Safety Management in Industry 5.0 Manufacturing

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Contributor: Stavroula Bourou, Apostolos Maniatis, Dimitris Kontopoulos, Panagiotis A. Karkazis

Safety management is a priority to guarantee human-centered manufacturing processes in the context of Industry 5.0, which aims to realize a safe human–machine environment based on knowledge-driven approaches. The traditional approaches for safety management in the industrial environment include staff training, regular inspections, warning signs, etc. Despite the fact that proactive measures and procedures have exceptional importance in the prevention of safety hazards, human–machine–environment coupling requires more sophisticated approaches able to provide automated, reliable, real-time, cost-effective, and adaptive hazard identification in complex manufacturing processes.

Keywords: Industry 5.0 ; employee safety ; intelligent detection system

1. Introduction

Over the years, numerous industrial revolutions took place, transforming the industrial scene. These evolutionary phases introduce the progressive integration of novel technologies into manufacturing procedures, aiming to enhance efficiency, productivity, and economic growth. Nowadays, Industry 5.0 is emerging, placing humans at the center of production. Specifically, the human-centered Industry 5.0 emphasizes the integration of smart technologies, automation, and data exchange in manufacturing. Beyond the human-centric focus of the Fifth Revolution, it also induces increased resilience and an improved emphasis on sustainability.

The human-centric Industry 5.0 places a high priority on employee safety in manufacturing, emphasizing a knowledge-driven approach to human–machine–environmental safety. Intelligent safety management that goes beyond conventional measures becomes necessary to deal with complex human–machine–environment interactions. Moreover, based on the capabilities and opportunities of Industry 5.0, it becomes pivotal to design and develop safety management strategies that not only address the unique challenges of each manufacturing setting but are also robust enough to be adapted across varying operational landscapes.

By leveraging advanced technologies, an efficient, flexible, and adaptable monitoring system can be established. Specifically, object detection algorithms can be integrated into video surveillance systems to analyze the footage in real-time and identify potential hazards within an industrial environment. However, the accuracy of such a complex process, based on AI methods, is strongly dependent on datasets.

The acquisition of real data poses significant challenges both in terms of cost and safety, specifically in cases where human participation is required. Especially in hazardous environments, such as manufacturing, obtaining real data involves significant risks, mainly concerning the safety of personnel involved in data collection. Those challenges can be addressed by utilizing game development platforms, such as Unity, to generate high-quality synthetic data via virtual reality (VR). This not only diminishes the time spent on data collection and annotation but also substantially reduces the requisite human effort and cost. Moreover, synthetic datasets can be created to accommodate the specifics of various industrial scenarios. VR acts as an immersive simulation tool, offering safe and controlled environments that mimic real-world scenarios. VR is utilized in various fields, such as education, healthcare, engineering, etc., with potential enhancements through sensors available in VR systems [1].

One of the fundamental methods to protect workers is to monitor and control their exposure to hazards, as well as to detect and identify potential risks in the workplace. According to the National Institute for Occupational Safety and Health (NIOSH) in the U.S., the sequence of control measures begins with the utilization of personal protective equipment (PPE), which refers to specialized gear or clothing intended to protect individuals from potential hazards in the workplace. PPE is used to minimize the risk of injury or exposure to various physical or other types of hazards. Some examples of PPE include safety helmets, vests and other protective clothing, safety goggles, etc.

2. Safety Management in Industry 5.0 Manufacturing

2.1. Evolution of Industrial Revolutions and Industry 5.0

The first industrial revolution, Industry 1.0, rooted in the late 18th century, marked the transition from manual production methods to mechanized ones through the utilization of water and steam power. This shift brought about an increase in production and was primarily driven by the need for greater output and advancements in engineering. Progressing to Industry 2.0 in the early 20th century, the focus transitioned to mass production and assembly line techniques powered mainly by electricity. This change was necessitated by the growing demands of the growing global population and was characterized by the assembly lines of the automotive industry. Industry 3.0 came about in the late 20th century and was focused on the integration of computers and automation into the production process. The motivation for this transition was the rapid developments in electronic technology and the need for more precision, speed, and efficiency in production.

Industry 4.0 began in 2011 with an initiative in the high-tech strategy of the German government [2]. It describes the transformation of traditional industries through the integration of digital technologies, automation, and AI. It refers to the digitization of the manufacturing sector, which is driven by the rise of data, connectivity, analytics, and advancements in robotics. The integration of digital technologies into manufacturing reduces setup and processing times and labor and material costs, resulting in higher productivity in production [3]. Furthermore, this integration mitigates energy consumption and minimizes waste generation [4]. The capabilities of Industry 4.0 solutions allow the collection, analysis, and interpretation of a vast amount of data in real-time, empowering the rapid acquisition of actionable insights and enhancing decision-making accuracy. However, from a socially sustainable perspective, the technological changes associated with Industry 4.0 should carefully recognize the central importance of human participation in the loop [5].

The idea of Industry 5.0 appears as an extension of Industry 4.0, originating from the observation that Industry 4.0 places less emphasis on the principles of social fairness and sustainability but more on digitalization and AI-driven technologies. Consequently, the concept of Industry 5.0 was introduced in 2017, emphasizing the importance of research and innovation to support the industry in its long-term service to humanity and adding humans into the equation while respecting planetary boundaries [6] and social aspects. Specifically, the Fifth Industrial Revolution emphasizes the necessity of placing humans at the heart of production processes, involving them in every step. This means that smart machines and robots are working together with humans to improve the efficiency of industrial production, considering the environmental impact. Additionally, Industry 5.0 identifies the ability of industry to fulfill social objectives by taking into account the limitations of our planet's resources as well as placing importance on employee health [7].

Industry 5.0 can yield numerous advantages for the manufacturing sector. Firstly, by combining advanced technologies with human intelligence, manufacturers can attain significant improvements in productivity and efficiency, resulting in enhanced competition while reducing costs. The enhanced collaboration between humans and machines holds the potential to establish manufacturing processes where machines handle routine tasks while humans undertake more complex tasks demanding advanced skills like innovation, decision-making, and problem-solving. Therefore, the accuracy and speed of manufacturing activities can be improved [8]. Industry 5.0 can also improve efficiency via collaborative robots, known as cobots, which can safely work together with human employees, offering assistance in activities like assembling, packaging, and ensuring quality [9][10]. Moreover, Industry 5.0 focuses on the creation of a safe and secure working environment to prioritize physical and mental health as well as the wellbeing of workers within the production process while protecting fundamental rights of workers, such as dignity and privacy.

2.2. Employee Safety in Industry 5.0 Manufacturing via Safety Management

In human-centered Industry 5.0, ensuring employee safety in manufacturing is of high importance. The manufacturing sector has historically been characterized by elevated injury rates stemming from the complexities and risks associated with its operations. Specifically, in 2020, the EU reported that manufacturing had the highest number of non-fatal accidents (18.2% of the total) and was the sector with the second-highest number of fatal accidents (14.6% of the total) [11]. By establishing protective measures, employees can concentrate on their tasks rather than being preoccupied with potential risks and hazards in their environment. Studies indicate that employees who perceive their workplace as secure and safe tend to exhibit enhanced performance compared to those who feel insecure [12][13].

Since Industry 5.0 places humans at the center of the new-generation manufacturing system, emphasis should be given to human–machine–environmental safety based on knowledge-driven approaches. One fundamental component to ensure human-centered manufacturing towards Industry 5.0 is the establishment of intelligent factory safety management [14]. Conventional approaches to safety management involve employee training, routine inspections, the utilization of warning signs, etc. Those preventive measures hold significant importance for proactively mitigating safety hazards and risks. However, those traditional measures ignore the complexity of human–machine–environment coupling, which requires more sophisticated approaches able to provide automated, reliable, real-time, and cost-effective safety management methods.

In the context of Industry 5.0, advanced technologies can be utilized to create intelligent factory safety management. This can be achieved by establishing an efficient monitoring mechanism to identify potential hazards in manufacturing. The system could comprise cameras strategically positioned in the space to capture real-time footage, which is then processed by object detection algorithms trained specifically on application-related data. Real-time detection can trigger alerts to relevant personnel when non-compliance events occur. The robustness and efficiency of the monitoring system heavily depend on the available data for object detection training.

However, the complexity of the interaction between humans, machines, and the environment imposes challenges in formulating robust safety management strategies. A significant challenge lies in the adaptability of these safety methods; while one approach can be suitable for a particular case, it might not be relevant or applicable to another [15]. Therefore, it is crucial to develop safety management approaches that can be adaptable for exploitation in various manufacturing environments. This can be achieved by generating data tailored to specific applications and scenarios.

A paper [16] presents a robust detection system to identify hazards in manufacturing processes and enhance the safety management of Industry 5.0. Considering the characteristics of the Fifth Industrial Revolution, the proposed detection system takes advantage of more sophisticated approaches and digital methodologies, such as game development platforms and advanced AI algorithms, to provide automated, reliable, real-time, and cost-effective safety management capabilities. In addition, the system is flexible and adjustable to meet the requirements imposed by the complexity of the human–machine–environment coupling. Specifically, the synthetic dataset creation methodology provides all the methodologies required to generate data via a VR environment, ensuring that the data can be modified and restructured to simulate new scenarios and environments.

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