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Toward a Social Holonic Manufacturing Systems Architectures based on Industry 4.0 assets

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Abstract. For the last decade, the question of anthropocentric approaches has made its way through the research, and fully technocentered approaches have been questioned. The integration of social relationships between the components of systems has already been identified as a crucial issue for the future development of reference architectures. However, the current research lacks a global approach based on both consideration of the human as an integrated agent of the system and the use of social concept to characterize inter-agents' relationships. The purpose of this paper is to bring an overview of these aspects' consideration in the manufacturing control architecture and to outline some guidelines allowing to revise the architecture of reference PROSA.

Keywords: Industry of the future, MAS, HMS, CPS, IoT, Social approach, Human integration

1 Introduction

Over twenty years have passed now since the proposition of the PROSA architecture for HMS [1]. Based on the constant evolutions of the market and of the technology (especially Information and Communication Technologies (ICT)), many agile, adaptative & reconfigurable architectures for HMS control have emerged [2]–[9]. These architectures were using various approaches, like the centralized, decentralized, hybrid or product driven ones.

They have been classified by Cardin & al. [10] as “generic”, “multi-agent oriented”, “holonic architectures' extensions”, “service & cloud oriented” or “dynamic”. According to the authors, if Data have been established as well integrated into these, some issues appeared as maybe insufficiently challenged. Among them: ability to adapt to unplanned issues, sustainability, Data warehousing, and integration of the human in the loop. In short: these architectures are still mainly techno-centered.

Therefore, they are difficult to implement within actual industrial systems and their adaptation to future ones might stay uneasy.

Hence, future work should aim to answer the two following questions:

1. How to make today's reference architectures suitable for concrete implementation within concrete industrial systems?
2. How could these architectures take advantage from new concepts introduced by paradigms such as Industry 4.0?

Most of Intelligent Manufacturing System (IMS) community researchers agree on the lack of human aspects' consideration in manufacturing control architectures to answer these questions. Indeed, concrete industrial systems face with legacy systems, where multiple aspects of human factors need to be considered, e.g. cooperation support between either human or technological entities, development of human-inspired social interactions, integration of human on different decisional levels. Co-operation between human and technological entities has been widely studied, especially in air traffic, car/train driving and robotic applications domains. Concerning human-machine cooperation, many efforts have been provided about balancing human-machine interactions, improving human-machine communication, or understanding human behaviour [11].

Anyway, human integration in manufacturing systems is a challenging issue [12]. Cooperation must be established between different kind entities/agents from different nature, such as intelligent products, intelligent resources, or humans. Because of these differences of nature, cooperation between agents could be achieved through different approaches. Our idea is, that a social approach for the description of relationships between a system's different agents (human or artefact) might ease the future design and implementation of human-adapted Holonic and Multi-Agent Systems (MAS) control architectures into real systems as well as their apprehension by human agents.

We believe that integrating the human back in the loop into industrial systems, along with other agents is at the heart of the initiative Industry 4.0. As a matter of fact, Industry 4.0 is today taken as background for almost all current research and publications concerning these systems' architectures design. For this reason, we have chosen to investigate an approach based on the notions of Cyber-Physical Systems (CPS) and Internet of Things (IoT), which are fundamentals in Industry 4.0, applied to Multi-Agent Systems.

2 Industry 4.0 & its main assets

2.1 Industry 4.0

The Industry 4.0 [13] has burst out in 2011 during Hanover Fair, forwarding the effort that Germany was doing to promote computerization in industry. In 2013, the *Final Report of the Working Group Industrie 4.0* [13] was submitted, identifying several keys for successful implementation. If the concept was born in Germany,

many national initiatives are currently led across the world. We can especially mention the USA's "National Network for Manufacturing Innovation (NNMI)", the United Kingdom's "High Value Manufacturing Catapult (HVMC)", the South Korean "Manufacturing Industry Innovation 3.0 Strategy", the French "Industry of the future" and the Chinese "Made in China 2025" [14]. The innovative vision and concepts that all these initiatives brought have marked the beginning of what is now considered as the fourth industrial revolution, simply referred as "Industry 4.0".

Today's literature is mainly focused on the technological aspects and developments that will be needed to support the transition to future industrial's systems. Artificial Intelligence and all its aspects (neural networks, Big Data, Data mining & refining, Deep Learning, etc.) might be the most wildly known ones. These new technologies have brought out the two new paradigms of Internet of Things (IoT) and of Cyber-Physical Systems (CPS). In what follows, we will focus on these two notions, that have already been widely studied for the last 15 years. Our focus will be on the integration of human factors that is at the heart of Industry 4.0's considerations.

2.2 CPS & IoT

The CPS paradigm is commonly recognized as the main pillar of Industry 4.0. Since the popularity of this concept is rather new in the scientific world (first enunciated by Lee in 2006 [15]) and because of the wide range of its potential applications despite standardization attempts, its definition and limits are still fuzzy and unclear. In fact, the term of CPS is often associated with the one of Internet of Things (IoT), appeared in the 2000s [16]. Hence, IoT is the eldest concept, while the CPS term only appeared 7 years later.

For the Internet of Things, Madakan & al. [17] gave the definition of: "*an open and comprehensive network of intelligent objects that have the capacity to auto-organize, share information, data, resources, reacting and acting in face of situations and changes in the environment*". In this definition, the IoT is clearly considered as a link between physical objects within a system.

Cyber-Physical Systems were defined by Lee [15] as "*physical and engineered systems whose operations are monitored, coordinated, controlled and integrated by a computing and communication core. This intimate coupling between the cyber and physical will be manifested from the nano-world to large-scale wide-area systems of systems. And at multiple time-scales*". Here, the CPS concept is related to the notion of "coupling" between physical and computational objects, and this is the definition we will be willing to stick to.

Considering the previous definitions, the Bagheri & Lee's conception seems adequate to represent CPS and IoT as we see them. IoT linking objects through horizontal connectivity / synchronization and CPS using cloud and sensors connection to link physical objects to their digital twin through vertical connectivity / synchronization (Fig. 1) [18].

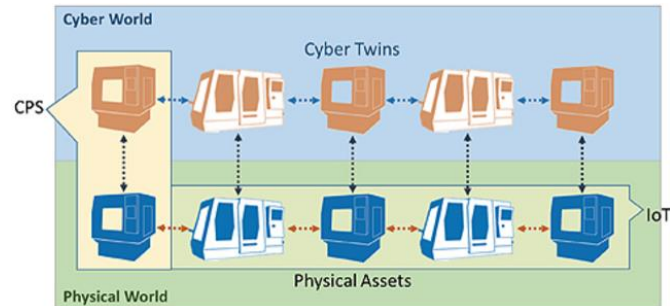


Fig. 1. CPS & IoT [18]

El Haouzi [19] as well as Bordel & Alcarria [20] stated that the definition and use of the terms CPS and IoT were differing depending on the scientific community (mechatronic engineering used to the CPS term) or to the geographical area considered (America: CPS; Europe & Asia: IoT). Hence, it is sometimes difficult to fully get an author's purpose, for its comprehension and use of these terms might be unclear. For this reason, we will not do any dichotomy based on the previous elements between CPS and IoT in the subsection 2.3 and the section 3.

2.3 The Industrial aspect

In the previous subsection, we are presenting the CPS and the IoT as pillars of the Industry 4.0. However, their industrial application is not obvious. The concept of Industrial Internet of Things (IIoT), Industrial Internet (II) or Cyber-Physical Production Systems (CPPS) has emerged as an implementation of IoT and CPS within industrial contexts.

Schneider [21] have stated that the IoT could be seen as divided into two main subsets: The Consumer IoT and the Industrial IoT (respectively CIoT & IIoT). The CIoT would concern the connectivity of things around humans while IIoT would exclusively be concerning connectivity around industrial things. It is defined as *“A system comprising networked smart objects, cyber-physical assets, associated generic information technologies and optional cloud or edge computing platforms, which enable real-time, intelligent, and autonomous access, collection, analysis, communications, and exchange of process, product and/or service information, within the industrial environment, so as to optimize overall production value”*. The IIoT is then considered as a fully techno-centered application of the IoT's concepts in the restricted area of an industrial system. In Boyes & al.'s publication [22], this approach is confirmed. The functions of the IIoT were there defined as *“to monitor, collect, exchange, and analyse information so as to enable them to change their own behaviour, or else instruct other devices to do so, without human intervention”*.

Hence, authors like Schneider, Boyes & al or Gilchrist [21]–[23] are putting forward a dichotomy between “humans” and “things” connectivity, humans being only considered as the “customers” of connected industrial things. These reasonings are

differentiating the human operator from other agents and are accentuating the lack of human-oriented considerations during the system's design. This leads to a system where human agents might face physical or mental overloads, lower their situational awareness, etc. perturbing the completion of their tasks and the global system itself. These issues are at the very basis of the "Magic human" phenomena [24] and are incompatible with Industry 4.0's considerations.

On the other side, Monostori's development of CPS [25] presents the CPPS as an interconnection of cooperative elements and sub-systems "*in situation dependent ways, on and across all levels of production, from processes through machines up to production and logistics networks*" that would be the communication's enabler and support between "*humans, machines and products alike*". In this conception, human's integration into systems is implicit: human-machine symbiosis is even enunciated as one of the future R&D challenges for CPPS. Though, it has to be taken carefully, for a too strong dependence of the human on the system could raise important issues [26]. In the next section, we will study some of the main - approaches that have been initiated for human integration.

3 Human integration

3.1 Human's current consideration

A little while before the advent of Industrie 4.0, the lack of consideration of the human factors into the development of CPS led Wang [27] to promote the concept of Cyber-Physical Social System (CPSS). With CPSSs, he assesses the importance of human factors' integration within systems. In order to achieve this integration, along with **cyber** and **physical** spaces, **physiological**, **psychological**, **social** and **mental** spaces are considered [28], [29].

This concern has been shared by Schirner & al. [30] and Pirvu & al. [31] who have respectively worked on the concepts of Human-In-The-Loop Cyber-Physical-Systems (HITL-CPS) and Anthropocentric Cyber-Physical-Systems (A-CPS). The later development of these being Cimini & al.'s Social Human-In-The-Loop Cyber-Physical Production System (Social-HITL-CPPS) [32].

HITL-CPS consists in an embedded system enhancing a human being's ability to interact with its physical environment and A-CPS is defined as a reference architecture integrating the three physical, computational/cyber and human components. The purpose of these works is the integration of human factors into systems (mainly but not exclusively industrial ones).

But even if the need to consider elements such as physiology, psychology, social and mental aspects is recognized, a neat distinction is made between humans and "things" constitutive of the system. The human is considered as a stranger needing to be integrated within a system through interfaces and then stays distinct from other agents. These approaches are forwarding technological development to link the human to the systems.

Concerning the Social HITL-CPPS, Cimini & al. [32] are defining humans as agents fully integrated to the system. The authors have identified the interpretation of human agent’s behaviour and their coordination with other agents as the two main challenges in the integration of humans into social environments (and not only manufacturing ones). To answer these challenges, a three-layer architecture has been proposed. This architecture is connecting, on one hand, human users to the cyber part through user interfaces, and on the other hand, physical parts (i.e. non-human agents & environment) to the cyber part through a network.

In all these approaches, human integration is achieved through human-machines or human-systems interfaces. Hence, these can be considered as techno-centered approaches for human integration. If the term “social” is here used as a keyword to mark the human-centered considerations of the authors, it can also refer to a completely different conception.

3.2 The social approach

In order to structure the IoT despite the growing number of objects composing it, Atzori & al. [33] have used the idea to cross Social Network Services (SNSs)’ patterns to the IoT concept, initializing the concept of Social Internet of Things (SIoT). Inspired from the Social Web of Things (SWoT) [34], the SIoT is built on the transposition to human’s relationships into society to intelligent objects into Multi-Agent Systems (MAS). According to Mala [35], this paradigm can be defined as a “*social network of intelligent objects bounded by social relationships*”. From the work of Fiske [36], the five following relationships are established: Parental Object Relationship (POR), Ownership Object relationship (OOR), Co-Work Object Relationship (C-WOR), Social Object Relationship (SOR) and Co-Location Object Relationship (C-LOR) (Table 1).

Table 1: Social Relationships [33]

Relationship	Description
POR	Established among usually homogeneous objects produced during the same period by the same manufacturer
OOR	Established among heterogeneous objects belonging to the same user
C-WOR	Established among objects collaborating to provide a common IoT application
SOR	Established among objects coming periodically or spontaneously into contact because of their owner’s relationship
C-LOR	Established among objects either homogeneous or heterogeneous objects used always in the same place

In this vision, social relationships are established and exploited among things, but not among their owners. The supportive architecture enabling object-objects interac-

tions, services and resources discovering in order to relieve human from any intervention is concretely excluding it. Nevertheless, social relationships are an interesting way to set up a better integration of the human holon into holonic architecture, and to facilitate the system's acceptance by human operators.

Then, we have detailed, in one hand, techno-centered approaches for human's integration within manufacturing systems, and in the other hand, social approaches for artefact agents' integration. Our idea consists in exploiting the social concepts enunciated by Atzori & al. [33] and to associate them to the holonic reference architectures PROSA for human-integration.

4 Future directions toward a social holonic systems

Today, holonic architectures' relevance is commonly recognised into manufacturing systems. Based on their supporting literature, we would like to propose an evolution regarding what we presented in the previous parts. To do this, we will rely on a recognized reference architecture: PROSA reference architecture for holonic manufacturing systems, released by Van Brussel et al. in 1998 [37]. This was the first attempt to define a holonic control architecture dedicated to an industrial system. PROSA was conceived on a holonic modular basis, structured in a bottom-up aggregation, and based on three main interconnected basic holons plus an optional one: Resource, Product, Order and Staff Agent.

The holons are only coordinated by the sharing of different data sets: Process knowledges are shared between Product and Resource holons, Execution knowledges are shared between Order and Resource ones and Production knowledges are shared between Product and Order holons.

Some recent revisions of this architecture have emerged to try to better integrate human factors. This is especially the case for the works of Leuvenink, Kruger & Basson [38]. In their considerations [38], two approaches for human integration with HMS are detailed with the PROSA model as a basis. The first one, called Interface Holon Architecture (IHA) is considering the worker as outside of the holon. It is considered as an interchangeable tool used by the holon to perform various tasks. The second one, called Worker Holon Architecture (WHA), is considering the worker as part of the holon. But this integration is only relying on technical features (its interfacing with the system, the systems' protocols, etc.).

Another interpretation has been proposed by Valckenaers & Brussel [39] in the book *Design for the Unexpected: From Holonic Manufacturing Systems towards a Humane Mechatronics Society*[39], the authors show the importance of humans for the agility of future production systems and the shift from holonic production systems to a more human mechatronic society. Hence, they propose an extension of their ARTI holonic systems architecture [36] with a new holon called e-Person. This one would be an aggregation of the roles that can be played by the human in his environment and could either be a resource, a decision maker for an activity or for other resources, a part of an activity, etc

In our opinion, heading toward a social holonic system implies the exploration of 3 axes:

1) Consideration and integration of human holons along with artefact ones. Scientific locks concerning the way to model these holons – humans or artefact, the consideration of physical, energetic or Data transformations as well as the consideration of human factors (physiological, psychological, etc.) will then arise.

2) Consideration of the relationships between these holons as more than data exchanges, but with other forms of relationships that will be able to govern this hierarchy. For example, we can cite the service providing or customer - furnisher relationships that are usually found in Service Oriented Architectures (SOA) [40], symbiosis relationships, as proposed by Monostori & al. [25], or other forms of social organization like Fiske's Communal Sharing, Authority Ranking, Quality Matching & Market Pricing [36]. These will have to be defined and formalized in order to be tested onto experimental CPS-based platforms. The nature of the relationship would, for example, give information about shared objectives, requirements, results, states, or actions.

3) Consideration of a recursive aspect of the holonic structure that goes beyond the simple composition/decomposition of a holon into other ones, and that considers the notions of social relationships. The same holon can belong to several different holons depending on the nature of the social relationships between them (an operator can belong to the workshift X AND to the work-shop Y). This raises the issue of the formalization of these relationships with-in the framework of HMS and of the specification of their impact (for example on the nature of the information shared, trust, etc.).

5 Conclusion

In 40 years, industrial systems have significantly evolved. Research has focused on system's automation, integration, centralization, decentralization, human integration, socialization, etc. Considering the past research and industrial evolution, we believe that future development should be directed to the elaboration of hybrid holonic architecture based on social relationships allowing the human to be no more considered as a disturbance factor but as a fully integrated agent to the systems. For this reason, we will direct our future research on the notion of social relationships, their definition and characterization and their implementation into reference architectures. A lot of work is still to be done, starting with the exploitation of the three directives that we have presented below and their testing through simulation or real models on our research platforms.

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