices have special emphasis. The BCI can help humans in the field of manufacturing system as well and within a few years BCI can get higher role especially in collaborative robotics.

A new paradigm, the biologisation of manufacturing (biologicalisation) can be the next step beyond CPPS in the field of production. In the biologisation of manufacturing the applied technologies are the result of deep integration of fully different fields (biology, ICT, manufacturing). These high level interdisciplinary technologies can apply more efficient, energy saving, green technologies, but parallel can generate challenges that are not easy to answer. The acceptance of these new technologies from the side of individuals, companies and the society, solving the connected moral/ethical problems are the biggest challenges for the future. Some of these challenges have been introduced in the paper and these have to be discussed by the manufacturing community to give proper answers in time.

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