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Application of Wearable Devices in Construction Safety and Worker Occupational Health

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Abstract

The potential of wearable devices has been recognized in a number of areas, including construction safety and worker occupational health. However, there is a lacks of an overview of specific applications. This article integrated the wearable device applications in the field of construction safety and workers' occupational health related literature, summed up the application of seven categories: monitoring location information, evaluate the physiological and mental state, evaluate the hazard identification and risk awareness, reduce occupational diseases occur, to ensure the safety of working environment, improve the protective equipment and strengthen safety inspection and training, and analyses the possible challenges. Finally, an integrated safety management system can be developed to realize the intelligence and efficiency of safety management.

Keywords

Wearable Devices; Construction Safety; Worker Occupational Health.

1. Introduction

Wearable devices are emerging intelligent device, which have been widely used in many fields such as medical treatment, military, entertainment and industry due to their advantages of convenience and real-time. In addition, wearable devices use virtual reality, augmented reality and exoskeleton technology to assist people in production and life.

In mining and other industries, the application potential of wearable devices has been confirmed [1]. Wearable devices can be divided into two categories: large equipment and small equipment. Large equipment based on mechatronics and ergonomics reduces the physical demands and fatigue of construction workers and helps improve workers' safety and health [2], such as exoskeleton technology;Small devices are relatively simple, mostly equipped with sensors for different purposes, which can actively monitor or collect the user's physical data and environmental data. The supporting technologies are chips, batteries, flexible components, wireless transmission and human-computer interaction, etc. , as shown in Figure 1. Since exoskeleton technology has little connection with management science and there are many research barriers, this paper focuses on the application of small wearable devices in construction safety and worker occupational health.

In the existing literature, there are many classification methods of wearable devices. According to the scope of device application, wearable devices are divided into four categories: auxiliary devices, workplace devices, medical and health devices and consumer products [3]. In terms of physical form, it can be divided into smart watches, smart glasses, health trackers, smart clothing, wearable cameras and wearable medical devices [1]. Changbum et al. focused their research on the application of wearable devices in the field of building safety and health, thus elaborating physiological sensing devices[4].Physiological sensing devices can be measured by a single organ or organ system,covering multiple organs or tissues such as the heart, skin, muscle, eyes and brain. Their research positively evaluates the potential of wearable devices for building safety and worker occupational health.

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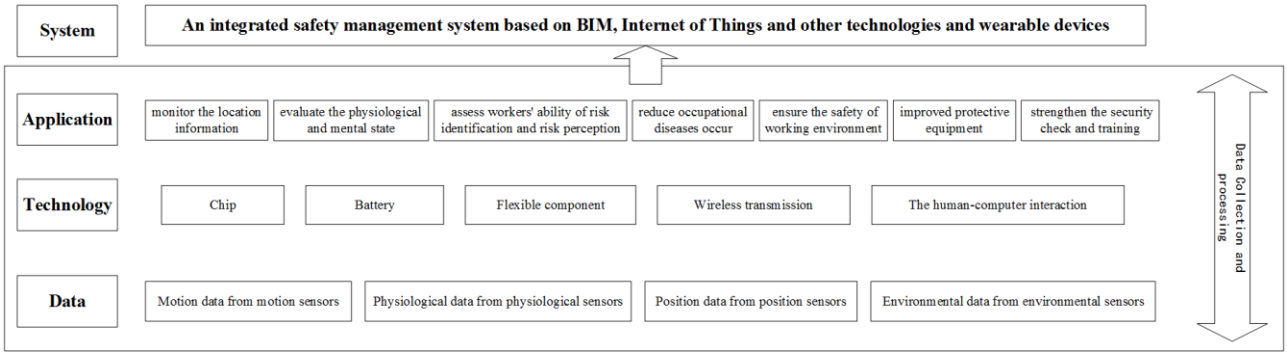

Figure 1. Application of wearable devices in construction safety and worker occupational health

One of the advantages of wearable devices is to provide real-time and accurate physiological and environmental data based on sensors. Therefore, this paper divides wearable devices into four categories based on sensors of wearable devices: motion sensor devices, physiological sensor devices, position sensor devices and environmental sensor devices. Motion sensors mainly rely on accelerometers or gyroscopes to measure real-time motion data of users; Physiological sensors collect user's heart rate, pulse and other physiological data; The position sensor equipment relies on the Internet of Things technology to provide real-time feedback on the position of the human body or equipment; Environmental sensor equipment is closely related to environmental detection and can accurately detect the surrounding environmental conditions. The specific sensor classification and representative applications are shown in Table 1.

Table 1. Classification and application of sensors for wearable devices in the field of building safety and worker occupational health

Equipment Category	Representative Data	Common Tools	Application
Motion sensor	Accelerated speed	Inertial Measurement Unit(IMU)	Gait analysis
Physiological sensor	Heart rate\Activity ntensity	Electrocardiogram/ Electroencephalogram	Measure the heart rate or blood pressure
Position sensor	Position data	Proximity sensor	Construction site autonomous monitoring system
Environmental sensor	Temperature/ Humidity/Gas concentration	Smoke detector	Fire alarm system

2. Application of wearable devices in construction safety and worker occupational health

In the field of construction safety and worker occupational health, the research contents of wearable devices are different according to different technologies and devices. In the early stage, wearable devices mostly combined with RF, positioning, Bluetooth and other technologies and position sensors to determine and track workers' positions and issue danger warnings when they are close to dangerous areas. In recent years, with the gradual development of physiological sensors in the field of medical and health, the construction field is also increasingly attaching importance to wearable devices equipped with physiological sensors. Awolusi et al. proposed four types of applications of sensors in safety monitoring in the field of construction engineering, namely physiological monitoring, environmental remote sensing, close monitoring and position tracking [5]. Ahn et al. summarized the current application status of motion sensors and physiological sensors in building safety and worker health, and proposed six types of applications, including prevention of musculoskeletal diseases, prevention of falls, assessment of physical load and fatigue state, assessment of risk recognition ability and monitoring of worker's mental state [4]. Li et al. studied the application of VR and AR

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technology in building safety management, such as hazard identification, safety training, safety guidance and inspection, etc [6].

Combining the above review classes existing in the field of literature and the related research results, the wearable technology application in the field of construction safety and occupational health workers are divided into the following seven categories: monitor the location information, evaluate the physiological and mental state, assess workers' ability of risk identification and risk perception, reduce occupational diseases occur, ensure the safety of working environment, improved protective equipment, strengthen the security check and training.

Monitoring position information is mainly realized through position sensors and Internet of Things technology. By monitoring the positions of workers [7] or incoming materials and vehicle equipment [8], collisions can be reduced and the construction site is more safe and efficient. Shahi et al. [9] used UWB positioning technology to track indoor project activities with many obstacles. Single location tracking cannot give full play to the potential of wearable devices in the field of building security. Therefore, some scholars focus on the integration of wearable technology and information system. Teizer et al. [10], Fang [11], Park et al. [12] all combined the BIM model to carry out safety monitoring on the construction site. The extensive location data combined with the original building information, resource information and progress information of the BIM model can help project managers to clearly grasp the trend of the construction site and realize the efficient operation of the project.

Evaluating the physiological and mental state mainly relies on physiological sensors. Physiological sensors can collect important physiological data of human body, such as heart rate, blood pressure, skin electrical activity, brain electrical activity and so on. Most of the existing physiological and psychological tests for workers are unable to achieve continuous and objective measurement. For example, chemical reagent tests will interrupt the ongoing activities of workers. Questionnaire surveys are subjective. Therefore, the prominent advantages of wearable devices in detecting workers' physiological and psychological states are real-time, continuous and objective. Jebelli et al. [13], Hwang et al. [14], Li et al. [15] and Chen et al. [16] respectively studied the stress, emotional state, mental fatigue and mental load of workers by combining EEG, and the results showed that wearable EEG devices could achieve real-time and accurate measurement of the physiological and mental state of workers during activities to a certain extent. In addition to EEG devices, a variety of small, portable measuring devices can also be used to detect workers' status. For example, wristbands can detect workers' electrical skin activity, skin temperature and photoplectometry to assess workers' stress levels [17] or measure the level of physical demand for different activities, with a view to scheduling production by assigning workers with different physical strength levels [18]. Studies on workers' state are not limited to physiological indicators. Lee et al. studied the TWH status of construction workers, especially roofers, and paid attention to the comprehensive health status of workers during working hours and other times [19]. Pillsbury et al. compared the health and productivity of different workers in different environments and construction activities with the help of wearable devices [20]. As a means to assess the physiological and psychological state of workers, wearable devices can be monitored in real time and continuously. Moreover, they can guide project managers to pay attention to the health of workers and adjust the work content and shift order according to the situation of workers, so as to improve the working environment of employees.

Assessing workers' ability to identify and perceive risks can provide a level of interference when necessary, increase alertness and prevent unsafe behavior due to inattention or fatigue. Wang et al. developed a wireless wearable EEG system that can quantitatively and automatically assess the attention level of construction workers [21]. Hasanzadeh et al. used mobile eye tracker to study the differences of workers' attention distribution under different situational awareness [22]. Wang et al. studied the relationship between EEG signals and alertness level, and evaluated and screened the alertness indexes related to EEG [23]. Jeelani et al. used three-dimensional point cloud to track workers, and analyzed workers' viewing behavior and calculated the distribution of attention by

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positioning fixation points [24]. Dzeng et al. used eye tracker to compare the visual search strategies of workers with different experience levels, and the results showed that the recognition speed of skilled workers was faster than that of novices, but the accuracy was not necessarily better [25]. Compared with 2D or 3D hazard identification technology, wearable technology focuses more on revealing workers' subjective reaction when facing danger. Combined with brain science or psychology, wearable technology deeply studies workers' reaction when facing danger, and scientifically and systematically trains workers to improve their risk identification ability.

The occurrence of occupational diseases and accidents is closely related to the characteristics of complex tasks and high intensity physical labor in the construction industry. Wearable devices can be used to correct incorrect posture, prevent falls and reduce physical labor intensity. Valero et al. [26] and Yan et al. [27] found and corrected workers' inappropriate working postures through the inertial measurement unit (IMU) to reduce musculoskeletal disorders caused by long-term incorrect postures. Umer et al. [28] and Dzeng et al. [29] used smart phones to detect the fall warning of construction workers. Jebelli et al. analyzed workers' gait data by using an inertial measurement unit attached to the waist or lower back to measure the risk of falling in different walking states [30]. Measuring better posture and muscle load and warning of accidents based on wearable devices could help extend the working life of workers and reduce the loss of workers due to occupational diseases or accidents.

In terms of ensuring the safety of the working environment, Zuluaga et al. used wearable devices to evaluate the performance of the new anti-falling system and improve the safety of the working environment [31]. In addition, relying on environmental sensors, the working environment can be inspected and evaluated. Margaret et al. conducted an investigation and study on workers working outdoors [32]. Combining meteorological conditions and workers' own physical quality, they used smart phones as a platform to monitor environmental exposure and related health results. According to the survey results, three out of four workers said they would be willing to adjust their jobs based on heat warnings from wearables. The environmental data obtained by the wearable device can eventually be integrated into the integrated safety management system to realize automatic early warning of the working environment.

The improvement of protective equipment requires that additional functions should be added on the basis of protecting the original protective performance to ensure the safety of workers. Wu et al. tried to improve the design of safety helmet to reduce traumatic brain injury caused by falls [33]. Mehata et al. developed intelligent wearable devices based on the Internet of Things, which can not only detect the vital signs of workers, but also provide help for workers in dangerous states [34]. Combined with environmental sensors, wearable devices can detect changes in the environment in a more timely manner than fixed or handheld measuring devices. The mining industry has started to combine safety helmets with personal dust monitors to monitor hazardous dust concentrations in the environment around workers [35], and this technology could also have benefits for the construction industry.

Safety inspection and safety training are an important part of safety management, but the previous safety inspection is relatively backward, but AR technology has great potential in the process of inspection, supervision, construction planning, etc. [36]. AR equipment developed by Yeh et al. allows inspectors to input the current position and automatically retrieve relevant safety information. Using VR or AR for safety training can enhance workers' proficiency and raise their risk awareness [37]. VR has significant advantages in training workers to dry-hang stone and cast-in-place concrete, effectively promoting students' attention [38], and the danger identification result is better than 360 panorama [39]. Choi et al. combined VR and situational awareness to study accident prevention awareness of forklift drivers, so as to improve safety training plan. In addition to risk identification, emergencies are another area of research [40]. Tang et al. studied the role of emergency signs in escape and may shorten the evacuation time based on VR emergency evacuation exercise [41]. In general, VR and AR technologies are widely used in the field of building safety, especially in inspection and training, which improves the efficiency and reliability of safety management.

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3. The challenges and prospects of wearable devices

Through the research and analysis of the existing literature, this paper briefly describes the application of wearable devices in the field of construction safety and worker occupational health. Although the wearable device industry has a broad prospect, the research in relevant fields is still in its infancy and has certain limitations.

3.1 Challenges of wearable devices

Reviewing the literature, most of the applications of wearable devices in the field of construction engineering are still in the theoretical stage or laboratory stage, and there are few large-scale field cases for reference and research. Ahn et al. believe that the main research difficulties lie in the quality of sensor signals, individual differences in safety and risks, user resistance in the promotion process and uncertainty of benefits [4]. Awolusi et al. pointed out that privacy and security, operability, technical standardization and personal acceptance need to be considered [5]. In the field of EEG, Zhang et al. believe that the research hindrance lies in the lack of available references and the wide coverage of research content [42].

Therefore, the challenges of wearable devices are concentrated in the following aspects: (1) Technical limitations, including but not limited to sensor technology, signal processing technology and algorithm. (2) the price disadvantage, the cost of the equipment is high and it is difficult to quantify the specific benefits. (3)Potential safety problems. Wearing wearable devices may cause safety risks. (4) Data privacy and data security, wearable devices directly read workers' physiological data, but how to access and protect these data, and whether different levels of physiological data will cause employment discrimination has not been clear opinions. (5) Lack of large research cases, small laboratory research is difficult to compare with the real field environment, lack of large application cases for in-depth study. Although wearable devices face many challenges, most relevant scholars recognize the application potential of wearable devices in the field of construction and engineering, and put forward many valuable development directions.

3.2 Prospects of wearable devices

With the increasingly advanced science and technology, it is foreseeable that large-scale application of wearable devices will improve work efficiency and protect workers' health and safety after solving the obstacles related to technology, economy and society. Some scholars have also discussed the specific development or application direction. Ahn et al. divide the future development of wearable devices into three directions, corresponding to sensors, large cases and risk classification respectively [4]. Chen et al. proposed that the future application of EEG devices should be gradually expanded in scale, and consider combining building information system and etc. [16].

The future development of wearable devices, can be combined with BIM, such as the Internet of things technology, on the basis of developing integrated safety management system, as shown in figure 1, application in the above categories, covering personal protection, personal physiological monitoring, risk early warning, the auxiliary construction equipment and device management and safety inspection training and other aspects, promote the intelligence of the construction site and the information, help to improve working efficiency, protect safety and health of workers.

4. Conclusion

Wearable devices have been favored by many industries due to their advantages of portability and intelligence, and the construction industry is also concerned about this emerging device. Wearable devices in the field of building safety and workers' occupational health are classified according to sensors, which are mainly divided into motion sensor devices, physiological sensor devices, position sensor devices and environmental sensor devices. In this paper, the application of corresponding fields is divided into seven categories, which are monitoring location information, assessing workers' physiological and psychological state, assessing workers' ability of risk identification and risk perception, reducing occupational diseases and accidents, ensuring the safety of working environment,

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improving protective equipment, and strengthening safety inspection and training. Although the application potential of wearable devices has been affirmed by scholars, there are still many challenges and obstacles, such as technical limitations, security risks, data security and privacy issues, and lack of large cases. Over time, after overcoming the research difficulties, the application prospect of wearable devices will be more broad. A collaborative and highly integrated construction site safety management system can be established based on the combination of BIM and Internet of Things technologies.

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