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Overview of emerging technologies advancing Industry 4.0

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Abstract: This paper summarizes the key technological pillars that define the concept of *Industry* 4.0 (the fourth industrial revolution) and analyzes their transformative potential for modern manufacturing and industrial operations. *Industry* 4.0 is characterized by the fusion of digital and physical technologies, leading to the creation of intelligent, fully connected and flexible manufacturing systems.

Keywords: Industry 4.0, new trends, industrial engineering.

INTRODUCTION

Significant progress in nascent technologies like the *Industrial Internet of Things* (*IIoT*), autonomous mobile robots, additive manufacturing techniques, industrial communication networks, and solutions empowered by artificial intelligence are propelling the evolution of industrial automation. The trends within the realm of *Industry* 4.0 (Fig. 1) and the startup landscape, as presented in this document, represent only a preliminary overview of the patterns discerned through our comprehensive investigation. Other technologies, including but not limited to, volumetric visualization, distributed ledger technology, and cloud-based computational resources, are poised to fundamentally reshape the industry. Proactive identification of novel opportunities and the integration of emerging technologies into business operations at an early stage can substantially contribute to the establishment of a competitive edge.

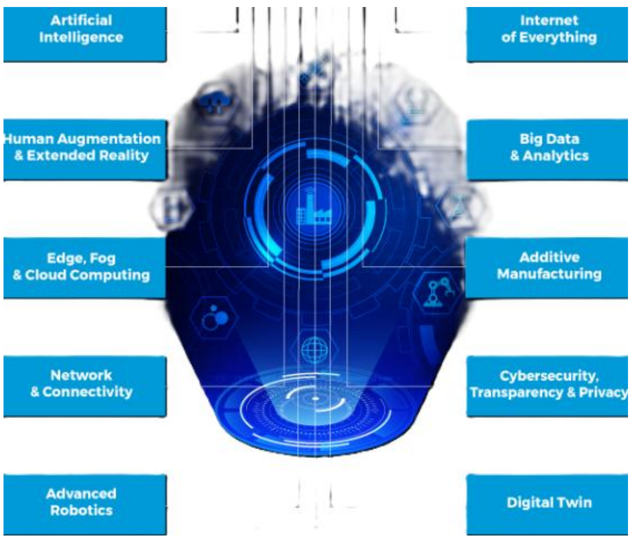

Fig. 1. The trends in *Industry* 4.0 [6]

These digital representations provide crucial intelligence pertaining to each phase of the production workflow. Moreover, digital twins enable the simulation of various scenarios and the refinement of processes without jeopardizing physical resources, thus fostering enhanced ingenuity and security.

1 THE IMPACT OF THE INDUSTRY 4.0 TECHNOLOGY TRENDS

A hierarchical visual representation highlights the ten most prominent Industry 4.0 trends projected to influence organizational operations by 2025. The integration of artificial intelligence methodologies across various technological assets and operational workflows constitutes the foremost trend within this industrial evolution. A growing number of innovative enterprises are engineering portable technological solutions specifically tailored for industrial environments, with the goal of enhancing occupational safety and optimizing manufacturing efficiency.

The acquisition of data through the implementation of both cloud-based and edge-based computational infrastructures, alongside the design and deployment of robust cybersecurity protocols, enables businesses to construct the foundational infrastructure required for the establishment of intelligent manufacturing facilities. Furthermore, sophisticated robotic technologies, encompassing autonomous mobile units, collaborative robots (cobots), and distributed robotic systems, as well as the advancement of robotic software development, represent a significant facet of the prevailing Industry 4.0 trends (Figure 2).

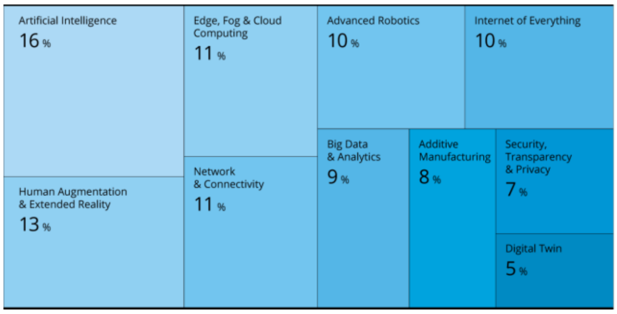

Fig. 2. The trends and innovations in *Industry* 4.0 [6]

Artificial Intelligence (AI) and Machine Learning are catalyzing advancements across various sectors and operational domains. The creation of specialized *AI* hardware and innovative algorithmic approaches is refining existing systems and providing solutions to complex manufacturing issues. Industrial facilities are increasingly integrating *AI* into their production workflows and systems. The emergence of sophisticated *AI* has facilitated developments such as predictive upkeep, cognitive computation, collective intelligence, context-aware processing, intelligent machinery, hardware acceleration, and generative design. These technologies are guiding manufacturing plants towards complete automation and unmanned operations. Effective supply network management is now achievable, facilitated by *AI-driven* algorithms. These algorithms excel at anticipating requirements and automating stock control, thereby optimizing processes.

ATG Artificial Intelligence Division is an *Italian* startup, provides a solution for *intelligent company* 4.0. The startup's solution comprises three elements: prediction, predictive upkeep, and categorization of waste. The startup's prediction capability enables manufacturers to discern patterns and tendencies in industrial process information through the utilization of machine learning.

Moreover, the startup employs *AI* and the *Internet of Things* (*IoT*) to enable predictive maintenance of industrial resources. These elements allow manufacturers to foresee unforeseen energy usage surges and equipment malfunctions to diminish downtime and execute environmentally conscious measures. Its waste categorization solution also aids in averting quality concerns and pinpointing defect morphology.

Oqton (AI-Powered Data Integration) is a *US*-based startup, develops *FactoryOS*, an *AI*-enhanced platform for consolidating manufacturing system information to optimize factory production and yield. Machinery, systems, and information from manufacturing establishments are commonly maintained as discrete information repositories, rendering it challenging to extract tangible benefit from them. The cloud-based platform assimilates and leverages information from all phases of the industrial ecosystem, encompassing design, production, and the supply network. Progressively, the *AI* acquires knowledge continuously from these data inputs to generate crucial perspectives for enhancing overall efficiency.

Human Augmentation & Extended Reality are technological advancements are increasingly focused on enhancing human performance through human augmentation and *extended reality* (*XR*). Wearable devices and exoskeletons, for example, are being deployed to improve both physical and cognitive functions. This represents a key development within the broader context of the Fourth Industrial Revolution. The increased availability of industrial mobile computing, user-friendly interfaces, and portable machine control solutions is facilitating wider adoption of these technologies [1].

ULS Robotics (Exoskeleton Technology Platform) is a nascent *Chinese* enterprise, is engaged in the creation of an exoskeleton technological infrastructure. A considerable segment of the manufacturing workforce experiences lassitude, enervation, and diverse forms of corporeal unease as a consequence of the recurrent and standardized nature of their occupational duties [1]. The deployment of exoskeletal devices in manufacturing environments facilitates heightened operational efficacy among personnel, concurrently mitigating or precluding physical exertion. Generally, these exoskeletons furnish support for the lumbar region, the superior extremity (incorporating four degrees of kinematic freedom), and the inferior extremity (incorporating twelve degrees of kinematic freedom). [3]

Arkellis Technologies, an emerging Indian enterprise, provides a streamlined, low-code platform for constructing *industrial metaverse* environments. This platform facilitates the ready-made creation of augmented and virtual reality applications suitable for diverse commercial sectors. [4] The framework encompasses a suite of development instruments, catering to applications such as instruction, rectification, upkeep, visualization, and employee integration. By affording organizations the capability to incorporate comprehensive digital replicas with data synthesis, the framework expedites operational processes. Consequently, it curtails the duration required to introduce products to the market and obviates the need for costly, bespoke in-house product evolution. [5]

The substantial volume of data engendered by the industrial *Internet of Things* (*IIoT*) is driving the incorporation of *edge, fog, and cloud computing within Industry* 4.0. Bespoke hardware and software resolutions, including interconnected clouds, distributed cloud systems, distributed processing and storage, and hybrid computing models, are influencing this trajectory. Technological advancements such as low-code development interfaces, microservices architecture, portable computing, and multi-access edge computing are fostering the consolidation of edge, fog, and cloud computing across a range of industries. This stratified approach guarantees effective data management, ranging from immediate processing at the network periphery to comprehensive analysis in centralized cloud infrastructure.

Network infrastructure and interconnectedness represent key catalysts in facilitating the realization of *Industry* 4.0. Progress in technologies like edge-to-cloud computing, high-bandwidth time-synchronized networks, *low-power wide-area networking* (*LPWAN*), *fifth-generation wireless* (*5G*), and machine-to-machine (*M2M*) communication are prompting manufacturing facilities to embrace the *Industrial Internet of Things* (*IIoT*), thereby converting them into advanced *Industry* 4.0 sites [7].

These advancements are continuously improving interaction between equipment and personnel, as well as data conveyance. Developments in this domain are augmenting velocity, strengthening safeguards and efficacy, and diminishing network accessibility expenditures. The combination of diverse connectivity options is fostering a unified, reactive, and versatile industrial milieu. This assimilation constitutes an essential element in the advancement of intelligent production facilities. Within the framework of the Fourth Industrial Revolution, the extensive acquisition of production information facilitates the evolution of industrial plants into sophisticated establishments. The inherent challenge associated with substantial datasets resides in their utility, which is contingent upon expedient and economical acquisition, storage, and scrutiny.

Progress in technology has enabled the exploitation of this information for penetrative evaluations of industrial processes. The accessibility of contemporaneous and immediate information has created avenues for prescriptive and predictive analysis across the hierarchical tiers of an organization's fabrication infrastructure. Furthermore, it equips enterprises with the capacity to utilize expansive volumes of information for strategic comprehension. These technologies methodically process and analyze information derived from diverse origins, *encompassing sensors*, *machinery*, and *platforms*, thereby providing a comprehensive perspective on operations and augmenting decisional processes and operational efficacy.

Driven by the imperative to develop novel technologies capable of satisfying escalating market requirements, industrial producers have increasingly adopted additive manufacturing methodologies. Initially employed as a rapid prototyping methodology, additive manufacturing is currently undergoing a transformative evolution, fostering the decentralization of production processes [6]. Hybrid manufacturing, which seeks to integrate *additive and subtractive techniques*, represents a key advancement in this domain.

Concurrent advancements in materials science and the refinement of techniques such as stereolithography and metal-based three-dimensional printing have significantly facilitated the construction of intricate geometries and constituent elements. *Additive manufacturing* is facilitating a transition towards highly customized and ecologically conscious cloud-distributed production models. Moreover, the synergistic incorporation of additive manufacturing with digital design paradigms and computational simulations serves to enhance dimensional accuracy and abbreviate product development cycles.

The inherent interconnectedness characteristic of Industry 4.0 engenders a data exchange which prompts anxieties regarding safety, explicitness, and confidentiality. As production methodologies progress towards increased personalization and individualization, data administration protocols, both internal and external to the production environment, substantially impact an organization's desirability.

Robust protection of sensitive industrial information during transmission and processing is crucial to avert digital incursions targeting vital infrastructure. [8,9]

Improvements in *automated systems are accelerating*, improving, and securing operations within the fourth industrial revolution. Self-governing automated machines, cooperative automated machines, anthropomorphic automated machines, ambulatory automated machines, network-connected automated machines, application programming interfaces, object manipulation automated machines, and collectives of automated machines are prominent technological contributors influencing production.

In the realm of industrial production, contemporaneous interconnectedness constitutes the fundamental infrastructure of the *Internet of Everything* (*IoE*). This pervasive connectivity extends across automated systems, operator interfaces, and interpersonal communication. It encompasses the *Industrial Internet of Things* (*IIoT*), the interconnectedness of professional competencies, the network of service provisions, the integration of operational systems, and the comprehensive connectivity of the production facility.

Digital twin technology leverages the convergence of dynamic, real-time data acquisition and visual representation to construct virtual instantiations of industrial equipment. This approach demonstrates considerable potential across various applications, encompassing model-based engineering, simulated prototyping, simulated system verification, production rate maximization, and incremental improvement. The increasing integration of digital twins is propelling advanced manufacturing towards a highly automated paradigm.

3 CONCLUSIONS

The convergence of instantaneous information, automated reasoning, and human capabilities expedites fabrication procedures, resulting in enhanced efficacy and economic viability. A standardized architecture for the *Internet of Things* (*IoT*) and interoperability are indispensable for the effective deployment of *Industry* 4.0. Furthermore, *IoE* facilitates immediate observation and regulation of all integrated resources, leading to streamlined allocation and thereby optimizing the performance of manufacturing procedures.

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