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Patented intelligence: Cloning human decision models for Industry 4.0

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ABSTRACT

Industry 4.0 is a trend related to smart factories, which are cyber-physical spaces populated and controlled by the collective intelligence for the autonomous and highly flexible manufacturing purposes. Artificial Intelligence (AI) embedded into various planning, production, and management processes in Industry 4.0 must take the initiative and responsibility for making necessary real-time decisions in many cases. In this paper, we suggest the Pi-Mind technology as a compromise between completely human-expert-driven decision-making and AI-driven decision-making. Pi-Mind enables capturing, cloning and patenting essential parameters of the decision models from a particular human expert making these models transparent, proactive and capable of autonomic and fast decision-making simultaneously in many places. The technology facilitates the human impact (due to ubiquitous presence) in smart manufacturing processes and enables human-AI shared responsibility for the consequences of the decisions made. It also benefits from capturing and utilization of the traditionally human creative cognitive capabilities (sometimes intuitive and emotional), which in many cases outperform the rational decision-making. Pi-Mind technology is a set of models, techniques, and tools built on principles of value-based biased decision-making and creative cognitive computing to augment the axioms of decision rationality in industry.

1. Introduction

Industrial automation, if understood simply as an integration of software components, electronics and mechanical devices on the factory floor, is not anymore giving companies any competitive advantage or industrial leadership. The tendency towards automation was established more than a half-century ago and since then it has managed to become a reality for the whole industry. A number of IT solutions for high-tech industrial production, which have been developed, introduced and standardized, were gathered under the concept of the Third Industrial Revolution and considered to be a history now. The current phase of the industrial development is shaped by the features of the so-called Fourth Industrial Revolution or Industry 4.0. According to the definitions by one of its ideologists, *it is characterized by a fusion of technologies that is blurring the lines between the physical, digital, and biological spheres* [1]. The era of the Industry 4.0 does not bring new technological solutions or the evolution of the old ones; it offers a principally new vision on how the company should operate: manufacture products, provide services, manage assets and do business in general [2,3]. The main design principles of the Industry 4.0 are interoperability of all its components (machines, devices, sensors, software, data, people, etc.); virtualization of the physical world; decentralization of control and decision-making; real-time capability; use of service-oriented architectures; and modularity of the systems [4].

The leading consulting groups report that many industrial and service-oriented sectors are facing strong barriers set by the new non-trivial tasks appeared in the period of transferring to the technologies 4.0 [5,6]. The main implementation barriers are related to coordination of actions across different organizational units, cybersecurity issues, data ownership when working with third-party providers, lack of workers' courage and necessary talents [6]. Companies fail to ensure sufficient digital culture and are not capable of creating a vision of the future.

The success of the transformational processes, within the increased uncertainty and system resistance context, is strongly dependent on the expertise of individual employees, *change agents*, who are introducing new business models, launching smart processes, developing smart products and providing assistance and guidance to others. To widely deploy Industry 4.0 solutions, companies need quite many skillful change agents. This is especially critical for a successful decision-making. Wide adoption and understanding of the new decision-making models and practices require continuous organizational learning, experience transfer and benchmarking.

While the routine and physically demanding jobs have become robotized almost completely, a creative, strategic or emergent decision-

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making is still a human-dominated sphere today. However, the rise of the Internet-of-Everything and emerging advances in AI (particularly, in Deep Learning) is rapidly changing such human dominance. Artificial decision-makers and problem solvers are capable of providing more accurate and fast decisions and they will soon replace many of human employees. Artificial agents, which are installed in various planning, production, and management processes, can take the initiative and responsibility of making decisions throughout the whole factory life-cycle and implement the Intelligence-as-a-Service paradigm for the real-time automated decentralized decision-making. This brings up an issue of the artificial decision makers' learning and benchmarking.

Current technologies are focused mainly on the normative models emphasizing the rational aspects of decision-making. Though the creative cognitive capabilities of an agent's behavior are as important as the features of the environment, in which this behavior takes place. New models of judgment and decision-making must follow the principles of cognition to augment the axioms of decision rationality.

In this research we focus on the models capable of capturing cognitive aspects of creative human decision-making based on personal values and preferences and their application in industrial cyber-physical systems. We create a mechanism of cloning humans' decision models aiming to approach automatic decision-making but still keeping a human in the loop (Collective-Intelligence-as-a-Service). We aim to answer: how to digitize, evaluate, appreciate, share and reuse expert decision-making skills and experience; how to embed cognitive aspects of decision-making and problem solving into the existing schemes of the industrial operation; how to create an infrastructure around a digital pool of best industrial practices; how to enhance human-machine collaboration; how to make decisions based on self-awareness.

The rest of the paper is organized as follows. In section 2, we introduce the research on collective intelligence, emergent from human-robot interactions in cyber-physical environments of Industry 4.0. Section 3 presents our technology aimed at digital twinning (or cloning) of a human decision-making behavior, we show how it can be introduced into Industry 4.0 processes to enable virtual and ubiquitous human presence in the decision-making. The industrial approbation and several possible use cases are discussed in section 4. Section 5 contains description of our future research related to the proposed solutions. And we conclude in Section 6.

2. Related work

Creation of intelligent physical and software-based systems, which are programmed to learn and adapt, is among the top strategic technology trends announced in the latest analytical reports [5,6]. Interaction of people, devices, content, and services, sometimes called Intelligent Digital Mesh [7], has evident effect on transformations across industries and fields: the virtual and physical worlds are becoming more intertwined due to new bridging technologies enabling advanced communication and interaction of diverse intelligent objects, both human beings and machines.

In manufacturing this trend causes a paradigm shift towards Industry 4.0 (see Table 1) with the core idea of smart factories [2,8,9] using cyber-physical systems (CPS) [10,11,12] for industrial automation.

Complex cyber-physical systems are controlled by a collective intelligence of interacting human and artificial decision makers in addition to embedded automation. Important research questions are how the responsibilities and duties should be distributed between humans and machines and how their interaction should be organized throughout all phases of a factory life cycle.

Depending on the level of human engagement a CPS can be either a) fully autonomous, i.e., the one that acts independently of humans, b) triggered by human inputs, or c) dependent on a close interaction with humans, including a shared control [13]. The latter one is called a human or a human-in-the-loop cyber-physical system (HCPS). It includes a necessary loop involving a human in addition to the cyber component and the physical environment [14]. HCPS imply that human employees have greater freedom to make their own decisions, become more actively engaged into creative design and planning processes as well as into the operational working environment and they are able to regulate their own workload. Humans, in this case, are the central component of the factory ecosystem. They are empowered by the comprehensive assistance of smart machines with multimodal, user-friendly interfaces. Romero et al. [15] emphasize on a human-centricity of the smart factories' deploying systems, which enhance the cooperation of machines with humans. Such human-automation symbiosis and appropriate human-centered architecture for the next generation balanced automation systems has been reported in [16]. Kagermann et al. [8] argue that increase of human involvement is closely related to the social responsibility.

A high-quality human-AI communication, mutual understanding, coordination and collaboration, not only on a physical level but also on a cognitive level, is a key demand to make CPS efficient. A variety of interaction types increases due to the emerging socio-technical interaction models and advanced communication technologies. Application of intelligent agent-based architectures, robotics and alternative interfaces between humans and the cyber-physical environment makes such interactions smart, cooperative and self-managed [17]. In Schirner [14], for instance, it is shown how the new brain-computer interfaces (BCIs) and controlled assistive robots can be integrated into HCPS to restore a fundamental autonomy for people who are functionally disabled due to various neurological or physical reasons. New collaborative robots, such as the Kuka LWR [18] and the Universal Robot UR [19], have been deployed in factories to provide complementary skills to human co-workers. Collaborative robots (or cobots) are capable of human-robot collaboration (HRC) and work hand in hand with their human colleagues on the factory floor for manufacturing in real-world settings. The vision of collaborative robots' role has changed since early understanding of the cobot concept as *an intrinsically passive robotic device, which provides assistance to the human operator by setting up virtual surfaces, which can be used to constrain and guide motion* [20], to today's

Table 1
Comparison of the key concepts from the paradigms of Industry 3.0 and Industry 4.0.

Industrial system features	Industry 3.0	Industry 4.0
Architecture	Hierarchical architectures	Clouds of services
Processes construction	Waterfall-based	Agile factory
Automation trend	Automation	Virtualization
Operations and actions support	5-layer automation pyramid (sensor actuator hardware and PLC, PC and PID, SCADA network, MES and ERP)	Advanced manufacturing (additive manufacturing, advanced materials, smart, automated machines), IoT, CPS, Big Data, Cognitive technologies, Artificial Intelligence
Type of interactions	"Worker – function"	"User – service"
Organization of the technological process	Rigidly defined sequence, Closed interaction, Autonomic specialists	Creative process, Collaborative interaction, Cross-functional teams
Decision-making	Person (worker) + Automatic systems	Human decision makers + Smart agents + Cyber-physical systems