Artificial Intelligence from Industry 5.0 perspective: Is the Technology Ready to Meet the Challenge?

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Abstract

Industry 5.0 has been defined on the basis of principles of Human Centrality, Sustainability, and Resiliency by considering that the fourth industrial revolution does not pursue these goals. This new vision, fostered by the European Commission, aims to drive the future industry towards the Europe's 2030 goals where environmental and societal dimensions are of paramount importance. However, as in any previous industrial revolution, the feasibility of Industry 5.0 depends on the scientific and technological advances that pave the path of progress. This paper analyses the key technologies that Industry 5.0 will require, concluding that a radical improvement of the current Artificial Intelligence capabilities will be an absolute requirement. We propose the emerging concept of Augmented Intelligence as the key technology to transition Industry 4.0 to the fifth industrial revolution.

Keywords

Industry 5.0, artificial intelligence, augmented intelligence.

1. Introduction

The fourth industrial revolution is leveraging productivity to unseen limits in manufacturing, continuous processes, etc. [1-3]. The evolution and massive availability of general purpose ICT technologies [4] has endowed companies with a wide range of tools and means that lead to substantial improvements in production efficiency [5], quality control [6] and optimisation [7], planning & scheduling [8, 9], maintenance [9,10], etc.

While the concept of Industry 4.0 aims to improve industrial/business objectives (OEE, production KPIs), the European Commission extends this scope by defining Industry 5.0's role "in transitioning to a sustainable, human-centric and resilient Europe and how it contributes to top Commission priorities" [11]. According to this vision, "Industry 4.0 is not the right framework to achieve Europe's 2030 goals". Aligned with the Strategic Agenda [12, 13], the two main pillars of Industry 5.0 consist of 1) the integration of environmental and sustainability aspects across the entire value chain and 2) the inclusion of an "inherently social dimension" oriented to the wellbeing of workers and looking for models based on complementing human capabilities rather than substituting them. Table 1 shows the main differences between current Industry 4.0 approaches and the goals pursued by Industry 5.0.

All industrial revolutions have been possible thanks to underlying scientific and technological advances. In the case of the 4th revolution, a set of Key Enabling Technologies (KETs) have been crucial to make it happen [14]. The following list shows a summary of Industry 4.0 KETs [15]: IIoT (Industrial Internet of Things); CPS (Cyber-physical systems); High performance communications, wired and wireless; Interoperable communication standards; Blockchain; Additive Manufacturing; Virtual-Augmented Reality, Digital Twin; Big Data; Data Science and Artificial Intelligence;

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Graphics and Media Technologies; Edge, Fog, Cloud computing; Cybersecurity (as an unavoidable requirement to enable all previous concepts).

Table 1
Differences between Industry 4.0 and Industry 5.0 [11]

Industry 4.0	Industry 5.0
Centred around enhanced efficiency through digital connectivity and artificial intelligence	Ensures a framework for industry that combines competitiveness and sustainability, allowing industry to realize its potential as one of the pillars of transformation
Technology – centred around the emergence of cyber-physical objectives	Emphasises impact of alternative modes of (technology) governance for sustainability and resilience
Aligned with optimization of business models within existing capital market dynamics and economic models – i.e. ultimately directed at minimization of costs and maximization of profit for shareholders.	Empowers workers through the use of digital devices, endorsing a human-centric approach of technology.
No focus on design and performance dimensions essential for systemic transformation and decoupling of resource and material use from negative environmental, climate and social impacts.	Expands the remit of corporation's responsibility to their whole value chains. Introduces indicators that show, for each industrial ecosystem, the progress achieved on the path to well-being, resilience, and overall sustainability.

2. Key enabling technologies for Industry 5.0

While Industry 4.0 relays on a broad set of mainly ICT technologies, Industry 5.0 will mainly depend on the "cognitive revolution" of such systems that will have to evolve from current narrow domain knowledge capabilities to much broader and context aware cognition.

The automation pyramid (Figure 1) defined by ISA-95 [16] describes a model based on incremental complexity and abstraction from field level to business level. In general terms, Artificial Intelligence is being applied in activities where the goal can be clearly specified, and training data can be obtained. For example:

Level 0 Predictive maintenance [17]

Level 1 Soft sensors [18], computer vision for quality assessment [19], basic control loops overcoming PIDs limitations [20], etc.

Level 2 Multivariate controls, Model Predictive Control (MPC) systems [21] that command multiple Level 1 subsystems, optimisers.

Level 3 Work Order schedulers [22] and planning optimisers [23]

Level 4 Machine Learning based optimisers for logistics and supply chain management [24]. Financial risk estimation [25].

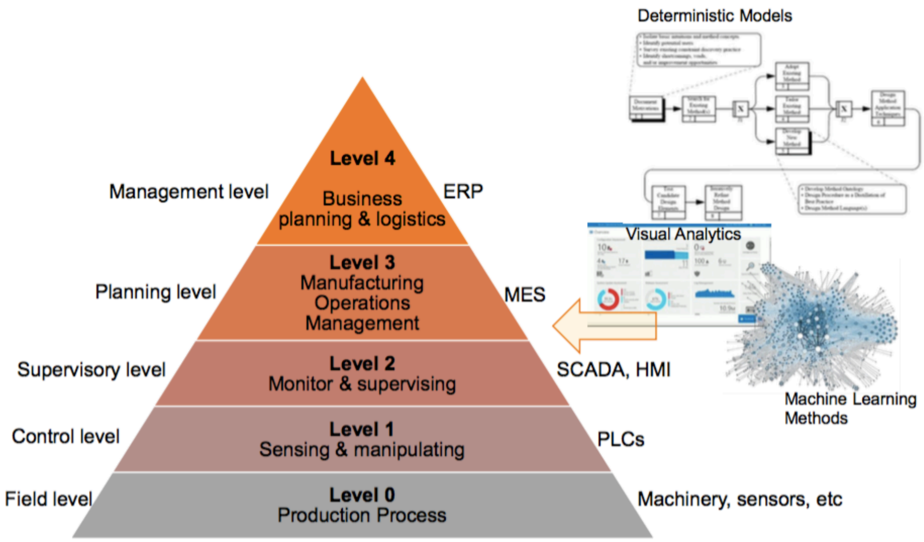

Figure 1: Automation Pyramid (ISA-95) [16]

The layered Industry 4.0 automation pyramid does not satisfy Industry 5.0 requirements. Specially those factors that are not directly related with the industrial process or regulatory constraints such as holistic environmental vision, bioeconomy interrelation along the value chain, etc. are out of the scope of Industry 4.0 and require a broader and interconnected *suprasystem* that is able to allow companies to modulate their decisions while maintaining their internal processes and KPIs (Figure 2). This Industry 5.0 *suprasystem* will require a completely new cognitive level that neither humans nor existing machines will be able to achieve independently.

Figure 2: Integration of automation pyramid in a broader scope where business decisions are able to include real-time value chain aspects and other global objectives such as societal or environmental ones.

The second pillar of Industry 5.0 aims to create working environments where humans and robots work together [26], taking benefit from the best qualities of both.

Ultimately, both identified requirements, the aforementioned *suprasystem* and machines/robots that are able to fluently collaborate with humans, point at the same Key Enabling Technology: **Augmented Intelligence**.

According to the European Commission [27], there are some KETs shared by Industry 4.0 and Industry 5.0. Just to mention a few, edge computing, data and system interoperability, big data management etc. When referring to Artificial Intelligence, the vision documents of European Commission stress the need of augmenting the intelligence of current industrial production and decision-making systems:

- Brain-machine interfaces;
- Individual, person-centric Artificial Intelligence;
- Informed deep learning (expert knowledge combined with Artificial Intelligence);

- Ability to handle and find correlations among complex, interrelated data of different origin and scales in dynamic systems within a system of systems;
- Causality-based and not only correlation-based Artificial Intelligence.

3. Limitations of current state-of-the-art

In contrast to all these *expert* systems that construct Industry 4.0, the fifth revolution will require much broader cognitive capabilities. The current AI state-of-the-art, based on Machine Learning models that gather data samples to train on them and infer predictions [28], cannot afford Industry 5.0 challenges where knowledge domains are fuzzy and complex, and where prior and contextual knowledge must be given explicitly. The lack of success of IBM's Watson in healthcare [29] is a paradigmatic example of the current limitations of AI in domains that imply high analytical complexity and intricate workflows. In more general terms, training & testing-based methods that extract implicit knowledge from data have to be efficiently combined with explicit knowledge that can be described as ontologies [30], equations, rules, and even in the form of natural language.

In the same way that GPUs boosted Deep Learning [31] consequently producing a global revolution of AI, a new computing paradigm will be needed to trigger the next technological revolution that will allow the development of Augmented Intelligence. Quantum computing is showing an enormous potential to perform simulation and optimisation tasks [32], however current Quantum AI is presented as a dramatic speed up of training processes, which is not going in the direction of Augmented Intelligence's main requirements. Besides that, neuromorphic Computing [33] appears as the most promising technological candidate for making the breakthrough advances in Artificial Intelligence.

3.1. Next cognitive level

According to Confucious' words: "By three methods we may learn wisdom: First, by reflection, which is the noblest; Second, by imitation, which is the easiest; and third by experience, which is the bitterest" [34]. Current state-of-the-art shows that while so ware based systems can be extremely powerful on learning from the third way (trial and error), human reflection capabilities are far from what machines will be able to do in a near future. The effective combination of these two capabilities, even if hard to achieve, is the most promising way to overcome the current limitations of Artificial Intelligence.

Artificial Intelligence, fuelled by Big-data availability and High Processing power (e.g., GPUs for Deep Learning) has experienced a dramatic success in many activities, outperforming humans' capabilities in specific tasks. However, this kind of success stories are always limited to narrow scope activities where the implicit information contained in data samples can be used for further inference [35]. Broader ways of thinking are still beyond the capabilities of machines, from both technological and methodological perspectives [36].

3.2. Augmented Intelligence

Augmented intelligence can be understood as the "synergistic technology of humans and computers" [37]. As stated in the IEEE Digital Reality whitepaper [38], "It's goal is to enhance human intelligence rather than operate independently of or outright replace it. It's designed to do so by improving human decision-making and, by extension, actions taken in response to improved decisions". However, even if the functional foundations of Augmented Intelligence are clearly defined, technical implementations are far from becoming a reality. Jain et al. [39] identify four basic problems that current Artificial Intelligence systems will have to solve to reach Augmented Intelligence capabilities: intuitive reasoning, causal modelling, memory and knowledge evolution. However, physical word aspects (crucial for robotics) are not considered by these authors. We propose a model where functional capabilities and technological requirements are combined to lead the technology towards the Augmented Intelligent concept that includes both virtual and physical aspects (Figure 3).

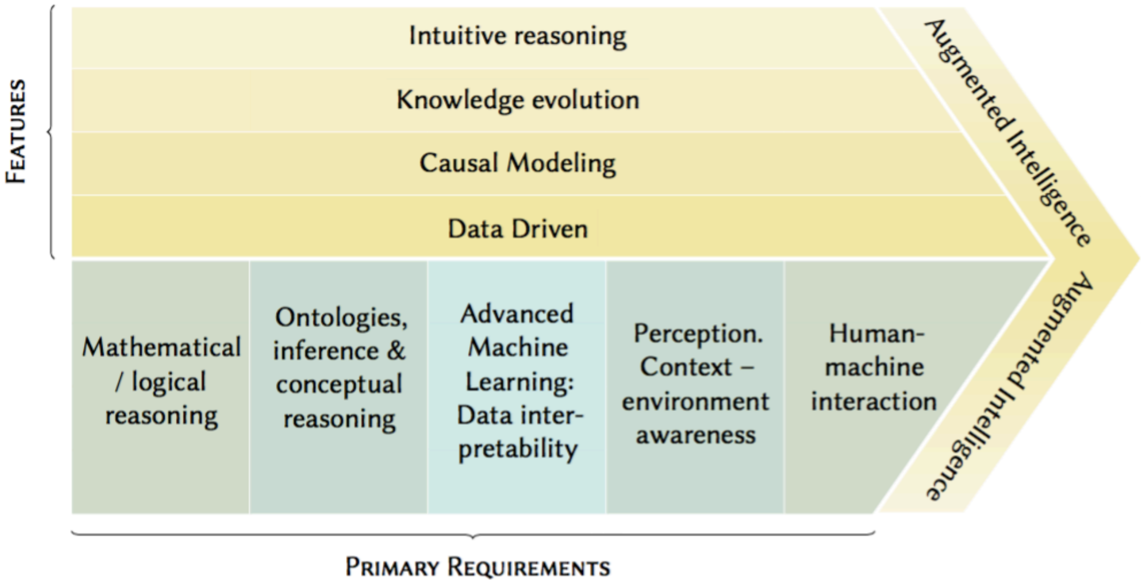

Figure 3: Augmented Intelligence: Primary requirements and Features (based on [39])

4. Co-working with robots

As humans have never effectively collaborated with robots, many questions arise in aspects such as ethical, psychological, societal, economical, regulatory, etc. [26]. From a technological perspective, the co-working with robots is still in its early stages. Hentout et al. [40] define three human-robot interaction (HRI) categories:

- **Human-Robot Coexistence**: Capability of sharing the dynamic workspace between humans and robots without a common task.
- **Human-Robot Cooperation**: Humans and robots are working on the same purpose and fulfill the requirements of time and space simultaneously.
- **Human-Robot Collaboration**: Complex tasks with direct human interaction, either with explicit contact or human communication.

The Human-Robot Collaboration level, will require very advanced aspects of natural language processing, cognitive perception, logical inference, human behaviour interpretability, etc. Safety and efficiency will require a robust and detailed understanding of the surrounding environment (as in the case of Autonomous Driving).

In general terms, the concept of robot can be extended to an Autonomous Agent. Autonomous Agents might be endowed with a body (robots, Cyber-Physical Systems–CPS) or might be virtual. In both cases, they will have to fluently interact with humans, sharing information and contributing to decisions [41].

5. Sustainability

The environmental impact of industrial activities is mainly regulated by laws created from global perspectives. Companies incorporate the regulation aspects and introduce them as constraints in their processes. The European Commission foresees that within the "context of climate crisis and planetary emergency" a new paradigm beyond Industry 4.0 is needed [12]. Vaio et al. [42] perform a systematic review of Artificial Intelligence business models in the sustainable development goals perspective, concluding that "To achieve high sustainability standards, it is necessary to improve the technical-scientific quality of the production systems" through the implementation of Knowledge Management Systems (KMS) that share internal and external knowledge. This view, points at the need of a holistic

Augmented Intelligence that is able to provide the perspective of a global benefit and the most suitable trade-off between individual companies' objectives and general interests in terms of sustainability and environmental impact.

The development of such *suprasystem* will require a cultural drift together with regulatory adjustments that support the inclusion of general interest metrics in individual business KPIs. Not less important, the effective management of all the Big-data and associated multiple industrial activities will require a cognitive level that is not available in the current state of the art.

6. Conclusions

Whether Industry 5.0 will solve or mitigate big societal and environmental problems will be conditioned by two main factors: 1) a change in the socio-cultural and business mindset and 2) a big step forward in the cognitive capabilities of decision-making processes. We have addressed this second condition to conclude that the next cognitive revolution will not rely exclusively on artificial intelligence. Instead, the synergy between humans and machines will be the key to deal with the challenges that big data based broad reasoning will present. While humans will have to learn to collaborate in such way, the big scientific and technological gap between artificial and augmented intelligence is due to the weakness of current AI systems in perception, natural language communication, mathematical & conceptual reasoning, and data interpretability (Figure 3). A roadmap towards Industry 5.0 should look for the excellence in these aspects.

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