Augmented Reality in Complex Manufacturing Systems as an Informational Problem: a Human-Centered Approach

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Abstract. The informational complexity that characterizes future manufacturing environments raises new problems in the Information Science and Information Management fields. New facets of the information overload problem are being revealed e.g., as textual and "smart data" from the manufacturing processes are continuously generated and pushed to the workers, beyond their cognitive capabilities. The challenge of making use of augmented reality in manufacturing processes, empowering the human-worker, has not yet been addressed by Information Science as an information organization and retrieval problem. Furthermore, manufacturing processes are more and more knowledge-intensive, so knowledge codification, transfer, and use are another challenge not addressed so far from the information management point of view. Therefore, the objective of this doctoral research project is to study the combination of augmented reality technology (as a way to convey real/virtual visual information), centered in the human-worker (as the crucial key user) as an information organization/retrieval problem, from the theoretical perspectives of Information Field. In this poster, we present the research design and the preliminary results of the literature review.

Keywords: Augmented Reality, Human-Computer Interaction, Information Organization and Retrieval, Manufacturing Industry.

1 Introduction

The fast dissemination of complex manufacturing environments where human workers and automated devices (e.g., robotic devices) share physical and informational spaces is challenging the traditional ways of managing information in this type of organization [1, 2]. This dissemination is taking place under the movement of the so-called Industry 4.0 (i4.0), also known as the fourth industrial revolution, whose discourse is centered on the intention to create more intelligent and autonomous industrial organizations (also known as “smart factories”) as well as smart services, embedded in an internet of things and internet of services [3, 4]. Several concepts were created under this movement such as cyber-physical systems or digital twin, that aim to establish forms of interaction fundamentally based on a virtual copy of the physical world - the industry digitalization - but also facilitate the communication and cooperation with humans [5, 6], in real-time, to optimize and leverage their decision-making capabilities. The work here presented addresses one of the four long-term paradigm shifts in the European Production landscape: the empowerment of workers in the context of complex and knowledge-intensive processes [7].

Despite the increasing ambition to automate in all sectors of society, particularly in the industrial sector, the human worker will continue to be the most flexible entity in the production system since he/she will continue to plan, control, manage, and solve problems [1]. The digital transformation in which most of the manufacturing organizations are engaged with, pose another critical challenge: the exponential increase in the information (some call it now “smart data”) available to be retrieved or simply pushed to the workers. As in the past, information still has to be managed in order to be used efficiently and effectively alongside the tasks and processes of the value chains [8-10].

However, current worker-centered management tools in general and information management tools in particular still live in a logical-physical dichotomy, which hinders the human-worker from developing and applying the full potential of his ingenuity, creativity, and know-how. To overcome these difficulties, there is a need for a socio-technical change.

Current information and knowledge management systems supporting manufacturing activities are mainly designed and implemented for conventional product design and manufacturing operations. With the change of business models, and the evolution of technology, manufacturing industry need information management models capable of supporting the exchange and access to information in real-time (between all the stakeholders), the reuse of information in different perspectives or processes and effectively fostering knowledge sharing between the stakeholders[9].

2 Problem

Regardless of the current development in the technology and application of virtual reality and augmented reality (AR) approaches to manufacturing environments, the informational complexity that characterizes future manufacturing environments raises new problems in the Information Field. This happens in a socio-technical context characterized by collaboration-intensive processes - human-to-machine, machine-to-machine, and human-to-human - whose support requires not only information for operational action but also codified knowledge for learning.

New facets of the information overload problem are being revealed, e.g., as textual and "smart data" from the manufacturing processes are continuously generated and pushed to the workers, challenging their cognitive capabilities.

To the best of the authors’ knowledge, the challenge of making use of AR for manufacturing processes, empowering the human-worker, has not yet been addressed by the Information Field as an information organization and retrieval problem. Furthermore, manufacturing processes are becoming more and more knowledge-intensive, so knowledge codification, transfer, and use are another challenge not addressed so far from an information management point of view. Considering both the state-of-the-art and the identified research problem, the research questions that lead this doctoral research work are:

RQ1: What will be the role of AR technology towards the empowerment of the human worker and the improvement of the quality of working life?

RQ2: How can digital information management models and AR applications be combined to create powerful cognitive tools fostering support to action, learning, and collaboration in the factories-of-the-future?

To answer these questions, the following goals were established:

1. To map AR technology current and future applications in factories-of-the-future according to their potential for empowering the worker and improve his/her working conditions;
2. To develop an information/knowledge model capable of considering the context and the situation where human actions are occurring, to support human activities and collaboration-intensive processes both human-to-machine and human-to-human in a factory-of-the-future context by using AR technology.

The expected results will be used to create models for a new generation of information management tools, fundamental to empower human-workers and improve their work conditions in complex manufacturing environments where physical/virtual interaction will be predominant.

3 Methodology

The research paradigm chosen to develop this research project is the Design Science Research (DSR). DSR was originated in the general engineering principles and on the book "The sciences of the artificial" by Simon [11] and has been essentially considered as a problem-solving oriented research paradigm in the field of Information Systems [12].

Following the DSR process interaction described in [13], the following steps were planned: (i) problem characterization; (ii) definition of the solution objectives; (iii) design and development of artifact; (iv) demonstration and Evaluation; (v) and Communication. Case-Based Research (CBR) will be considered as the first option for this methodology. As Ketokivi and Choi [14] propose, there are three different methodological approaches to CSR, in order to analyze its methodological diversity and to increase its transparency: (i) theory generation (inductive research); (ii) theory testing (deductive research); and (iii) theory elaboration (abductive research). For the type of research to be developed in this doctoral project, theory elaboration will be the more effective methodological approach: data will be collected from case studies, possible theories will be drawn from literature, and adequate theory will be adapted in order to develop the required artifacts.

Moreover, a survey addressing the topics of research question 1 will be undertaken. The results of this survey will provide inputs for two case studies design, aiming to understand the current methods and approaches used within real application cases to manage the relationships between organizational knowledge, digital content and visual management. These case studies will be used to identify the main gaps and challenges that can be seen as main requirements for an effective AR implementation.

4 Preliminary results: a literature review

One of the literature areas related to this work is the human-machine interaction. "In the Smart Factories of (i4.0), the main role of humans shifts from an operator of machines towards a strategic decision-maker and a flexible problem-solver. [5:3933]. Also, as said by other authors, "today smart factories can exploit the linkage between the cyber-ends and the physics-ends to realize an interactive environment considering the external conditions, the features of machines and interface, and the workers' capabilities" [15:347]. For instance, in the context of i4.0, robots have a collaborative role: interact with humans and other robots. This recent improvement in human-machine and machine-human interaction will promote new ways of operation of manufacturing organizations.

As in the past, information still has to be managed in order to be used efficiently and effectively alongside the tasks and processes of the value chains [8]. Therefore, "Identifying and gathering the right data, deploying them for the right purposes, and effectively analyzing them will be critical in making the right i4.0 decisions." [16:467]. Visual computing is very important in i4.0 approaches since it can be thought of as unifying diverse applications. A key characteristic of the product configuration and manufacturing flexibility required for the adoption of i4.0 by the organizations is the application of visual techniques of products and processes [17]. This requires not only new ways of handling the sheer volume of information, but also new forms of organizing the information so that it can be understood by humans and will allow them to make decisions." [22:31]. Visual computing is a leading technology that is being identified as one of the critical technologies regarding i4.0. It can be interpreted as the whole field that concerns the acquisition, analysis, and synthesis of visual data through means of computers that provide relevant-to-the-field tools [18-20]. AR is an example of these technologies, and although it has been around longer than we might think, only in the last few years, we have seen companies and researchers exploring its practical applications for manufacturing [21-24]. From these studies, it is clear that there are many promising manufacturing applications for AR, including training, factory planning, maintenance, automation, and assembly. However, most of the recent research focused on technological and managerial aspects, leaving behind the information management aspects, fundamental to deal with the organizational context, and for the success and sustainability of the AR applications [25].

The high potential for using the AR approaches in complex manufacturing environments is well known and is being researched and exploited for many years. AR approaches have an impact on people's knowledge of the environment around them by overlaying information in the context of the real world [26]. We can find approaches to the use of AR in particular processes such as learning [1], maintenance operations [27] or visual management lean techniques using the operational information [26]. As Capozzi et al. stated, the "Visual approach is commonly used for information transfer in productive environments where many management and production operations are guided/ helped/ facilitated by visual information" [31:235]. Nevertheless, most of the empirical studies do not address the development of knowledge management processes and tools to support and leverage the application of i4.0 technologies [2]. It is, therefore, relevant to study this problem from the viewpoint of information/knowledge organization and to propose new ways to manage information and knowledge to support visual-based, collaboration-intensive processes in the factory.

Reviewing the literature, we can perceive the importance of building a model capable of considering the contextual and all dynamic information that represents the situation where actions are occurring. Thus, the capability to visualize and manipulate data and information has a direct impact on the way how the information can be perceived, understood, and interpreted and, consequently, dictate the quality and efficiency of the decision making [28]. Additionally, the information should be context-adaptive, ensuring the usefulness in and to different contexts [28]. Information visualization must work as an interdisciplinary discipline focused on the way how complex information can be understood through its visual representation of complex information. The role of information visualization must be seen as a way to show information in the proper way in order to leverage the natural human cognition capabilities to resolve problems, to think, and reason [29].

Organizations must understand the importance of promoting employees' capability to "consume data" is as important as the capability to capture, processing, and store this same data. We can see Business Information Visualization (BIV) as the way of using a computer-supported interactive visual representation of the business data to amplify cognition and consequently improve business understanding, towards a more effective decision making [39]. As defined by these authors, BIV is based on the need to use computer-supported interactive visual representations of business data (e.g., communication boards) to amplify cognition, support communication and a better understanding of the system to improve problem-solving and decision making to create business impact [30-32].

5 Conclusions and future work

Aiming to support augmented reality application in i4.0 context, this research project wants to demonstrate the importance of exploring information organization/retrieval and knowledge management domains. Indeed, most of the research focused on the technology and its technical and environmental application and not in the information management needed to deal with the organizational context and socio-technical problem that can support the success and sustainability of the AR applications.

As future work, a survey and two case studies will be developed in order to better understand current scenarios within real companies, as well as the gaps and limitations for augmented reality implementation, in order to support the problem statement and requirements definitions.

Acknowledgements. The first author was funded by the Ph.D. Grant PD/BD/143163/2019 from Portuguese funding agency, FCT - Fundação para a Ciência e a Tecnologia.

References

1. Quint, F., Sebastian, K., Gorecky, D.: A Mixed-reality Learning Environment. Procedia Comput. Sci. 75, 43–48 (2015).
2. Dalmarco, G., Ramalho, F.R., Barros, A.C., Soares, A.L.: Providing industry 4.0 technologies: The case of a production technology cluster. J. High Technol. Manag. Res. 100355 (2019).
3. Kagermann, H.: Change through digitization - value creation in the age of industry 4.0. In: Management of Permanent Change. pp. 23–45 (2015).
4. Hofmann, E., Rüsch, M.: Industry 4.0 and the current status as well as future prospects on logistics. Comput. Ind. 89, 23–34 (2017).
5. Hermann, M., Pentek, T., Otto, B.: Design principles for industrie 4.0 scenarios. In: Proceedings of the Annual Hawaii International Conference on System Sciences (2016).
6. Sniderman, B., Mahto, M., Cotteleer, M.J.: Industry 4.0 and manufacturing ecosystems: Exploring the world of connected enterprises.
7. Keller, M., Rosenberg, M., Brettel, M., Friederichsen, N.: How Virtualization, Decentrazliation and Network Building Change the Manufacturing Landscape: An Industry 4.0 Perspective. Int. J. Mech. Aerospace, Ind. Mechatron. Manuf. Eng. (2014).
8. Stock, T., Seliger, G.: Opportunities of Sustainable Manufacturing in Industry 4.0. In: Procedia CIRP. p. 536 (2016).
9. Wan, S., Li, D., Gao, J., Roy, R., Tong, Y.: Process and knowledge management in a collaborative maintenance planning system for high value machine tools. Comput. Ind. 84 OP-In, 14 (2017).
10. Dhuieb, M.A., Laroche, F., Bernard, A.: Context-awareness: A Key Enabler for Ubiquitous Access to Manufacturing Knowledge. In: Procedia CIRP. pp. 484–489 (2016).
11. Simon, H.A.: The Sciences of the Artificial. MIT Press (1996).
12. Hevner, A.R., March, S.T., Park, J., Ram, S.: Design Science in Information Systems Research. MIS Q. 28, 75–105 (2004).
13. Peffers, K., Tuunanen, T., Rothenberger, M.A., Chatterjee, S.: A Design Science Research Methodology for Information Systems Research. J. Manag. Inf. Syst. 24, 45–78 (2007).
14. Ketokivi, M., Choi, T.: Renaissance of case research as a scientific method. J. Oper. Manag. 32, 232–240 (2014).
15. Peruzzini, M., Pellicciari, M.: A framework to design a human-centred adaptive manufacturing system for aging workers. Adv. Eng. Informatics. 33, 330–349 (2017).
16. Lee, M.-X., Lee, Y.-C., Chou, C.J.: Essential Implications of the Digital Transformation in Industry 4.0. J. Sci. Ind. Res. 76, 465–467 (2017).
17. Posada, J., Toro, C., Barandiaran, I., Oyarzun, D., Stricker, D., Amicis, R., Pinto, E., Eisert, P., Döllner, J., Vallarino, I.: Visual Computing as Key Enabling Technology for Industry 4.0 & Industrial Internet. IEEE Comput. Graph. Appl. 35, 26–40 (2015).
18. Paelke, V.: Augmented reality in the smart factory: Supporting workers in an industry 4.0. environment. In: 19th IEEE International Conference on Emerging Technologies and Factory Automation, ETFA 2014 (2014).

19. Posada, J., Toro, C., Barandiaran, I., Oyarzun, D., Stricker, D., De Amicis, R., Pinto, E.B., Eisert, P., DÖllner, J., Vallarino, I.: Visual Computing as a Key Enabling Technology for Industrie 4.0 and Industrial Internet. IEEE Comput. Graph. Appl. 35, 26–40 (2015).
20. Shellshear, E., Berlin, R., Carlson, J.S.: Maximizing Smart Factory Systems by Incrementally Updating Point Clouds. IEEE Comput. Graph. Appl. 35, 62–69 (2015).
21. Choi, S., Jung, K., Noh, S. Do: Virtual reality applications in manufacturing industries: Past research, present findings, and future directions. Concurr. Eng. 23, 40–63 (2015).
22. Ferraguti, F., Pini, F., Gale, T., Messmer, F., Storchi, C., Leali, F., Fantuzzi, C.: Augmented reality based approach for on-line quality assessment of polished surfaces. Robot. Comput. Integr. Manuf. 59, 158–167 (2019).
23. Jetter, J., Eimecke, J., Rese, A.: Augmented reality tools for industrial applications: What are potential key performance indicators and who benefits? Comput. Human Behav. 87, 18–33 (2018).
24. Liao, T.: Future directions for mobile augmented reality research: Understanding relationships between augmented reality users, nonusers, content, devices, and industry. Mob. Media Commun. 7, 131–149 (2019).
25. Masood, T., Egger, J.: Augmented reality in support of Industry 4.0—Implementation challenges and success factors. Robot. Comput. Integr. Manuf. 58, 181–195 (2019).
26. Capozzi, F., Lorizzo, V., Modoni, G., Sacco, M.: Lightweight augmented reality tools for lean procedures in future factories. In: Lecture Notes in Computer Science (including subseries Lecture Notes in Artificial Intelligence and Lecture Notes in Bioinformatics). pp. 232–246. Springer Verlag (2014).
27. Espíndola, D.B., Pereira, C.E., Schneider, E., Ventura, R.: Improving Maintenance Operations Through Application of Mixed Reality Systems. 46, 11 (2013).
28. Bai, X., White, D., Sundaram, D.: Context Adaptive Visualization for Effective Business Intelligence. In: Ma, H and Wang, M. (ed.) 2013 15th IEEE International Conference on Communication Technology (ICCT). pp. 786–790. IEEE, NEW YORK (2013).
29. Patterson, R.E., Blaha, L.M., Grinstein, G.G., Liggett, K.K., Kaveney, D.E., Sheldon, K.C., Havig, P.R., Moore, J.A.: A human cognition framework for information visualization. Comput. Graph. 42, 42–58 (2014).
30. Bacic, D., Fadlalla, A.: Business information visualization intellectual contributions: An integrative framework of visualization capabilities and dimensions of visual intelligence. Decis. Support Syst. 89, 77–86 (2016).
31. Bateman, N., Philp, L., Warrender, H.: Visual management and shop floor teams – development, implementation and use. Int. J. Prod. Res. 54, 7345–7358 (2016).
32. Franklin, A., Gantela, S., Shifarraw, S., Johnson, T.R., Robinson, D.J., King, B.R., Mehta, A.M., Maddow, C.L., Hoot, N.R., Nguyen, V., Rubio, A., Zhang, J., Okafor, N.G.: Dashboard visualizations: Supporting real-time throughput decision-making. J. Biomed. Inform. 71, 211-221 (2017).