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Digital technologies applied for supporting OSH management: a state of the art for automatic surveillance and digital assistant systems

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Digital technologies are transforming occupational safety and health (OSH) across the different industrial sectors, presenting both opportunities and challenges. Currently, the adoption of digital technologies in the OSH field seems to be promising as several applications are starting to be applied; new emerging risks and criticalities must be now evaluated for these technologies aiming to provide a safe and efficient application. The focus of the study is on two main technologies applied in the OSH field: automatic surveillance and virtual assistant systems. The first category aims to monitor worker conditions to provide dynamic alerts and/or real time interventions. The latter aims to support workers and safety managers in providing more efficient support during hazardous tasks.
The study proposes a critical literature analysis about the applications of these technologies for supporting OSH management, presenting different catalogues of the mostly used in terms of ease of use and perceived intrusiveness. Moreover, the study highlights four main categories concerning open challenges for OSH. On the one hand, the adoption of different technologies enhances situational awareness, proactive hazard management, and data-driven decision-making. On the other hand, a more human-centric and more personalized approach, including organizational strategies, communication, and workers interaction, is critical to maximize benefits, still not clearly regulated. Integrating feedback from workers and OSH experts supports a stronger safety culture, prevents psychosocial risks related to digitalization, and support the design of effective training programs.

Keywords: digital surveillance, virtual assistant, occupational safety and health, AI systems, wearable technologies

1. Introduction

The increasing evolution of digital technologies and the diffusion of the AI systems applications is leading to a strong growth of a new era of human-computer interaction in safety field. Digital surveillance is increasingly being adopted to improve safety and workers' health, supporting prevention, detection and different risks management. One of the main features of the tools involved in the surveillance process is their ability to support faster decision-making, relying on real-time data. Digital surveillance includes several interesting technologies - such as wearable sensors, unmanned aerial vehicles (UAVs or drones), virtual/augmented reality, building information modelling - as means to improve occupational safety and health (OSH) outcomes. Technologies like wearable sensors (smart personal protective equipment, PPE) and drones, in fact, are attractive for the ability to directly monitor conditions in real time and reduce dangerous situations for workers. Virtual assistants (VAs) are also contributing to this transformation, as they're considered innovative tools for users to perform tasks or activities in a smart and effective way (Baek et al. 2024). In detail, a VA is developed to give information in real time, by extrapolating and elaborating information from big databases for providing personalized suggestions to users (Hermann et al. 2016). The application of this technology can lead to several advantages, such as full-time accessibility, useful services by using text or speech, multiple languages comprehension, real time responses, access to skills and knowledges in wide fields, etc. However, the adoption of VAs entails also several challenges, such as ethical concerns, security and privacy issues, chaotic work environments, etc. (Piñeiro-Martín et al. 2023; Bolton et al. 2021). Despite the several applications and the diffusion of these innovative devices in different sectors, the adoption of such technologies in OSH is still in its infancy. Nonetheless, their application could help improving the performance of processes in terms of efficiency, accuracy and timeliness. Current studies typically address each technology class in isolation, while an integrated perspective that compares different digital safety technologies and situates them within a common framework could be more helpful. For this reason, the aim of the study is to carry out a structured literature analysis about the current application of these technologies by using a common classification based on four building blocks. The paper has been organized as follows: section 2 and 3 explain the main features of digital surveillance and VA, respectively; section 4 is dedicated to the methodology applied, in particular the classification approaches used; a discussion on the main considerations about the classification obtained is presented in section 5 and finally conclusions are summarized in section 6.

2. Digital Surveillance: brief introduction of the main features

Over the years, the use of digital surveillance technologies at workplaces has rapidly increased (EU-OSHA 2022, EU-OSHA 2024, ILO 2025). Despite their adoption, occupational safety remains a major concern in sectors that still experience high rates of accidents and fatalities. With respect to manual supervision, new digital aspects of the technologies —such as Artificial Intelligence (AI), Virtual/Augmented Reality (VR/AR)—are strengthening both physical and psychological monitoring of workers, improving prevention, and supporting more effective interventions, mainly through wearable devices (Moon et al. 2024). Conversely, a key feature on the innovation process is the adoption of technologies that do not need the participation of the worker, as for wearables, thus reducing workers' direct exposure to dangerous conditions. Drones equipped with cameras and sensors can perform remote inspections of high-risk areas, including scaffolding and confined spaces, identifying safety non-compliances (e.g., missing protective gear) without requiring workers to enter hazardous zones (Zhong et al. 2025). Along with hardware-based solutions, and with the advection of remote works, the concept of Electronic Performance Monitoring (EPM) is gaining traction, relying on algorithms and digital tools to track remote workers' location, activities, and performance (Kalischko 2021, Konig 2025).

Regardless of the field of application and the specific technology adopted, the continuous monitoring of workers addresses challenges for OSH (Giacosa et al. 2023). Beyond safety issues, caused by possible hardware malfunctions or data transmission errors and delay, emerging issues are related to human-factor concerning:

(i) *Comfort and Acceptance*: prolonged use of wearable devices may result in physical discomfort. Poor or uncomfortable design and sizing issues often leads to workers non-compliance with consequent non-correct use.

(ii) *Psyco-social aspects*: workers that do not have the knowledge of advanced technologies or have not received training, tend to consider themselves less useful in the factory, and psycho-social risk increases. Moreover, workers often tend to interpret constant tracking as intrusive surveillance, potentially increasing stress.

(iii) Privacy and ethical issues: data usage, storage, and sharing raise concerns about consent, security, and misuse by employers or third parties. As a result, the adoption of digital surveillance technologies requires a careful balance between the operational value of real-time data and the ethical implications for worker acceptance, trust, and well-being.

3. Virtual assistant: brief introduction of the main features

Soofastaei (2021) defines VA as "a software agent that can perform tasks or services based on commands or questions". Its activation occurs by voice or text inputs, and it can also operate based on the analysis of the environment or context to proactively respond to user needs (Soofastaei 2021). Several technologies can be integrated in VAs, like machine learning, speech recognition, data mining, text-to speech synthesis etc. (Sarikaya 2017). An interesting tool often regarded as a simplified form of VA is the chatbot, a computer program developed for interacting with humans by using voice or text (Adamopoulou e Moussiades 2020). Chatbot is considered essential for VA, as it enables the interaction between the user and the computer, allowing to give instructions to the assistant (Sarikaya 2017; Pereira et al. 2023). The value added of VAs compared to chatbots is the type of interaction that it offers to user, simulating human conversation by using natural language (Pereira et al. 2024). Soofastaei (2024) describes two generation of virtual assistant: the first one, developed as simple voice-activated assistants like Apple's Siri and Google Assistant, is based on predefined rules and basic algorithms for performing limited tasks and answer queries; the second one incorporates more sophisticated AI technologies, such as machine learning and natural language processing (NLP), enabling it to better understand user intent, context, and preferences. This led to the development of advanced VAs able to carry out complex tasks, supporting more in-depth conversations, and providing personalized experiences. The structure of a typical VA is summarized by Pereira et al. (2024), which define that a VA is usually composed by three modules, namely:

(i) the user interface: this module allows the interaction with the user;
(ii) the core: the module dedicated to the elaboration of information;
(iii) external data and services: this module carries out the external research of the information and task performing.

VAs have great potential both socially and business-wise, as they can support workers both in increasing their efficiency and in making decisions (Hoyer et al. 2020).

4. Methodology

This study followed a structured literature review approach, surveying academic and industry publications on wearable sensors, EPM, drone technologies for safety and virtual assistant. We focused on literature published in the last decade, with an emphasis on 2018–2025 to capture recent innovations. The sources were gathered through database searches (Scopus, Web of Science, Google Scholar) using keywords such as "smart helmet safety", "wearable sensor work safety", "construction drone inspection", "electronic performance monitoring safety", "virtual assistant in safety process", "digital assistant in safety field" and related terms. Additional references were identified from citations within key papers and from relevant review articles. In total, about 65 publications were selected for in-depth analysis based on their relevance to construction or industrial safety and their focus on one of the target technology classes. The publications analysed include journal and conferences articles, systematic review papers, and reports from European OSH organizations. In particular, in 2025 the International Labour Organization (ILO) unveiled an updated report (ILO2025, 2025) investigating key areas of technological changes, which include digital tools and the novel role of AI. For both digital surveillance and virtual assistant technologies, a common classification of the contributions found in literature has been used based on the following four pillars:

- *Technology used* (hardware/software);
- *Field of application* (type of industry /work/narrow field);
- *Safety process/function* (proactive or reactive, or both (if any);
- *Active-dynamic* (i.e. real-time data collecting) or passive–static data set (pretrained data source, i.e. safety protocols, procedures, documentations).

Benefits and challenges are also highlighted. Two different approaches have been used to apply the above classification for each type of technologies studied and are explained below.

4.1. *Classification of Digital Surveillance contributions in the OSH management*

For digital surveillance a top-down classification has been applied, as we started from the technology category identified for synthesizing and classifying the findings of the relevant studies in accordance to the 4 pillars of the classification.

In particular, we have identified six main categories: smart helmets, chest bands, smart clothing, wearable sensors, algorithmic performance monitoring tools, inspection drones. The application of these technologies in OSH is summarized in Table 1 and discussed in Section 5.

Table 1 Digital Surveillance Technologies Classification

Tech Categories	**Field of application**	**Safety function/ process (PROACTIVE/REACTIVE/ BOTH)**	**Data set Static/Dynamic)**	**Benefits & Challenges**
IoT smart helmets	Mining and heavy industries, construction sites	-Monitoring environmental parameters (temperature, humidity, pressure, air quality, noise toxic gases). -Real-time notification with local and remote alerting. Data transmission via Wi-Fi, and Bluetooth for lower-power local communication (PROACTIVE)	Dynamic	BENEFITS: -Early detection of hazardous environmental conditions (gas, dust, temperature); real-time worker localisation and alerting; support to safety management through continuous monitoring CHALLENGES: -Wearability and comfort issues; limited battery life; sensor reliability; communication and connectivity constraints
Wearable multi-sensors (Multiparametric chest bands)	High-heat environments, physically demanding works (Firefighters)	- Measurement of ECG, heart rate, heart-rate variability (HRV), respiratory rate, and movement; machine-learning algorithms are used to classify key metrics (PROACTIVE)	Dynamic DB & Static DB	BENEFITS: -Continuous physiological monitoring; assessment of fatigue and heart stress in high-risk activities; support to real-time decision making CHALLENGES: -Wearability and user comfort; battery autonomy; signal quality and data accuracy (challenges)
Smart clothing (smart PPE)	Construction sites, hazardous industrial environments (oil, gas, logistics, defence)	-Biometric sensors (PPG/ECG, respiration, skin/core temperature), environmental and motion sensors; Real-time feedbacks (vibrations, LEDs, alerts) warns workers. -Advanced platforms support digital twin and AI integration. (PROACTIVE) -Emergence response, heatmaps of risks (REACTIVE)	Dynamic & Static DB	BENEFITS: -Active systems interacting with the user and the environment. Continuous monitoring of the workers (fall detection/man-down); proximity warning; hands-free operations CHALLENGES: -Usability and comfort of garments, energy consumption and battery life. Workers' acceptance, data management and privacy concerns
Wearable ergonomic and physical-workload sensors	Repetitive tasks, manual material handling, ergonomics	-IMUs (accelerometers, gyroscopes and magnetometers) and plantar sensors for posture and workload assessment, with possible heart rate and temperature monitoring; haptic or visual feedback; (PROACTIVE)	Dynamic	BENEFITS: -real-time feedback to workers; prevention of musculoskeletal disorders CHALLENGES: -User acceptance and privacy concerns; need for accurate calibration; sensor placement and battery limitations
Algorithmic / Electroni	Digital workplaces	-Tracking of keystrokes, clicks, time, and location; possible integration with biometric	Dynamic & Static DB	BENEFITS:

c Performance Monitoring (EPM) tools	and office-based work	sensors; reporting and analytics; (REACTIVE).		-Improved organisational oversight and compliance; data-driven performance analysis and reporting CHALLENGES: -Workers' acceptance: increased stress due to perceived surveillance; privacy and ethical concerns; potential negative impact on job satisfaction
Safety and Inspection Drones	Inspections of construction sites, buildings, and infrastructures; hard-to-reach areas	-Collection of images and videos and point clouds; computer-vision algorithms are used to detect PPE use and hazardous zones (PROACTIVE)	Dynamic	BENEFITS: Remote inspection of hazardous or hard-to-reach areas, with reduction of worker exposure to risks CHALLENGES: Limited flight autonomy; environmental and weather constraints; regulatory restrictions; privacy and acceptance issues

4.2. *Classification of Virtual assistant contributions in the OSH management*

Virtual assistance, instead, is a specific technology and not a category, for this reason a bottom-up approach has been preferred: each single relevant contribution in literature has been analyzed for categorizing the application of this technology in accordance with the 4 pillars of the classification defined. Details are summarized in Table 2 and discussed in the next section.

Table 2 Classification of Virtual Assistant applications

Tech used (paper)	Field of application	Safety function/ process (PROACTIVE/REACTIVE/BOTH)	Data set Static/Dynamic)	Benefits & Challenges
Large Language Model (LLM)-based VA (Devarapalli 2025)	Chemical manufacturing plants	-Monitoring of the compliant application of safety procedures (PROACTIVE) -Predictive Maintenance (BOTH)	Static DB & Dynamic DB	BENEFIT: -Real time data useful for supporting safety process -Supporting the decision making in contextualized unsafe situation
NLP-based VA + other (IOT, AR etc.) (Soofastei 2024)	Mining sector	-Hazard detection (PROACTIVE) -Real time training modules (PROACTIVE) -Emergency response for accidents (REACTIVE)	Static DB & Dynamic DB	BENEFIT: -Big data sets analysis in real-time reduce the probability of costly exploration errors, boosting mining operations' overall efficiency and financial viability
KobBot VA: NLP and natural language understanding (NLU) automatic speech recognition (ASR) machine learning (Torregosa Bonet et al. 2025)	Construction sector	-Support to safety protocol application (PROACTIVE) -Emergency management (REACTIVE)	Static DB & Dynamic DB	BENEFIT: -High accuracy in speech recognition and technical responses, significantly reducing incident rates -Lowering of the cognitive burden on operators and facilitation of decision-making for workers with varied experience levels -Scalable solution

Voice-enabled VA (Plitman et al., 2024)	Healthcare sector	Monitoring of PPE procedures (PROACTIVE)	Static DB	BENEFIT: -Improvements of the application of PPE donning and doffing procedures -Automated and scalable system CHALLENGE: -No identification of errors and prevention of breaches in PPE procedures
CHATBOT based on Pretrained LLM-based VA (Contreras et al. 2024)	Mining sector	User assistance in safety training activities (PROACTIVE)	-Static DB	BENEFIT: -Scalable solution CHALLENGE: -no dynamic data-set useful to other safety processes
NLP-based VA (Pillai 2023)	Automotive sector	Predictive maintenance alert by using sensors and other sources (PROACTIVE & REACTIVE)	Static DB & Dynamic DB	BENEFIT: -Reduction of distractions while driving CHALLENGE: -Accurate and reliable algorithms necessary for languages, accents and dialects interpretation -Implementation of robust security measures to protect data from unauthorized access and misuse
Multilevel spatiotemporal model like a digital twin (Tianxing et al. 2023)	Urban Transport Industry	Hazard detection (PROACTIVE & REACTIVE)	Dynamic DB	BENEFIT: -Scalable solution -increment of the average reaction speed of personnel in hazard situations 35% CHALLENGE -increased accuracy of events detection by almost 10%, but it gets better with more complex algorithms
Deep learning (Iyenghar et al., 2022)	Safety Field	Machinery risk management (PROACTIVE)	Static DB & Dynamic DB	BENEFIT: -Support to unskilled personnel on safety issue CHALLENGE: -With deep learning is difficult to manage large amount of training data -The accuracy of the prediction depends on the model architecture and complex parameters

5. Discussion

Most of the digital surveillance technologies considered implement proactive systems, with a real-time risk prediction aim. However, some of them also allow to collect and store the different types of data (static DB), in order to be later analyzed, extracting key metrics. Data-driven decisions represent a strategic benefit for OSH, allowing to investigate the root causes on aggregated data with a prevention perspective. Construction sites is a dominant field of application. Some of the classified technologies are increasingly used in narrow hazardous fields (e.g. use of smart helmets in mining, multiparametric chest bands increasingly used by firefighters), suggesting specific sectors facing acute safety challenges addressable through the considered technology. While the primary application mainly addresses physical hazards in high-risk environments, our classification also encompasses specific solutions designed for monitoring sedentary roles and remote work scenarios. All of the technologies are subject to privacy issues, which still remain a challenge.

Next to this, literature on virtual assistants has highlighted that to date there are still few applications of this technology supporting OSH management, despite its great potential. There are applications or preliminary study in several fields, especially in the mining sector, and there are both experimental and real case study. The dataset used for feeding the database is usually static, and in some cases also dynamic but focused on supporting other processes, such as maintenance; only in few applications real time data are used for supporting safety processes. This could be an improvement point for future research in this topic. Another interesting issue could be the type of safety process supported, as most of the studies analyzed support proactive safety processes focused on preventing hazardous situations, but few include also the reactive or resilient OSH processes; this could be another improvement point for future research. For both digital surveillance and VA applications, it can be observed that a clear communication about the parameters monitored and the reasons, together with a training program for the users, are fundamental for the acceptance and correct use by the users.

6. Conclusion

Digital technologies are emerging as a support of OSH processes. This new trend brings benefits but also challenges, as these new systems are changing the landscape of workplace risk management, supporting the management of existing risks, but also introducing new possible risks related to these technologies. This study focused on two specific categories: digital surveillance and VAs. A study of their main characteristics and an in-depth literature analysis were conducted. A detailed classification, based on four relevant elements -technology used, field of application, safety function/process impacted, type of data-set- has been carried out for these applications, highlighting also benefits and challenges. Interesting insights for future studies emerged for both categories, such as the importance of transparency about the monitored data, especially sensitive data, and the need of a specific and detailed training for effective worker acceptance and proper use.

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