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The Smart Factory: Exploring Adaptive and Flexible Manufacturing Solutions

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Abstract

Nowadays we live in a world,whicha decade ago would only be described in the science fiction literature. More and more things become *smart* and both scientists and engineers strive for developing not only new and innovative devices, but also homes, factories, or even cities. Despite of continuous development, many of those concepts are still being just a vision of the future, which still needs a lot of effort to become true.

This paper reviews the usage of adjective *smart*in respect to technology and with a special emphasis on the *smart factory* concept placement among contemporary studies. Due to a lack of a consensus of common understanding of this term,a unified definition is proposed. The conceptualization will not only refer to various*smart factory* visions reported in the literature, but also link the crucial characteristics of this emerging manufacturing concept to usual manufacturing practice.Subsequently, the authors discuss the challenges of the potential *smart factory* applications in SMEs, and also propose a future research outlook in order to further develop the *smart factory* concept.

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1. Introduction

Nowadays people are surrounded by many things that are called *smart*. Nearly everyone have a *smart*phone, some people have *smart* homes [1], which are connected to *smart* grids[2]. South Korea's government in collaboration with the local industry haseven launched the project to build the*smart* city [3]. In order to create those large *smart*

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systems, *smart* devices[4]havebeen used. The label*smart* (and interchangeably used– *intelligent*) seems to be abusedin many different contexts, because itsmeaning with regards to objects is yet not clearly defined.

Smart, in some contexts, refers to an independent device, which usually consists of: a sensor, and/or an actuator, a microcomputer and a transceiver[5]. However, adjective *smart* is alsocommonly used to characterize an object that was enhanced by implementation of additional features, which introduce multiplatform communication and increase its computational abilities. The *intelligence* of suchdevicecan be revealed by cooperation in a network of other *smart* devices, which havethe ability to check the system state updates and decide whether to act on them or not [5]. What is not surprising, such a network is called a *smart* network[5].One can also find a reference to *smart* objects, as items having the ability to store, link related data as well as may offer access to it for a human or machine consumer[4]. There are also *smart* products, which are equipped with memory understood as a sort of product diary [4].

In the case of homes, *smart* is frequently used as a synonym of excessively automated [6][5]. It also refers to homes with systems for monitoring and controlling appliances [2].What is important, a monitoring function should not be limited to turning devices on and off; devices included in a *smart* home should be able to operate semi–autonomously according to the predefined patterns or user requirements [6].

The overuse of the adjective *smart* is frequently encountered. For example, some scholars write about *smart* radio-frequency identification(RFID) tags [7]. Even though RFID tags comply with a number of above mentioned definitions of *smart* devices, those are inherent properties of each RFID tag, so adding aRFID tag label *smart* is a misuse (due to the lack of enhancement of a basic product).

It has been observed, that scholars have started to use the term *smart factories* in describing their visions of future manufacturing. However, there is no consensus about a clear definition of what *smart* means in respect to manufacturing facility. That is why, the purpose of this paper is to survey a considerable literature and summarize the *smart factory* concepts from a combination of different literature streams in order to clarify the term and develop a uniform definition that will contribute to the future research within this field.

2. Smart Factory - different visions of a concept

The term *smart factory* is used by both industrial practitioners and scholars, but there is no consistent definition. There are several other terms used in terchangeably: aU-Factory (ubiquitous factory) [8], a factory-of-things [9], a real-time factory [11], or an intelligent factory of the future [7]. Scholars refer to *smart factory* as a technology [10], an approach [11][9],or a paradigm [8].

2.1. A conceptual frameworkof Ubiquitous Factory

Yoon et al.[8],have developed a conceptual framework based on product design, manufacturing, and recycling via so called ubiquitous computing technology. According to them, the conventional manufacturing paradigms, such as flexible-, lean-, holonic-andagile-manufacturing systems are not very promising in solving the main contemporary manufacturing problems e.g. inaccuracy in the demand forecasting or difficulty with individualized production control. The authors find potential and capabilities in following the idea of Weiser [12], who introduced the concept ofubiquitous computing technology in manufacturing. The key characteristics of U-Factory (which they denote as a synonym of *smart factory*) are to be: information transparency, autonomous control, as well as sustainable manufacturing. The main means for implementing this vision are said to be: compatibility with i.a.RFID, UbiquitousSensor Networkor Real Time Location System (RTLS) technology [8].

According tothe vision of Yoon et al., the U–Factory should be *"an innovative factory combining ubiquitous computing technology as an enabler for solving problems on the shop floor with existing components"*[8]. Therefore, they define U–Factory as *"a factory system in which autonomous and sustainable production takes place by gathering, exchanging and using information transparently anywhere anytime with networked interaction between man, machine, materials and systems, based on ubiquitous technology and manufacturing technology"*[8]. Nevertheless, the U-Factory concept has not been realized yet. What is more, in order to progress, it is still necessary to develop *"software and hardware technology, including manufacturing technology, information technology and ubiquitous technology, and to combine them"*[8]; what is in the pipeline for their upcoming research. This is where we still may be waiting for the technology, which 5-10 years ahead may give new possibilities to realize the *smart factory* vision.

2.2. Smart Factory embedded in wireless communication infrastructure

Another vision of a factory of the future has emerged as a collaborative initiative (SmartFactoryKL, Technology Initiative) of academic (German Research Center for Artificial Intelligence DFKI) and industrial (Siemens, Bosch, BASF and Endress – Hauser among the others) partners in Kaiserslautern, Germany. It waspresented by DetlefZuehlkeon the pages ofAnnual Reviews in Control [11].The presented goals were: *"thedevelopment, application, and distribution of innovative, industrial plant technologies and to create the foundation for their widespread use in research and practice"*[11]. Zuehlke, realisticallypoints out that in the current stage of technological development we are still far away from Weiser's vision of ubiquitous computing: *"…when technology recedes into the background of our lives"*[12].

Smart factory in Zuehlke's view is a way towards a factory-of-things, which seems to be very much aligned with Internet-of-things (IoT). The IoT in this vision is perceived as an open network of items equipped with enough computing and communication capabilities togive them an ability to act independently, without direct human intervention [13]. Contrary to Yoon et al., Zuehlke strongly indicates the role of the conventional manufacturing paradigms, namely lean technologies, which, with help of upcoming *smart* technologies, should lift manufacturing systems into more advanced level. Prerequisites for *smart factory* described by Zuehlke are: a degree of intelligence embedded in all, even very small, coupled devices, while some of the important functionalities should be provided by RFID technology. A *smart factory* should not only have a modular structure, but also be interconnected by a wireless network, where each device could have its own IP(Internet Protocol) address [11]. Zuehlke indicates few very important challenges of this visionary system - lack of a dominant standardized protocol and compatibility to make devices easily work together,and regulations allowing process control. Moreover, before all those devices will constitute to create a *smart factory*, their safety and reliability needs to be thoroughly tested.

The next generation of manufacturing is also studied at the University of Stuttgart, where, based on Weiser's *smart* environment approach [12], Lucke et al.[9] tried to interconnect a physical (i.e. position of a tool) and a digital world (i.e. electronic documents) [9]. They define a *smart factory* as *"a factory that context-aware assists people and machines in execution of their tasks […] by systems working in background, so-called Calm-systems and context-aware applications."*[9]. *Context-awareness*refers to knowledge of position and status of objects of interest, where so-called *calm-systems* are its hardware and *context-aware applications*arethe software [9]. In their view, the key characteristics of such system should be: the ability to enter into a real-time communication and interaction with its smart environment, where the relevant manufacturing information is decentralized. In their opinion wireless communication is also necessary; therefore Wi-Fi, Bluetooth, WIBREE or ZIGBEE could be used. Authors have already developed software to be applied in *smart* factory:the Nexus Platform [9]. Elements used to create a *smart factory*should set the main focus on the execution, maintenance, and education functions of a manufacturing enterprise[9].

2.3. Glocalized Factory

A slightly different vision of a *smart factory* is provided by Hadar and Bilberg [14],who propose a decentralized supply chain setup. In this case they focus more on the factory function and do not define its actual design. Instead of building few, centralized factories, which would be a part of the global supply chain they suggest a local focus setup where a set of intelligent facilities - reconfigurable *smart factories*- would be able to completely supply a predefined area of market [14]. The authors investigate manufacturing challenges in Western Europe, their research focuses on global Danish companies like LINAK, STRECON, or LEGO, which face problems related to globalization and fragmentation of production, which increase supply chain complexity [15]. A glocalized approach, which they propose can be applied by large companies that not only operate in global markets, but also have many suppliers in different part of the globe [14]. On a supply chain level *smart factories* are characterized as self-sufficient facilities, which source raw materials from local suppliers. Those local partners and alliances should help in decrease lead time, minimize inventory and at the same increase customization and responsiveness of the supply chain, due to proximity both to suppliers and customers.

3. Smart Factory –a meaning and conceptualization

All above mentioned concepts and visions are very promising prospects of upcoming technological development. Nevertheless, even though both engineers and researchers are continuously working on those concepts, itstill remains just a vision. Despite of all involvement and success stories there is a long and winding road to go and multidimensional problemsto solve before we will transfer the vision of the *smart factory*into the reality. Zuehlke estimates the development enabling technologies for at least 5 - 10 years (from 2010) [11].

3.1. Smart Factory features and characteristics

Before mentioned visions of a *smart factory*are lacking to provide its clear definition. It seems that they focus too much on vague descriptions of used technologies like *ubiquitous*[9]and*Calm-systems*or *context-aware applications* [10], instead of providing more general characteristics of this solution. Moreover, based on previously mentioned visions, one could have an impression that (already old)Wi-Finetworks and RFID tags seem to be prerequisites for creating or implementing the *smartfactory* solution. It sounds like a significant limitation to presented theories, mostly due to neglecting the possibilities of other available technologies, underestimating future innovative solutions, andomitting other dimensions (e.g. organizational).

There are many technologies which could be used in a *smart factory* setup, but instead of going into their scrutinize review,the focus here is on functionalities that this factory should perform. The report about the future manufacturing in Europe points out that in the future, manufacturing companies will depend even more on flexibility and low cost [16], so an exemplary approach to achieve both of those properties simultaneously, is to work with modules and platforms[16].

Another multidisciplinary trend, which is underlined by the European report [16], iscollaboration across various types of borders e.g. cultural, geographical, cross-disciplinary etc. Those could increase the success rate of problem solving due to exchange of knowledge across many levels. Particularly in manufacturing field, those collaborative examples are still quite rare, but some have been reported in supply chain collaboration [17] and in knowledge sharing in collaborative engineering [18]. Scholars also suggest a combination of flexible and reconfigurable manufacturing systems [19][20][21], and underline importance of agility and leanness [22][23]. New emerging manufacturing trend, which could be very much linked to glocalized factory [14], is an adaptive or transformable manufacturing [24][25][26].

3.2. Smart Factory definition

Based on an analysis of future manufacturing literature, features that are desirable for the *smart factory* would relate to being flexible and reconfigurable, low cost, adaptiveor transformable, agile and lean. One of the ways to achieve some of those functionalities would be to apply modular structure with respect to both product/process technology and organization. Therefore as for a conceptualization we would suggest to a definition as follows

A Smart Factory is a manufacturing solution that provides such flexible and adaptive production processes that will solve problems arising on a production facility with dynamic and rapidly changing boundary conditions in a world of increasing complexity. This special solution could on the one hand be related to automation, understood as a combination of software, hardware and/or mechanics, which should lead to optimization of manufacturing resulting in reduction of unnecessary labour and waste of resource. On the other hand, it could be seen in a perspective of collaboration between different industrial and nonindustrial partners, where the smartness comes from forming a dynamic organization.

However, if we agree, that the adjective *smart* is used to characterize an object that was enhanced by additional features that increased its abilities, then the new conceptualization of the *smart factory* will definitely cover existing visions.

4. *Smart Factory* – an extension to SMEs

Important common denominators of visions discussed at the beginning of the paper are large companies and big organizations, which often operate in global markets. Applications of all aforementioned*smart* devices in *smart factories* aim at solving problems of global players. Those technologies are supposed to solve the problem of complexity of supply chains, but at the same time due to technological advancement they make the setup more complex by themselves.

4.1. Smart Factories for SMEs

Even after realization of so far discussed *smart factory* visions,would manufacturing small and medium enterprises (SMEs) be able to afford the cost of purchasing and maintenance of thissolution? One of the important drawbacks of*smart factory* visions existing in the literature is the lack of concepts applicable in SMEs. Most of them have a need for automation solutions in the area of manufacturing, which could be developed and applied in order to optimize their current operations. Those solutions may not be technologically as advanced as previously proposed *smart factory* visions, but the key characteristics would be affordability especially in terms of potential financial investment. What is more, previously discussed solutions are in the development by large organizations (like Siemens) or for large organizations (like LEGO)Our exploratory research conducted among manufacturing in the region of Southern Denmark concluded that despite of a big knowledge, experience and skills of industrial automation suppliers, in order to develop solutions for small companies, there is a need of in-depth understanding of their problems, needs and capabilities. Therefore development of *smart* automation solutions by SMEs for SMEs may be much more feasible than in the case when there is a disproportion of power. Similarobservations were also made by Westhead and Storey[27], who point out the uncertainty of the environment as well as consistency of motivation and actions as crucial distinguishing factors between large and small firms.

4.2. Automation solutions for SMEs

The literature about automation solutions for SMEs is very limited. Wadhva[28],basing on an action research approach, creates guidelines for flexible automation, which could improve foundries' responsiveness as well as support interaction between different collaborative partners. In a research related to foundries as well, Ribiero et al. [29] developed a methodology for benchmarking and got as far as to propose the performance measurement framework. An attempt to implement a *smart factory* concept in SMEs could allow for manufacturing several different products and at the same time, increase the degree of machine utilization, reduce in-process inventory as well as decrease response time in order to meet customer preferences. Additionally, in case of SMEs, it could also be a great help in the process of increasing their competitiveness and productivity.These years scholars discuss a lot, what may be the manufacturing of the future.This has taken place among universities and leading companies.Manufacturing activity represents about 21% of the total EU GDP [28]. What is more, it provides approximately 20% of all jobs in industry, which are largely dominated by SMEs [28]. That is why, we foresee that research conducted particularly in the field of manufacturing focused at SMEs have a huge potential not only in improving quality and delivery time of products, but also in generating widely understood wealth.

5. Conclusion

Much has been written about different *smart* objects, without a clear definition of this term. What is more, misuse of the adjective *smart* is not uncommon.This paper puts a special focus on the *smart* label with regard to factory and extension of the concept. Adopting a consistent definition of *smart factory*, and building upon it, would help to accelerate our understanding of this emerging approach to future manufacturing. We hope that our compilation of existing *smart factory* visions, along with grounding it in the traditional manufacturing theories, will help us move in this direction as a community of scholars.

So far the *smart factory* is just a great revelationof future developments in manufacturing facilities.The concept still needs to progress before fully reaching its practical application in an industrial production set up. In terms of solutions for large companies, most of the technologies are not yet mature to serve the realization of smart future manufacturingvision. As for research focused on SMEs in the field of automation and manufacturing, due to a scant attention given to this group as well as an incomplete understanding of their future production prospects, new research would be necessary to fill up this gap.

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References

[1] L. Jiang, D.-Y. Liu, and B. Yang, Smart home research, in Proceedings of International Conference on Machine Learning and Cybernetics, 2004, pp.659–663.
[2] A. Al-Ali, A. El-Hag, R. Dhaouadi, and A. Zainaldain, Smart home gateway for smart grid, in International Conference on Innovations in Information Technology (IIT), 2011, pp.90–93.
[3] D.-H. Shin, Ubiquitous city: Urban technologies, urban infrastructure and urban informatics, Journal of Information Science, vol.35, no. 5, Sage Publications, pp.515–526, 2009.
[4] W. Wahlster, SemProM: Foundations of Semantic Product Memories for the Internet of Things. Springer, 2013.
[5] R. S. Raji, Smart networks for control, Spectrum, IEEE, vol.31, no. 6, IEEE, pp.49–55, 1994.
[6] V. Ricquebourg, D. Menga, D. Durand, B. Marhic, L. Delahoche, and C. Loge, The smart home concept: our immediate future, in 1st IEEE International Conference on E-Learning in Industrial Electronics, 2006, pp.23–28.
[7] B. Hameed, F. Durr, and K. Rothermel, RFID based Complex Event Processing in a Smart Real-Time Factory, Expert discussion: Distributed Systems in Smart Spaces, 2011.
[8] J.-S. Yoon, S.-J. Shin, and S.-H. Suh, A conceptual framework for the ubiquitous factory, International Journal of Production Research, vol.50, no. 8, Taylor \& Francis, pp.2174–2189, 2012.
[9] D. Lucke, C. Constantinescu, and E. Westkämper, Smart factory-a step towards the next generation of manufacturing, in Manufacturing Systems and Technologies for the New Frontier, Springer, 2008, pp.115–118.
[10] C. N. Madu, C.-H. Kuei, J. Aheto, and D. Winokur, Integrating total quality management in the adoption of new technologies, Benchmarking for Quality Management & Technology, vol.1, no. 3, MCB UP Ltd, pp.52–66, 1994.
[11] D. Zuehlke, SmartFactory—towards a factory-of-things, Annual Reviews in Control, vol.34, no. 1, Elsevier, pp.129–138, 2010.
[12] M. Weiser, The computer for the 21st century, Scientific american, vol.265, no. 3, Nature Publishing Group, pp.94–104, 1991.
[13] J. Gubbi, R. Buyya, S. Marusic, and M. Palaniswami, Internet of Things (IoT): A vision, architectural elements, and future directions, Future Generation Computer Systems, Elsevier, 2013.
[14] R. Hadar and A. Bilberg, Glocalized Manufacturing - Local Supply Chains on a Global Scale and Changeable Technologies, Flexible Automation and Intelligent Manufacturing, FAIM2012, (2012).
[15] A. Bilberg and R. Hadar, Adaptable and Reconfigurable LEAN Automation - a competitive solution in the western industry, in FAIM 2012 22nd International Conference on Flexible Automation and Intelligent Manufacturing, Helsinki, 2012.
[16] I. Miles, M. W. ARC, and K. Flanagan, The Future of Manufacturing in Europe 2015-2020, EUROPE, vol.2015, p.2020, 2003.
[17] M. Cao and Q. Zhang, Supply chain collaboration: impact on collaborative advantage and firm performance, Journal of Operations Management, vol.29, no. 3, Elsevier, pp.163–180, 2011.
[18] D. Guerra-Zubiaga, L. Donato, R. Ramírez, and M. Contero, Knowledge Sharing to Support Collaborative Engineering at PLM Environment Practical Aspects of Knowledge Management, vol.4333, Reimer, Ulrich, ed. Springer Berlin / Heidelberg, 2006, pp.86–96.
[19] H. A. ElMaraghy, Flexible and reconfigurable manufacturing systems paradigms, International Journal of Flexible Manufacturing Systems, vol.17, no. 4, Springer, pp.261–276, 2005.
[20] M. G. Mehrabi, A. G. Ulsoy, Y. Koren, and P. Heytler, Trends and perspectives in flexible and reconfigurable manufacturing systems, Journal of Intelligent Manufacturing, vol.13, no. 2, Springer, pp.135–146, 2002.
[21] V. Malhotra, T. Raj, and A. Arora, Excellent techniques of manufacturing systems: RMS and FMS, International Journal of Engineering Science and Technology, vol.2, no. 3, King's College London, pp.137–142, 2010.
[22] J. Aitken, M. Christopher, and D. Towill, Understanding, Implementing and Exploiting Agility and Leanness, International Journal of Logistics Research and Applications, vol.5, no. 1, pp.59–74, 2002.
[23] D. Towill and M. Christopher, The Supply Chain Strategy Conundrum: To be Lean Or Agile or To be Lean And Agile?, International Journal of Logistics Research and Applications, vol.5, no. 3, pp.299–309, 2002.
[24] L. Wang and H.-Y. Feng, Adaptive manufacturing, Journal of Manufacturing Systems, vol.30, no. 3, Elsevier, p.117, 2011
[25] E. Abele, J. Elzenheimer, T. Liebeck, and T. Meyer, Reconfigurable Manufacturing Systems and Transformable Factories, Chapter 1: Globalization and Decentralization of Manufacturing, World Trade, pp.4–13, 2002.

[26] E. Westkämper, Strategic development of factories under the influence of emergent technologies, CIRP Annals-Manufacturing Technology, vol.56, no. 1, Elsevier, pp.419–422, 2007.
[27] P. Westhead and D. Storey, Management training and small firm performance: why is the link so weak?, International Small Business Journal, vol.14, no. 4, Sage Publications, pp.13–24, 1996.
[28] R. S. Wadhwa, Flexibility in manufacturing automation: A living lab case study of Norwegian metalcasting SMEs, Journal of Manufacturing Systems, Elsevier, 2012.
[29] L. M. Ribeiro and J. S. Cabral, A benchmarking methodology for metalcasting industry, Benchmarking: An International Journal, vol.13, no. 1/2, Emerald Group Publishing Limited, pp.23–35, 2006.