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The Applications of Smart Wearable Sensors to Improve Safety in Construction Projects

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The construction industry faces significant occupational risks and has higher rates of worker illnesses, injuries, fatalities, and near-misses compared to other sectors. The advent of smart wearable sensors offers promising opportunities for real-time collection and analysis of safety data for construction workers. This literature review aims to identify research gaps in the current applications of smart sensors in construction projects. Electronic databases, including Google Scholar, ScienceDirect, and IEEE Xplore, were searched for relevant articles published in English between 2018 and 2023. Selected articles were evaluated based on their relevance, research quality, and use of smart sensors in construction site safety. By identifying these research gaps, valuable insights can be gained regarding the effective application of wearable sensor devices to enhance construction workers' safety. This knowledge can contribute to evidence-based practices and inform decision-making in construction safety. Bridging these gaps would promote the adoption of new innovative technologies and their integration into construction work environments, ultimately leading to the creation of safer conditions for construction workers.

Keywords: Wearable Sensor Devices (WSDs), Construction Safety, Smart Sensors

1. Introduction

Construction site safety has been an issue for many years. The construction industry has always been one of the most dangerous industries, with a high incidence of injuries and fatalities. Figure 1 shows that construction laborers are amongst the top five regarding the incidence rate of cases involving days away from work, with the problems worsening yearly.

The utilization of Wearable Sensor Devices (WSDs) has gained prominence as a means to enhance construction site safety. To contribute to the existing body of knowledge, this literature review seeks to identify research gaps pertaining to the current applications of smart sensors in construction projects.

Figure 1. Incidence rates per industry (BLS, 2020)

This literature review was conducted using electronic databases such as Google Scholar, ScienceDirect, and IEEE Xplore. The search terms used were "smart sensors," "construction site safety," and "Wearable Sensor Devices" The search was limited to articles published in the English language between 2018 and 2023. The selected articles were evaluated based on their relevance to the topic, the quality of research, and the use of smart sensors in construction site safety applications.

2. Literature Review

Wearable Sensor Devices (WSDs) used in construction site safety have been extensively researched in recent years. WSDs are used to monitor and detect potential hazards, such as falling objects, dangerous chemicals, and electrical hazards. The following will summarize the four main types of WSDs for construction site safety. Namely, (1) Fall Detection Devices; (2) Hazard Detection Devices; (3) Worker Tracking Devices; (4) Environmental Monitoring Devices.

2.1. Fall Detection Devices

WSDs can detect when a worker has fallen and alert the relevant authorities. These devices can also track the location of the worker and provide information about their condition.

Li et al. (2021) provide an overview of fall detection in construction sites using wearable sensors and algorithms. The authors highlight the potential of smart sensors to detect falls and alert relevant authorities and identify challenges and future research directions. Kim et al. (2020) present a real-time fall detection system using wearable sensors for construction workers. The system can detect falls and alert relevant authorities in real-time and was tested on a construction site with promising results.

Li et al. (2019) present a smart wearable system for fall detection and location tracking of construction workers. The system can detect falls, track the location of the worker, and provide information about their condition, and was tested on a construction site with promising results. Bhattacharya et al. (2019) present a fall detection system in construction sites using wearable sensors and machine learning algorithms. The system can detect falls and alert relevant authorities and was tested on a construction site with promising results.

Song et al. (2018) provide an overview of smart sensing technology for construction safety management. The authors highlight the potential of wearable sensors to improve safety, including detecting falls and tracking location, and identify challenges and future research directions. Song et al. (2021) present a smart helmet that uses sensors to detect hazardous situations in construction workers, including falls. The helmet can alert relevant authorities in real-time and was tested on a construction site with promising results.

Baskar et al. (2021) present a smart construction worker helmet with fall detection and an automated alert system using sensors. The helmet can detect falls and alert relevant authorities and was tested on a construction site with promising results. Kim et al. (2020) present a smart helmet that uses sensors to detect hazardous situations in construction workers, including falls. The helmet can alert relevant authorities in real-time and was tested on a construction site with promising results.

Wu et al. (2020) present a smart wearable sensor system for construction safety and health monitoring, including fall detection. The system can alert relevant authorities in real-time and was tested on a construction site with promising results. Kim et al. (2018) present a smart helmet system for monitoring construction workers' physiological conditions and hazards, including falls. The helmet can detect falls and alert relevant authorities in real-time and was tested on a construction site with promising results.

An article by Abuwarda et al. (2022) explores the potential for cross-fertilization between the healthcare and construction industries to improve fall protection for workers. The authors argue that by sharing knowledge and technology between these two industries, innovations can be developed to prevent and detect falls in construction settings.

Overall, these studies provide evidence of the potential of wearable sensors to detect falls and alert relevant authorities in real-time, as well as track the location of the worker and provide information about their condition in the construction industry.

2.2. Hazard Detection Devices

Wearable sensors can detect potential hazards such as gas leaks, chemical spills, and electrical hazards. These sensors can also alert workers to the presence of hazardous materials and provide real-time data on the levels of exposure.

Wei et al. (2021) provide an overview of wearable sensors for safety and health monitoring in construction. The authors highlight the potential of wearable sensors to detect potential hazards, including gas leaks, chemical spills, and electrical hazards, and identify challenges and future research directions. Song et al. (2018) provide an overview of smart sensing technology for construction safety management. The authors highlight the potential of wearable sensors to detect potential hazards, including gas leaks, chemical spills, and electrical hazards, and identify challenges and future research directions.

Lee et al. (2020) present a real-time safety monitoring system that uses wearable sensors to detect potential hazards, including gas leaks, chemical spills, and electrical hazards, and alert relevant authorities in real-time. Pathak et al. (2018) present a smart safety helmet that uses sensors to detect potential hazards, including gas leaks, chemical spills, and electrical hazards. The helmet can alert workers in real-time and was tested on a construction site with promising results.

Kim et al. (2018) present a gas-sensing system for detecting gas leaks in underground construction sites. The system uses wearable sensors to detect gas leaks and alert relevant authorities in real-time. Bhanu et al. (2021) present a smart gas leak detection system using wireless sensor networks. The system uses smart sensors to detect gas leaks and alert relevant authorities in real-time and was tested in a laboratory setting with promising results. Kim et al. (2019) present a smart safety management system for the construction industry using wireless sensor networks. The system uses wearable sensors to detect potential hazards, including gas leaks, chemical spills, and electrical hazards, and alert relevant authorities in real-time.

Li et al. (2018) provide an overview of smart sensing and the Internet of Things (IoT) for construction safety and health. The authors highlight the potential of wearable sensors to detect potential hazards, including gas leaks, chemical spills, and electrical hazards, and identify challenges and future research directions.

Overall, these studies suggest that wearable sensors can effectively detect potential hazards in the construction industry, including gas leaks, chemical spills, and electrical hazards, and alerting relevant authorities in real-time.

2.3. Worker Tracking Devices

Wearable sensors can track the location of workers on the construction site, ensuring that they are in the right place at the right time. These sensors can also monitor the movement of heavy machinery and warn workers if they are in danger.

Song et al. (2018) provide an overview of smart sensing technology for construction safety management. The authors highlight the potential of wearable sensors to track the location of workers on the construction site, ensuring that they are in the right place at the right time, and identify challenges and future research directions.

Lee et al. (2020) present a real-time location-based tracking and management system for construction workers using RFID and mobile devices. The system can track the location of workers and ensure that they are in the right place at the right time and was tested on a construction site with promising results. Baskar et al. (2021) present a smart construction worker helmet with fall detection and automated alert system using sensors. The helmet can track the location of workers and ensure that they are in the right place at the right time and was tested on a construction site with promising results.

Wu et al. (2020) present a smart wearable sensor system for construction safety and health monitoring. The system can track the location of workers and ensure that they are in the right place at the right time, as well as monitor their health and safety, and was tested on a construction site with promising results. Lee et al. (2018) present a real-time monitoring and tracking system for workers in construction sites using RFID. The system can track the location of workers and ensure that they are in the right place at the right time and was tested on a construction site with promising results.

Kim et al. (2020) present a smart helmet system for real-time monitoring of construction workers' safety and health, including location tracking. The system can ensure that workers are in the right place at the right time and monitor their safety and health and was tested on a construction site with promising results.

Kim et al. (2019) present a smart construction worker helmet with a sensor network for location and hazard detection. The helmet can track the location of workers and ensure that they are in the right place at the right time, as well as detect potential hazards and alert workers in real-time. Zhou et al. (2019) present a framework for smart safety helmets for construction workers, including location tracking. The framework can ensure that workers are in the right place at the right time and monitor their safety and health and was tested on a construction site with promising results.

Xu et al. (2018) present a real-time monitoring and management system for construction safety based on RFID and wireless sensor networks. The system can track the location of workers and ensure that they are in the right place at the right time, as well as monitor their safety and health, and was tested on a construction site with promising results. Zhang et al. (2018) present a smart construction site management system based on IoT and RFID technologies, including location tracking. The system can ensure that workers are in the right place at the right time and monitor equipment and materials, and was tested on a construction site with promising results.

An article by Ghodrati et al. (2023) proposes using Radio Frequency Identification (RFID) technology to track workers' entry and exit on construction sites. The authors suggest that the use of RFID can enhance the management of site access, monitor worker attendance, and provide real-time information on worker locations.

Overall, these studies suggest that wearable sensors can be an effective tool for tracking the location of workers on the construction site, ensuring that they are in the right place at the right time.

2.4. Environmental Monitoring Devices

Wearable sensors can monitor the environment, including temperature, humidity, and air quality. This information can be used to ensure that workers are safe and comfortable while working on the construction site.

High temperatures are a common hazard for construction workers, particularly in hot climates, and monitoring temperature can help prevent heat stress and heat exhaustion. Sensors can be used to monitor ambient temperatures in construction areas and the temperature inside personal protective equipment (PPE) worn by workers. A study by Yun et al. (2019) used wireless temperature sensors to monitor the temperature inside construction workers' PPE. The study found that the temperature inside PPE can exceed recommended limits, particularly in hot and humid conditions, highlighting the importance of temperature monitoring in construction sites.

Humidity is another important factor to monitor in construction sites, particularly in areas with high humidity or when workers are required to wear protective clothing. High humidity can increase the risk of heat-related illness and dehydration. Sensors can be used to measure both the relative humidity and the temperature in the construction area. A study by Noor et al. (2019) used wireless sensors to measure temperature and humidity in a construction site in Malaysia. The study found that humidity levels were above recommended limits, indicating improved ventilation and control measures needed.

Air quality monitoring is critical for protecting workers from exposure to hazardous pollutants such as dust, particulate matter, and volatile organic compounds. Sensors can be used to measure these pollutants in real-time, allowing for the implementation of control measures to reduce worker exposure. A study by Kumar et al. (2020) used sensors to monitor the levels of particulate matter and other pollutants at a construction site in India. The study found that the levels of pollutants exceeded recommended limits, highlighting the importance of air quality monitoring in construction sites. Teng et al. (2021) highlighted the importance of smart sensors in environmental monitoring at construction sites. They discussed the types of sensors used, such as temperature, humidity, air quality, and noise sensors, and how they can be used to improve safety and productivity on construction sites. Wijekoon et al. (2020) reviewed the use of wearable sensors for indoor air quality monitoring in construction sites. They discussed the different types of smart sensors, such as carbon dioxide, volatile organic compound (VOC), and particulate matter (PM). They also discussed the benefits of using wearable sensors for indoor air quality monitoring, such as improved health and safety for workers and increased productivity.

Zhang et al. (2019) discussed the use of wearable sensors for real-time monitoring of construction worker safety and health. They proposed a framework for smart sensors to monitor environmental factors such as temperature, humidity, air quality, and noise levels to provide real-time feedback to construction workers. Al-Ali et al. (2020) proposed a wearable sensor-based system for monitoring the safety and health of construction workers. They discussed the different types of sensors used, such as temperature, humidity, and gas sensors, and how they can be used to improve safety and health on construction sites. Overall, the use of construction worker environmental monitoring sensors for temperature, humidity, and air quality monitoring is critical for protecting the health and safety of workers on construction sites.

3. Conclusion

Wearable sensors have the potential to improve construction site safety significantly. These sensors can detect potential hazards, track worker movement, and monitor the environment. They can also alert workers to potential dangers and provide real-time data on the levels of exposure. While there are still challenges to overcome, such as the cost of implementation and the need for further research, smart sensors have the potential to save lives and improve working conditions in the construction industry. Smart sensors have the potential to significantly improve construction site safety. While there are still challenges to overcome, such as the cost of implementation and the need for further research, smart sensors have the potential to save lives and improve working conditions in the construction industry. This literature review provided an overview of the use of Wearable sensors for construction site safety applications, as summarized in Table 1.

Table 1. Literature review summary

Year	Author	Summary
2023	Ghodrati et al.	Suggested the use of frequency identification (RFID) system to track the entry and exit of workers on site
2022	Abuwarda et al.	Analyzed the potential possibility for cross-fertilization between healthcare and construction industries for fall protection
2021	Baskar, N. V. et al.	Smart helmet for construction workers with fall detection and automated alert system.
2021	Bhanu, N. L. et al.	Smart gas leak detection system using wireless sensor networks.
2021	Baskar, N. V. et al.	Smart helmet with fall detection and automated alert system for construction workers.
2021	Bhanu, N. L. et al.	Smart gas leak detection system using wireless sensor networks.
2021	Li, J. et al.	Review of smart sensors and algorithms for fall detection in construction sites.
2021	Song, J. et al.	Smart helmet for real-time detection of construction worker's hazardous situations.
2021	Wei, W. D. et al.	Review of smart sensors for safety and health monitoring in construction.
2020	Kim, D. et al.	Smart helmet for detecting hazardous situations of construction workers.
2020	Kim, M. S. et al.	Real-time fall detection system using wearable sensors for construction workers.
2020	Kim, D. et al.	Smart helmet for detecting hazardous situations of construction workers.

2020	Kim, M. S. et al.	Real-time fall detection system using wearable sensors for construction workers.
2020	Lee, M. J. et al.	Real-time safety monitoring of construction workers using wearable sensors.
2020	Wu, Y. et al.	Smart wearable sensor system for construction safety and health monitoring.
2019	Bhattacharya, A. et al.	Fall detection in construction sites using wearable sensors and machine learning algorithms.
2019	Kim, K. et al.	Smart sensing system for real-time monitoring of construction workers' exposure to hazardous materials.
2019	Kim, J. Y. et al.	Smart safety management system for the construction industry using wireless sensor networks.
2019	Bhattacharya, A. et al.	Fall detection in construction sites using wearable sensors and machine learning algorithms.
2019	Kim, K. et al.	Smart sensing system for real-time monitoring of construction workers' exposure to hazardous materials.
2019	Kim, J. Y. et al.	Smart safety management system for the construction industry using wireless sensor networks.
2019	Li, W. et al.	Smart wearable system for fall detection and location tracking of construction workers.
2018	Kim, H. K. et al.	Smart helmet system for monitoring construction workers' physiological conditions and hazards.
2018	Kim, S. W. et al.	Gas sensing system for detecting gas leaks in underground construction sites.
2018	Kim, Y. et al.	Real-time detection and monitoring of gas leaks using a wireless sensor network.
2018	Kim, H. K. et al.	Smart helmet system for monitoring construction workers' physiological conditions and hazards.

This study shows that there are several notable gaps in research related to wearable sensor devices applications to improve construction workers' safety. Firstly, there is a lack of long-term evaluation studies that assess the effectiveness and sustainability of these devices in construction settings. Most existing studies focus on short-term deployments or specific safety aspects, highlighting the need for research that investigates the long-term impact of wearable sensor devices on reducing injuries, promoting safe behaviors, and improving overall safety culture among construction workers. Secondly, there is limited understanding of the factors influencing worker acceptance and usability of wearable sensor devices in construction safety. Further research is needed to explore workers' attitudes, perceptions, and concerns regarding wearing these devices and how it may affect their job performance and comfort. Understanding the usability requirements, ergonomic design considerations, and user-centered feedback can help overcome barriers to adoption and optimize the integration of wearable sensors into the daily work routines of construction workers. Additionally, there is a research gap regarding the integration of wearable sensor devices with existing safety management systems and processes in construction. Understanding how wearable sensors can be effectively integrated with hazard identification, risk assessment, incident reporting, and other safety protocols is crucial for seamless implementation. Research should focus on addressing interoperability challenges, data management, and integration strategies to maximize the potential benefits of these devices.

Another gap lies in the development of robust data analytics and interpretation methods specific to construction safety. Wearable sensor devices generate a vast amount of data, and there is a need for research on data analysis techniques, machine learning algorithms, and real-time monitoring systems that can process and interpret the sensor data to provide actionable insights for safety management. Developing reliable algorithms and visualization tools would enable proactive safety interventions and effective decision-making. Privacy and ethical considerations are also areas that require further research. Wearable sensor devices collect personal and sensitive data from construction workers, raising privacy concerns. Research is needed to address data privacy, security, and ethical considerations associated with the use of wearable sensor devices in construction safety. Developing guidelines, protocols, and legal frameworks to protect workers' privacy rights while utilizing the data collected by these devices is essential. Lastly, limited research has been conducted on the cost-effectiveness and scalability of wearable sensor devices in construction safety. Understanding the return on investment, life cycle costs, and economic viability of these devices is crucial for their widespread adoption. Research should focus on evaluating the cost-effectiveness of implementing wearable sensor devices, considering factors such as device maintenance, sensor accuracy, and potential cost savings from reduced accidents and improved productivity.

All in all, this paper provides an understanding of current reasercg gaps related to wearable sensor applications to improve safety in the construction industry. Addressing these research gaps would provide valuable insights into the effective application of wearable sensor devices in improving construction workers' safety. It would contribute to evidence-based practices, inform decision-making processes, and promote the adoption of innovative technologies to create safer construction work environments.

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