# Wearable Devices and Work Safety

Subjects: Engineering, Electrical & Electronic
Contributor: Ekaterina Svertoka

Today, ensuring work safety is considered to be one of the top priorities for various industries. Workplace injuries, illnesses, and deaths often entail substantial production and financial losses, governmental checks, series of dismissals, and loss of reputation. Wearable devices are one of the technologies that flourished with the fourth industrial revolution or Industry 4.0, allowing employers to monitor and maintain safety at workplaces.

Keywords: wearables ; smart devices ; occupational safety ; IIoT ; data collection ; communications ; localization

## 1. Introduction

The workplace is fraught with many sources of danger, especially in enterprises with harmful work conditions. For a long time, the work safety issue has been relegated to the background by employers for the sake of labor productivity. , statistics on industrial death accidents from 1970 to the present day have a shape close to Gaussian. However, the emergence of new technologies, including wearable devices, can also contribute to constraining mortality in industries nowadays [1].

Although the number of accidents per year tends to decrease, the level of mortality in workplaces is still considerable. According to the International Labor Organization (ILO) [2], approximately 1.9 million people have work-related diseases, and 2.3 million people die from work accidents annually. Besides, these statistics reflect only reported cases: not all enterprises openly register all cases, thus, not entailing inspections, sanctions, unrest among staff, loss of reputation, etc. Therefore, at least 4.2 million people suffer in the workplace per year, and 45% of countries have a population less than this number [3].

The problem of work safety in industrial environments is still on the crest of a wave. Worldwide statistics show a high rate of death and injury at work, a variety of hazardous industries, and sources of danger [2]. With the advent of Industry 4.0 and broad integration of the Internet of Things (IoT), employers are expected to achieve better safety mainly due to the emergence of various technologies [4]. Further discussion will focus on the Industrial IoT (IIoT) that emerged to design, maintain, monitor, optimize, and analyze industrial operations to gain real-time insights, make effective decisions and maintain occupational safety [5][6].

At this point, many entrepreneurs had doubts about the feasibility of introducing such an innovation due to the uncertainty about the impact that it will have on workers, labor processes, production, and, more importantly, profits. Due to the global pandemic situation, many enterprises terminated their businesses or even claimed bankruptcy. Indirectly, we can estimate a decrease in production capacity by an increase in unemployment. For example, Estimote has redesigned its industrial wearable tracking devices to remember contacts between workers closer than two meters [7][8].

By meeting two basic requirements for any IoT device, namely, access to the Internet and communication solutions, wearables have become one of the most important IoT concepts, forming IoWT as a promising yet young segment. Various forecasts state that the wearable device market will reach 57 billion USD by 2022 [9], or even 64 billion USD by 2025 [10], and 104 billion USD by 2027 [11]. Wristbands and bracelets currently occupy the leading position among wearable devices and smartwatches, which market share is almost 50% [12].

As of today, research literature still lacks comprehensive reviews on wearable technology and its industrial utilization [13]. In this paper, the authors distinguished 24 categories of wearable technologies and divided them into five groups depending on the functions; monitoring, tracking, augmenting, assisting, and delivering content. Moreover, they highlight six motivations behind the use of wearable devices in industrial environments: the ability to monitor employees' psychological and physiological factors, enhance operational efficiency, promote work environment safety and security, and improve workers' health. Finally, they revealed the main challenge groups compliant with the adoption of wearable devices; technological challenges (trade-off between size, weight, battery functions, accuracy, etc.), social challenges (confidentiality of data, lack of technical skills, high dependency on the wearable device), policies and standards set by governments, economic challenges (high cost of the wearable devices and its integration with other systems), and data challenges (data ownership issue, huge amount of data).

In particular, authors in [14] review wearable devices as part of the IoT concept, mentioning work safety in the list of areas where this technology is beneficial but without special focus on it. On the opposite, some other works explore the use of wearable devices in a narrow specific area of the industry. However, to the best of the author's knowledge, none of these works investigates industrial wearables focusing on occupational safety or reviews key aspects of data collection, data transmission, and localization. Driven by the works mentioned above, this paper aims to analyze and integrate information related to wearable devices and provides a comprehensive overview of the different features of their use in maintaining and increasing work safety in potentially hazardous industries.

## 2. Industrial Wearable Devices

The IIoT provides a wider view and a deeper understanding of the company's processes by integrating different sensors, wearables, software, and data processing tools. The clearest advantage of wearables in IIoT is lucre, which is reached by increasing operational efficiency, reducing downtime, and optimizing business processes. Less frequently discussed in the literature, the benefit is related to how wearable technology can maintain workplace safety. It is necessary to identify the main sources of security threats and the causes of workplace accidents to answer the first research question.

There are no general statistics on mortality from injuries by the industry sector. However, some countries keep such records providing statistics in ratios (commonly, the number of deaths per 100,000 workers) without mentioning the actual number of accidents. Hopefully, in the near future, the management of statistics in enterprises will be more widespread and, importantly, standardized so that data from different places can be easily compared, problems—identified, and experience in dealing with them—shared. Figure 2 outlines the results of investigations conducted in USA [15], Australia [16], Germany [17], Great Britain [18].

Notably, the four key causes in decreasing order of frequency are: fall from height, struck by moving/falling object, caught-in/between (when a worker is between the parts of machinery/object [19]), and hit by moving vehicle. According to [20], the main consequences that lead to death due to the last two reasons are chronic obstructive pulmonary disease and cancer (more often, lung cancer and mesothelioma). Nonetheless, constant stress should also be added to the list. In the long-term, it may entail severe psychological problems and several problems such as the higher risk of myocardial ischemia, cardiac arrhythmia, anorexia, Alzheimer's disease, insomnia, etc.

Importantly, industrial wearables have increased requirements for reliability. Harsh industrial surroundings, characterized by extreme environmental values (extra-low/high temperatures, high radiation level, etc.), require the wearable device's physical durability. Also, specific worksites impose the need to develop and improve the accuracy, range, response time, and robustness of traditional technologies. Table 1 provides an answer to the first research question by identifying wearable features and functions that help maintain occupational safety.

All industrial wearables functions can be categorized into four groups: monitoring, supporting, training, and tracking. The informing function providing just-in-time information at the workplace and proposed in [21] is seldom represented as a standalone function nowadays and can be, thus, merged with the supporting function. Table 2 gives examples of wearable solutions currently applied in the most hazardous industry branches.

In summary, industries are replete with hazard sources resulting in a high work mortality rate. However, work safety levels can be increased by using wearable devices through the ten functions mentioned above.

## 3. State-of-the-Art Techniques in the Field of Industrial Wearables

The use of a wearable device in the functions discussed above involves other technical aspects, such as data collection, data transfer technologies, and localization methods. This section reviews the existing approaches, pointing out the most promising ones for industrial uses.

The monitoring function is based on the collection of several metrics. In fact, no classification of metrics collected by wearable devices is currently available in research works. We, thus, divide these metrics into two groups depending on the data collected from wearables. The first group is related to the data "extracted" from the human body, and the second group deals with the environment's information.

In industrial scenarios and setups, the most important and frequent metrics related to the human body are temperature, heart rate, and location. However, the motion metric is essential for industries associated with lifting heavy loads (construction, logistics), and the perspiration can also be relevant for industries with a high probability of heat stress (e.g., mining) Developing a comprehensive, lightweight, wearable solution consisting of multiple sensors capable of measuring the human body's vital parameters as possible will make a significant contribution to eliminating accidents due to human error in hazardous industries. In the reviewed literature, temperature, relative humidity, and air quality are often used as environment metrics.

Historically, wearable solutions that appeared in the medical domain were based on a wired communication architecture, where wearable devices transmit their collected data to external processing units via wired links [22][23]. However, relying on wired connectivity restricts user mobility. The migration from wired to wireless connectivity for data transmission is a trend in healthcare monitoring systems and industrial wearables in general. As a result, we provide in Table 5 a summary of the main short-range, mid-range, and long-range connectivity solutions currently employed in industrial wearable systems.

Due to the battery lifetime consideration, most market-available wearable devices generally rely on smartphone-aided operations using short-range and mid-range communication technologies. In this architecture, the smartphone pre-processes the data sent by the wearable device and acts as a gateway to transmit the pre-processed data to the cloud (if needed). The short-range and mid-range connectivity solutions in industrial wearable applications include Radio Frequency Identification (RFID), ZigBee, Bluetooth, Bluetooth Low Energy (BLE), and Wireless Fidelity (Wi-Fi) [24]. For instance, Reactec company has designed a wearable wristband that measures the amount of Hand-Arm Vibration (HAV) that provides real-time monitoring and automated reporting of HAV exposure [25].

ZigBee and Bluetooth are among the Industrial Wireless Sensor Networks (IWSN) technologies based on the IEEE 802.15 standard and are characterized by the low energy consumption and the support of several topologies [26]. In [27], the authors proposed a wearable system that utilizes ZigBee technology and aims at improving the worker's safety in the energy industry. As depicted in Table 5, examples of Wi-Fi medium-range standards include IEEE 802.11b, IEEE 802.11g, IEEE 802.11n, and IEEE 802.11ac.

Several life insurance companies offer Intel Basis Peak smartwatches to their customers to measure their heart rates, sleep patterns, and physical activities [25]. These smartwatches utilize Wi-Fi and Bluetooth standards for connectivity purposes. The data collected from the smartwatches are stored in the cloud, and real-time analytics can be performed to identify customers having healthy lifestyles, while various challenges related to data privacy arise since wearables are essentially processing person-identifiable biometric information [28]. In particular, the data processing should follow regional-specific regulations, e.g., General Data Protection Regulation (GDPR) in EU [29].

Furthermore, wearable devices can be equipped with both short-range and long-range connectivity chipsets. It can be justified by the device manufacturers' aim to enable standalone and hands-free operations for wearable devices and end-users, respectively [30]. The main long-range connectivity solutions considered for industrial wearable applications are based on low-power wide-area (LPWA) standards. As their name suggests, LPWA technologies are optimized for low power operation, thus, the long battery life in low-end wearable applications.

Tracking applications are not the only services that can be provided by wearable solutions using long-range communication technologies. For instance, the AlertGPS wearable devices offer a multitude of functionalities for worker safety, including mass notifications in cases of fire, bad weather, or other emergency situations [25]. They also offer the feature of emergency calls where the worker can initiate a call with a safety agent using conventional Long-Term Evolution (LTE) cellular technology [31]. Although the adoption of licensed cellular technologies in wearable solutions has not received enough attention in the literature, the cellular IoT standards that were ratified by the 3rd generation partnership project (3GPP) to support the LPWA operations can enable wearable applications with better coverage, scalability, interoperability, quality of service (QoS), and security [14].

Communication technologies utilized in industrial wearable applications.

On top of the currently utilized short-range, mid-range, and long-range technologies provided in Table 5 and with the increasing attention addressed to industrial wearables, other candidate communication technologies are lately being taken into account and studied to support the novel requirements. Its extended range can provide wearable devices with seamless connections in challenging environments like industrial setups and, being backward compatible, is expected to allow seamless integration with higher energy efficiency [32]. Further, and on top of the cellular IoT standards for wearable mMTC, certain industrial wearable applications can have requirements [33] that are similar to the other two 5G service classes, namely enhanced mobile broadband (eMBB) and ultra-reliable and low latency communications (URLLC) [34]. For instance, AR and VR-based applications require high data rates, high reliability, and low latency and can utilize the millimeter wave (mmWave) 5G technology [35].

As mentioned, identifying the exact location of the objects is one of the most important functions performed by wearable devices. Accurate positioning is key to preventing worker collision with moving machinery, exclusion of an opportunity of unauthorized access to hazardous work areas and equipment, successful evacuation, and efficient distribution of labor. However, positioning continues to be one of the most challenging problems for industrial wearable devices due to the nature of the workplace (e.g., underground, underwater) and, at the same time, high accuracy requirements. Moreover, employee location tracking also raises data ownership, security, and privacy questions, which will be explored in more detail in the next section.

All location tracking techniques could be divided into two groups: methods depending on range and range-free techniques [36]. The first group considers the conversion of various parameters to the range. It comprises time-based measurements (Time of Arrival (ToA), Time Difference of Arrival (TDoA)) , angle-based measurements (Angle of Arrival (AoA), Angle of Departure (AoD), power-based measurements (Received Signal Strength Indicator (RSSI), in connection with which path loss models are used).

In the second group’s schemes, for example, in the Distance Vector-Hop algorithm (DV-HOP), anchors broadcasting their location to the whole network, and unknown nodes estimate their location based on the proximity to these known anchors (hop size and hope count). Such algorithms can be used without any additional equipment [36]. The choice between these two groups is based on the trade-off between price and accuracy: range-based techniques provide high precision, but their application is quite expensive. Range-free techniques are usually considered a cheaper and less precise alternative to the first group.

To choose the localization solution for a particular case, one should review such parameters as the environment (outdoor/indoor), coverage, power consumption, scalability, price, and accuracy.

The first question is what environment is more typical for industrial cases: outdoor or indoor. For the same reason, achieving high accuracy in the first case is much more complicated than in the second. However, it is more desirable, especially during evacuations from the rubble or other emergency cases. In outdoor cases, random existing static anchor stations are usually used to determine the location, whereas in indoor cases, anchors’ deployment could require complex preliminary calculations.

Usually, we want to identify the worker’s position in a relatively limited area, referring mainly to indoor localization. It is worth noticing that in such manufactures as construction or logistics, for example, just indoor localization is not sufficient. However, seamless localization is still a problem: there is no localization solution for both outdoors and indoor cases and cellular-based solutions have lousy accuracy. This situation is expected to be changed with the coming 5G that, as was announced, will ensure sub-meter accuracy.

As mentioned before, localization accuracy is still a big issue, especially in the indoor environment. To improve it, engineers explore and apply different combinations of technologies as it was done in QUUPPA Intelligent Locating System where RSSI was combined with AoA Direction Finding signal processing methodology [37]. However, the declared high accuracy of less than 10 cm is offset by high cost, small coverage, and relative deployment complexity [38].

For these purposes, ground-based pseudolites (pseudo-satellite transmitters) can provide localization in industrial environments where the GPS has poor or no coverage, such as deep, open-pit mining, high water dams; urban canyons; large indoor industrial halls. Both use a network consisting of fixed pseudolites installed on the ground, around the perimeter of the objective; mobile receivers installed on moving equipment such as heavy engineering vehicles and aircraft [39][40][41]. These pseduolite systems operate in industrial environments such as Boddington Gold Mine (Australia), Morenci Copper Mine (Arizona, USA), White Sands Missile Range (New Mexico, USA). For example, in the USA, since 2006, all mine operators must adopt electronic tracking systems, RFID being the most popular solution [42].

To conclude, choosing the appropriate localization techniques in each case compromises accuracy, coverage, power consumption, scalability, and price. When discussing localization techniques for industrial wearables, we need to consider that we usually deal with low throughput, low power, small size, and specific locations (underground, underwater). The position is an essential parameter for work safety providing and remains one of the main accuracy-related issues (especially in indoor and underground conditions) and smoothness of tracking.

## References


1. Wu, F.; Wu, T.; Yuce, M.R. Design and Implementation of a Wearable Sensor Network System for IoT-connected Safety and Health Applications. In Proceedings of the 5th World Forum on Internet of Things (WF-IoT)., Limerick, Ireland, 15–18 April 2019; IEEE: Piscatvey, NJ, USA, 2019; pp. 87–90.
2. International Labor Organization. World Statistics. Available online: (accessed on 27 May 2021).
3. Worldometer. Countries in the World by Population (2021). Available online: (accessed on 27 May 2021).
4. Masek, P.; Hudec, D.; Krejci, J.; Ometov, A.; Hosek, J.; Andreev, S.; Kroepfl, F.; Koucheryavy, Y. Advanced Wireless m-Bus Platform for Intensive Field Testing in Industry 4.0-Based Systems. In Proceedings of the 4th European Wireless C onference, Catania, Italy, 2–4 May 2018; VDE: Berlin, Germany, 2018; pp. 1–6.
5. Meticulous Research. Industrial IoT (IIoT) Market Worth 263.4 Billion Dollars by 2027- Exclusive Report Covering Pre a nd Post COVID-19 Market Analysis and Forecasts by Meticulous Research. Available online: (accessed on 27 May 202 1).
6. Hosek, J.; Masek, P.; Andreev, S.; Galinina, O.; Ometov, A.; Kropfl, F.; Wiedermann, W.; Koucheryavy, Y. A SyMPHOnY of Integrated IoT Businesses: Closing the Gap between Availability and Adoption. IEEE Commun. Mag. 2017, 55, 156–164.
7. The Influence of the COVID-19 Pandemic on the Internet of Things (IoT) Market. Available online: (accessed on 27 Ma y 2021).
8. Estimote. Workplace Safety with Wearables. Available online: (accessed on 27 May 2021).
9. Allied Market Research. Wearable Technology Market Overview. Available online: (accessed on 27 May 2021).
10. Industry ARC. Wearable Technology Market—Industry Analysis, Market Size, Share, Trends, Application Analysis, Gro wth And Forecast 2020–2025. Available online: (accessed on 27 May 2021).
11. Grand View Research. Wearable Technology Market Size, Share; Trends Analysis Report by Product (Wrist-Wear, Eye-Wear, Head-Wear, Foot-Wear, Neck-Wear, Body-Wear), by Application, by Region, and Segment Forecasts, 2020–202 7. Available online: (accessed on 27 May 2021).
12. Statista. Market Share of Wearables Unit Shipments Worldwide by Vendor from 1Q’14 to 1Q’20. Available online: (acce ssed on 27 May 2021).
13. Ometov, A.; Shubina, V.; Klus, L.; Skibińska, J.; Saafi, S.; Pascacio, P.; Flueratoru, L.; Gaibor, D.Q.; Chukhno, N.; Chuk hno, O.; et al. A Survey on Wearable Technology: History, State-of-the-Art and Current Challenges. Comput. Netw. 202 1, 193, 108074.
14. Dian, F.J.; Vahidnia, R.; Rahmati, A. Wearables and the Internet of Things (IoT), Applications, Opportunities, and Challe nges: A Survey. IEEE Access 2020, 8, 69200–69211.
15. Statista. Occupational Injury Death Rate in 2018, by Private Industry Sector. Available online: (accessed on 27 May 20 21).
16. Safe work Australia. Fatality Statistics by Industry. Available online: (accessed on 27 May 2021).
17. Quentic. The Top 3 Most Dangerous Industry Sectors to Work at in Germany. Available online: (accessed on 27 May 20 21).
18. HSE. Workplace Fatal Injuries in Great Britain. 2019. Available online: (accessed on 27 May 2021).
19. Constructconnect. Avoiding OSHA’s Fatal Four—Caught-In/Between Hazards. Available online: (accessed on 27 May 2 021).
20. World Health Organisation. Number of Deaths Due to Work-Related Accidents. Available online: (accessed on 27 May 2021).
21. Khakurel, J.; Melkas, H.; Porras, J. Tapping into the Wearable Device Revolution in the Work Environment: A Systemati c Review. Inf. Technol. People 2018, 31, 791–818.
22. Mine Safety and Health Administration (MSHA). Heat Stress in Mining. Available online: (accessed on 27 May 2021).
23. Rapin, M.; Wacker, J.; Chételat, O. Cooperative Sensors: A New Wired Body-Sensor-Network Approach for Wearable B iopotential Measurement. In Proceedings of the 5th EAI International Conference on Wireless Mobile Communication a nd Healthcare, London, UK, 14–16 October 2015; pp. 151–154.
24. Pyattaev, A.; Johnsson, K.; Andreev, S.; Koucheryavy, Y. Communication Challenges in High-Density Deployments of Wearable Wireless Devices. IEEE Wirel. Commun. 2015, 22, 12–18.

25. Kaul, A.; Wheelock, C. Enterprise Wearable Technology Case Studies. In White Paper; Tractica: Boulder, CO, USA, 20 16.
26. Gungor, V.C.; Hancke, G.P. Industrial Wireless Sensor Networks: Challenges, Design Principles, and Technical Approa ches. IEEE Trans. Ind. Electron. 2009, 56, 4258–4265.
27. Bernal, G.; Colombo, S.; Al Ai Baky, M.; Casalegno, F. Safety++ Designing IoT and Wearable Systems for Industrial Saf ety through a User Centered Design Approach. In Proceedings of the 10th International Conference on PErvasive Tech nologies Related to Assistive Environments, Island of Rhodes, Greece, 21–23 June 2017; pp. 163–170.
28. Bezzateev, S.; Afanasyeva, A.; Voloshina, N.; Ometov, A. Multi-Factor Authentication for Wearables: Configuring Syste m Parameters with Risk Function. In Proceedings of the 2nd International Conference on Advanced Wireless Informatio n, Data, and Communication Technologies, Lviv, Ukraine, 13–14 November 2017; pp. 1–7.
29. Voigt, P.; Von dem Bussche, A. The EU General Data Protection Regulation (GDPR). InA Practical Guide, 1st ed.; Sprin ger International Publishing: Cham, Switzerland, 2017; Volume 10, p. 3152676.
30. Djapic, R.; Vivier, G.; Zhen, B.; Wang, J.; Lee, J.; Haiming, W. Wearables White Paper; TNO: Den Haag, The Netherlan ds, 2018.
31. AlertGPS. AlertGPS Uses AT&T Connectivity to Help Keep Mobile Workers Safer. Available online: (accessed on 27 Ma y 2021).
32. Tian, L.; Santi, S.; Seferagić, A.; Lan, J.; Famaey, J. Wi-Fi HaLow for the Internet of Things: An Up-to-Date Survey on I EEE 802.11 ah Research. J. Netw. Comput. Appl. 2021, 2021, 103036.
33. Ometov, A.; Daneshfar, N.; Hazmi, A.; Andreev, S.; Carpio, L.F.D.; Amin, P.; Torsner, J.; Koucheryavy, Y.; Valkama, M. S ystem-Level Analysis of IEEE 802.11 ah Technology for Unsaturated MTC Traffic. Int. J. Sens. Netw. 2018, 26, 269–28 2.
34. Shafi, M.; Molisch, A.F.; Smith, P.J.; Haustein, T.; Zhu, P.; De Silva, P.; Tufvesson, F.; Benjebbour, A.; Wunder, G. 5G: A Tutorial Overview of Standards, Trials, Challenges, Deployment, and Practice. IEEE J. Sel. Areas Commun. 2017, 35, 1201–1221.
35. Elbamby, M.S.; Perfecto, C.; Bennis, M.; Doppler, K. Toward Low-Latency and Ultra-Reliable Virtual Reality. IEEE Netw. 2018, 32, 78–84.
36. ur Rehman, O.; Javaid, N.; Bibi, A.; Khan, Z.A. Performance Study of Localization Techniques in Wireless Body Area S ensor Networks. In Proceedings of the IEEE 11th International Conference on Trust, Security and Privacy in Computing and Communications, Liverpool, UK, 25–27 June 2012; IEEE: Piscatvey, NJ, USA, 2012; pp. 1968–1975.
37. Quuppa. Bluetooth Low Energy, Angle-of-Arrival, and the Magic Behind. Available online: (accessed on 27 May 2021).
38. Cao, Z.; Chen, R.; Guo, G.; Pan, Y. iBaby: A Low Cost BLE Pseudolite Based Indoor Baby Care System. In Proceeding s of the 2018 Ubiquitous Positioning, Indoor Navigation and Location-Based Services (UPINLBS), Wuhan, China, 22–2 3 March 2018; pp. 1–6.
39. Rizos, C.; Lilly, B.; Robertson, C.; Gambale, N. Open Cut Mine Machinery Automation: Going Beyond GNSS with Locat a. In Proceedings of the International Future Mining Conference, Sydney, Australia, 6–8 December 2011; Citeseer: Prin ceton, NJ, USA, 2011; pp. 22–23.
40. Zimmerman, K.R.; Cobb, H.S.; Bauregger, F.N.; Alban, S.; Montgomery, P.Y.; Lawrence, D.G. A New GPS Augmentatio n Solution: Terralite'XPS System for Mining Applications and Initial Experience. In Proceedings of the 18th International Technical Meeting of the Satellite Division of The Institute of Navigation (ION GNSS 2005), Long Beach, CA, USA, 13–16 September 2005; pp. 2775–2788.
41. Trunzo, A.; Benshoof, P.; Amt, J. The UHARS non-GPS based Positioning System. In Proceedings of the 24th Internati onal Technical Meeting of The Satellite Division of the Institute of Navigation (ION GNSS 2011), Portland, OR, USA, 19 –23 September 2011; pp. 3582–3586.
42. CDC. Basic Tutorial on Wireless Communication and Electronic Tracking: Technology Overview. Available online: (acce ssed on 27 May 2021).