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Digitising the European industry - holonic systems approach

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Abstract

It is a world trend that digital economy is merging with real economy. Through the use of digital technologies, investments and innovations take place in the fields of smart grids, self-driving vehicles, e-government, advanced manufacturing, etc. Our research deals with the question whether there is any general or formalised technology which could be equally used in various fields, and which could help to achieve digitalisation in everyday life, also in the industry or in manufacturing. Digital transformation is the key of competitive sustainable development in the long term. As it has been noted by industrial players, the fourth industrial revolution is happening now. In the centre of technological change, the fusion of the physical and virtual world is taking place. With elaborated technological recommendations, digitalisation could be realised in an efficient way. With the help of intelligent cyber-physical systems, a holonic (with distributed intelligence) manufacturing technology will be developed. Smart cyber-physical systems can help to make human life better and more convenient by having features which cannot be found in traditional systems. Their use is easier not only because they are smaller and more efficient, but also because they have such system-level characteristics as autonomy, distributed intelligence, self-organisation or co-operation based on adaptivity.

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Keywords: Digital Single Market; Digitising European Industry; Digitisation of manufacturing; ICT; Holonic Manufacturing Systems.

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1. What is the digitalization of manufacturing?

The German Industrie 4.0, the American Advanced Manufacturing and the Chinese Intelligent Manufacturing is based on digitalisation. Since the 1850s we have come from Manual Production, through Mass Production/Customized Mass Production, to the manufacturing paradigm of Mass Customization (personalisation), meeting individual customer demands. As a consequence of this change, service oriented manufacturing has become a multi-factor high-complexity process. [1]

In the beginning, digital manufacturing meant the use of computers in manufacturing. By now the digital conception has further developed. Full digitalisation aims to achieve a closed production and consumption cycle driven by the idea of sustainability, where particular attention is paid to the goals of optimisation and customisation. In various digital strategies the most important fields have been systematically organised in the name of sustainability. [2] One such strategic goal is the Smart City, with one of its pillars being Smart Economy, which is based on Smart industry, one element of which is Smart Factory or Smart Manufacturing. [3] [4]

In today's modern factories, as the result of digitalisation, manufacturing processes are operated by intelligent cyber-physical systems. With the increased use of digitalisation technologies, constructive or additive manufacturing will be put in the forefront, due to its efficiency, as it generates much less loss than subtractive manufacturing. It is enough to consider the differences between traditional cutting technologies and 3D printing, which now also allows the printing of metals. Their practicality is undoubted, although these solutions are regarded as novelties in the process of digital transformation. This transformation in manufacturing is based on digitalisation, and it will bring a hybrid solution by merging the virtual and the real world. The important elements of industrial digitalisation are those individual components which, for example, are able to communicate with each other, or to manage and control their own operation.

In the followings, we will present the agent-based approach of a cyber-physical system, in a way that the structure of the agent will be brought back to its basic elements and a parallel will be drawn between the system on package approach and the structure of cyber-physical systems. There is no doubt that cyber-physical systems have long appeared in many fields of our everyday life. This trend can also be observed in the European economy, industry and manufacturing.

A Smart Factory has both physical and cyber infrastructure. Electricity is provided by the physical infrastructure, while cyber infrastructure refers to communication and computer networks which ensure monitoring and controlling functions and enable interaction and feedback through smart industry to social-economic networks.

In order to improve economic conditions, innovation and investments must be combined with accelerating digitalisation, and by using the synergy of different systems [5], smart economy, smart industry, smart manufacturing and smart products must be realised within a smart city. This trend fits into the concept of Industry 4.0.

Industry 4.0 refers to the 4^{th} industrial revolution which is going on today. It originates from the German industrial trend which brings a technological change in manufacturing. This change is due to, for example, the spread of cyber-physical systems, of the AI, IoT, Big Data, Cloud Computing and M2M communication. The complexity of the products manufactured today is continuously increasing, while their lifetime is becoming shorter due to this complexity. Computer supported manufacturing has long helped the work of industrial players. However, shorter product lifetime, fast-changing market trends, the great diversity present in every field of life and unique consumer demands mean that a flexible manufacturing structure is needed to produce the products of the future. Therefore, the real Smart Product [6] can only be produced by a Smart manufacturing system. [7]

2. Research questions and hypotheses

Our research aims to answer three major questions:

Research question 1. What is the relationship between automation, digitalisation and the development of intelligent systems?

Research question 2. What does Machine Intelligent Quotient (MIQ) mean and is it possible to measure and define it?

Research question 3. Is there any rationale for using intelligent systems?
Hypothesis 1. Automation and digitalisation influence the characteristics and materialisation of intelligent systems.
Hypothesis 2. The intelligence of machine systems can be defined with the help of Smartness Indicators.
Hypothesis 3. Intelligent systems have an important role in ensuring sustainability and the well-being of humans.

3. General Smart System Theory

According to Aristotle, things should be approached from the point of their purpose. The purpose of intelligent systems is to make the human environment more "people-friendly". In case of manufacturing systems, this means the development of competitive, sustainable, safe, economic, flexible manufacturing systems which can be organised into a functional network. These intelligent or smart systems can be categorised in accordance with the system theory developed by Boulding (see Fig.1). According to our definition "An intelligent system is in which different structures are able to co-operate with each other in a coherent way. A smart system is an intelligent system in which services can be exploited by users to their maximum." [8] This definition implies that a more complete approach is needed to create such intelligent systems. This approach is represented by the holistic methodology. [9]

The concept of holism originates from the Greek word of "ὅλος" ("holos"), which means "complete" or "whole". The use of the holistic attribute is justified by the integration involving the complete structure which is related to the theme of industrial systems being researched. Therefore, the concept of digitalisation can be better defined than by the traditional system approach, if it includes all the aspects which are related to the industry. On the other hand, if these multiple factors are considered, this system will have a significant complexity. The complexity of systems is described by the Complexity theory. In case of personalised manufacturing, both production processes and smart products require much more complex solutions than those of mass production.

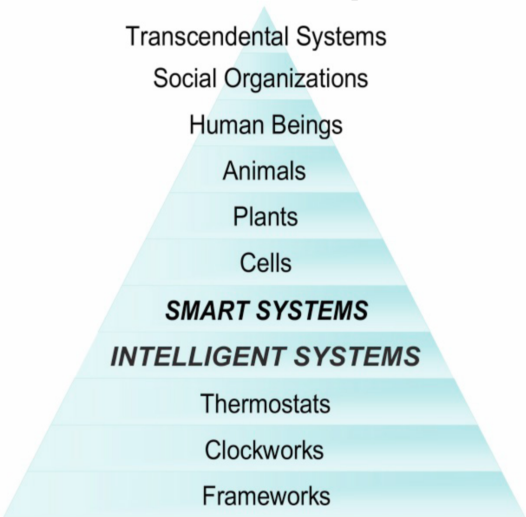

Fig.1. Boulding's Classification of Systems modification by Tokody's Intelligent System Theory [10] [11].

4. Smart System design

The basic idea of smart system design is the realisation of communication-based operation between the various units, where communication must have a uniform format. Therefore, in case of smart systems, network vision means that every machine/unit/holonic agent must use the same language, and the standards defined for this purpose will play an important part in the future development and success of this concept. Of course, it is possible that holonic agents will be able to communicate in more than just one "language", and therefore they will be capable of involving their less "intelligent" counterparts in the task-oriented ad hoc cluster which they create temporarily in order to achieve their goals.

What is the motivation to create such ad hoc clusters? Of course, it is the aim to perform a given task. In order to perform the task, the method of processing semantic information is required. [12] With the development of machine systems, instead of the former data processing performed by "mechanic" formal operations, it has become possible to create a global structure based on the performance of semantic operations which focus on meaning and content and which is closer to human thinking. This methodology can be used to connect the data generated in smart systems and their connotations.

Through the creation and networking of smart products and data-controlled services ensured by smart manufacturing, further valuable information can be gained during operation, which can make these processes more flexible, which in turn can result in reduced costs and shorter launch periods. According to Germany Trade and Invest, by 2021, 80 % of industrial investments will have been done within the scope of Digital Economy, and the increase of efficiency with regard to the whole economy will reach a volume of approximately 18%. By 2025, digital development will have generated up to EUR 425 billion of growth potential in Germany.

How and by what devices can be such systems created which help to achieve these goals? Agent design is a new area of research in the development of intelligent systems today. In our view, by developing a generally applicable (holonic) agent device (see Fig.2/b) the digital processes can be catalysed. To start with, it is a good example to consider the industrial trend which enables a single chip to have such characteristics which were formerly provided by the combination of different units. The "More-than-Moore" device (see Fig.2/a) is an integrated tool which is able to interact with the outside world and which includes a digital processing and storage and a power supplying sub-unit. It is in interaction with the outside world and it can detect the surrounding processes intervening in them if necessary. Following this analogy, a holonic agent has artificial intelligence, and stores the knowledge necessary for operation in ontologies with the help of semantic knowledge representations. It can also gain its knowledge by learning. With the help of this knowledge, it is able to change its environment. As the system on package or the system on chip is the building unit of a higher-level system, the holonic agent can also be the part of a greater whole.

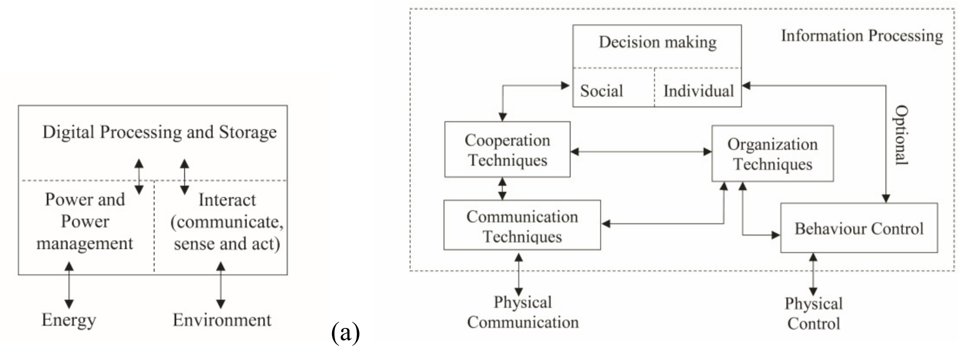

Fig.2. "More-than-Moore" devices (a) [13], generically applicable agent-oriented Holon architecture (b) [14].

The two rather different applications have some common basic properties. In both cases, sensors are used to collect various data about status, location or energy consumption, and their ability to communicate is also similar. [15] They achieve efficient operation by analysing the collected information in a combined way. This general method is the basis of preventive manufacturing or preventive maintenance. By making preliminary calculations, significant cost reduction can be achieved, due to the Data Driven methodology. [16]

In Europe, the development of a digital ecosystem has a great importance from the point of sustainability. Digital technology changes the entire range of economy and industry, and consequently, the structure of the manufacturing system, too. The informatisation of the industrial sector greatly affects for example the quality of life or energy efficiency. [2]

In smart manufacturing, communication has a key role. Man, Machine and Product communication must be realised. From the point of communication, the digital transformation of factories has three basic elements with regard to real-time data flow: data transmission protocols, data representation and presentation, and semantics or understanding data. [17]

Traditional Storage Programmable Systems will be replaced by CPSs. In manufacturing processes, humans have a more direct relationship with manufacturing robots, therefore, it is important to use parallel robot manipulators with a greater degree of freedom. [18] The articles by Mester et al. present such intelligent robots which help to build more flexible or adaptive systems. They can also be used in a Smart Factory. [19] [20] [21] [22]To achieve these manufacturing processes, it is necessary to realise the afore-mentioned “single-language” communication between humans, machines, logistic units and products in a real time by ensuring the critical information transmission processes. [16]

The holonic agent can be considered as a cyber-physical system which helps to achieve a self-organised production process. The Smart Factory performs a technological integration, for example by using smart materials (e.g. Shape-memory alloy, austenitic steel [23]) besides traditional materials. It is capable of M2M communication to transform materials, and it uses smart machines (with high degree of automation, human-robot co-operation) to create smart products. (see Fig.3)

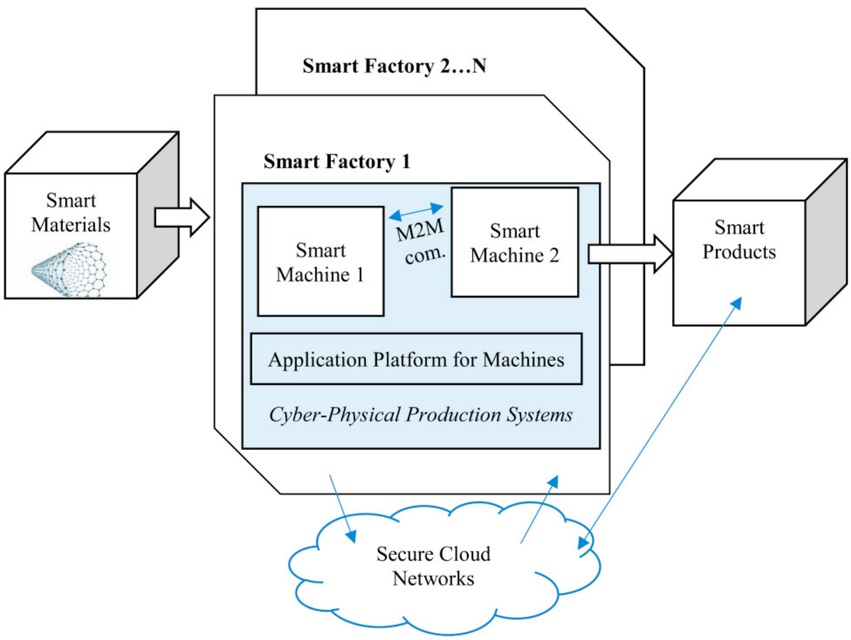

Fig. 3. “Smart factory” concept [24].

A Smart Product is supplied with memory, sensors and communication capacity. A Smart Product is able to store all information about its creation and its full lifecycle, and it is able to change its environment by monitoring both itself and its environment. [6] [16] In other words, a Smart Product can also be a CPS. With the networking of systems, further paradigms are integrated into manufacturing, such as, for example, Cloud Computing.

Cloud manufacturing is a new-generation, centrally controlled, service-oriented and networked manufacturing paradigm, which ensures the resources and services for users at various locations. The mainstream research topics of Cloud manufacturing focus on CPSs systems. [25]

The spread of cloud technologies brings new opportunities for manufacturing systems. One of the basic technologies of cloud building which can be used in case of manufacturing systems, and which is further confirmed by the holonic system approach, is Cluster technology. In case of a cluster, several components are doing the same activities, but from the world outside the cluster, the operation gives the impression of a uniform service. The members of the cluster have a democratic and equal relationship. In case of a failure, the operating members decide on the conditions of further operation. [26]

The theory of the Internet of Things can also be integrated into the model of smart manufacturing. The IoT is defined as an infrastructure which connects the objects, systems and information sources with the help of an intelligent service, while it also allows the processing of information from the physical and virtual world and is capable of reacting to them. [27] According to its definition, the IoT is connected to the CPS structure on a one-to-one basis, it is integrated into and also uses the Cloud, and the manufactured Smart Products are the "things" which can be connected into a network either via the internet or they can create cloud servicing or cloud manufacturing.

4.1. Generic Design Theory for Smart Systems such as a Smart Product

A smart product is a system in itself, and the system itself is a smart product, as it is suggested by the holistic approach. The basic structure of the system as a product includes a hardware and a software element which produces the generic product (such as, for example, the generically applicable agent-oriented Holon). From this basic/application-independent Holon and its supplementing application software and hardware, a generic application will be created, which can also be a generic CPS. This cyber-physical system can be generally used in managing, controlling and regulating systems. With the help of various application data, Holonic Manufacturing Systems can be created from this generic CPS. (see Fig.4)

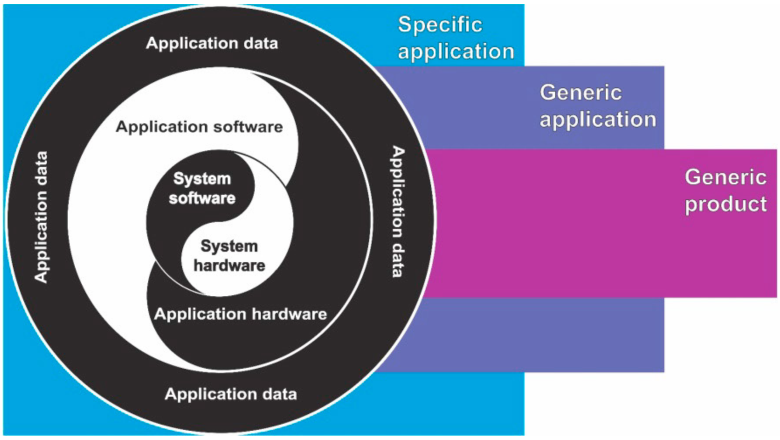

Fig. 4. The use of generic products for specific tasks [28] [29] [30].

4.2. Manufacturing ontology

In order to share knowledge among agents (to create distributed knowledge or distributed intelligence), it is necessary to develop concepts based on information and knowledge, which is the aim of ontology (the creation of a common language and dictionary). The mapping, defining, differentiating and paraphrasing of these concepts is called conceptualization. In other words, ontology describes the concepts and relationships in the world of agents. A key element of the development of artificial intelligence is the distribution and repeated use of knowledge. Ontology can be used for this purpose. Ontology is a hierarchic relation structure. In order to use the generated and stored data for decision making in the real world, a more specialised and more concrete domain-specific scheme must be created. In conclusion, a semantic network, a holonic network metadata-infrastructure must be developed, which allows the integration of data, the definition and description of their relationships, and the interpretation of such data. The intelligent knowledge representation network, based on a self-describing document, with the help of metadata, will be able to draw conclusions in accordance with formal logical rules.

In complex industrial processes, different participants must co-operate. This interaction takes place among individual machines, and also in the processes within the factory or in other mechanisms inside or outside the company. Smart devices are connected by communication and knowledge. This knowledge management is needed to ensure co-operation or to achieve successful communication and manufacturing. [31]

The increasingly complex manufacturing process results in an increased amount of accumulated data, information and knowledge in the system, which requires widespread and increasingly complex knowledge share and distribution among agents. [32] By using a semantic network, agents will also be able to draw conclusions or perform various tasks. [33]

5. Measuring Artificial Smartness

What makes a manufacturing system smart? In 2014 the International Organization for Standardization/ International Electrotechnical Commission Joint Technical Committee defined smartness as the following: Smartness means the abilities to use resources efficiently and seamlessly in order to achieve specific goals. In other words, smartness means how efficiently can different systems, sub-systems, humans, organisations, economic players, establishments, infrastructures, etc. operate individually and co-operate with each other. Therefore, they are able to co-operate and achieve holistic operation in an integrated and coherent way in a system, by using potential synergies. [34]

The degree of smartness can be defined by using Smartness Indicators. [35]

5.1. Defining Smartness Indicators

According to Lee et al., with regard to cyber-physical systems, the level of smartness can be defined with indicators of the 5C classification of their architecture. The first level is the Smart Connection level which describes, for example, Plug&Play technology. The next level is the Data-to-Information Conversion Level. This level refers to those systems which have a functionality of clustering for similarity in data mining. The fourth level is the Cognition Level, where systems are capable of collaborative diagnostics and decision making. And finally, the fifth level is the Configuration Level. The systems achieving the smartness level of 5C are also able to self-adjust for variation, Self-configure for resilience and Self-optimize for disturbance. [36]

6. Conclusion

The development of smart systems based on experimental results provides new information about smart systems. Automation is the first step toward intelligent systems. Digitalisation is taking place in an increasing number of applications including manufacturing. Our article has argued that it is possible to create a generic holonic agent, which can be further used to develop a generic CPS. A generic CPS gives the opportunity to build a Smart Factory. The definition of smartness provides basis for defining the Smartness Indicators which help to categorise various systems into five smartness levels. Intelligent systems play an important role in ensuring sustainability and the well-being of humans by giving manufacturing systems greater flexibility and efficiency.

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