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Wearable technology for personalized construction safety monitoring and trending: Review of applicable devices

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ABSTRACT

The construction process is considered a very risky endeavor because of the high frequency of work-related injuries and fatalities. The collection and analysis of safety data is an important element in measurement and improvement strategy development. The adoption of wearable technology has the potential for a result-oriented data collection and analysis approach to providing real-time information to construction personnel. The objective of this paper is to provide a comprehensive review of the applications of wearable technology for personalized construction safety monitoring. The characteristics of wearable devices and safety metrics thought to be capable of predicting safety performance and management practices are identified and analyzed. The review indicates that the existing wearable technologies applied in other industrial sectors can be used to monitor and measure a wide variety of safety performance metrics within the construction industry. Benefits of individual wearable sensors or systems can be integrated based on their attributes for multi-parameter monitoring of safety performance.

1. Introduction

The high rate of fatalities in the construction industry remains a major concern of both practitioners and researchers. Out of 4386 total worker fatalities in private industry in 2014, 899 were in construction, indicating that over one in five worker deaths are construction related [1,2]. Among industry sectors, workers in construction face the highest risk of occupational injuries and illnesses [3]. Despite the adoption of safety procedures and programs such as those developed and required by the Occupational Safety and Health Administration (OSHA), the rates of fatal and nonfatal construction injuries and illnesses have plateaued the past 10 years.

Given the high proportion of fatal and non-fatal accidents occurring in the construction industry, construction companies constantly seek novel strategies that promote safety [4]. Because of the transient and dynamic nature of construction, organizations must be able to quickly adapt to change by effectively capturing, storing, and disseminating new strategies that prevent injuries [5]. Thus, new technologies may be candidates for safety advancement. Although technology has undoubtedly played a major role in the improvement of construction processes, its application for personalized construction safety monitoring has not been fully explored [6].

In this paper, we review the various applications of wearable technology for personalized construction safety monitoring and trending. The specific objectives were to identify, catalog, and analyze attributes of wearable technology and resulting data thought to be capable of predicting construction safety performance and management practices.

2. Literature review

Due to the hazardous working environments at construction sites, workers frequently face potential safety and health risks throughout the entire construction process [7]. Construction safety has been traditionally measured and managed reactively by taking actions in response to adverse trends in injuries [8]. However, active monitoring of workers' physiological data with wearable technology may allow for measurement of heart rate, breathing rate and posture [6]. This section contains the review of relevant literature about safety performance monitoring, categories wearable systems and sensors as well as the applications of wearable technology in construction and other industries.

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2.1. Construction safety measurement and monitoring

Traditional approaches of measuring safety performance indicators are largely manual in nature and based on subjective opinions [9,10,11]. These approaches rely on massive manual data collection efforts; consequently, data are collected at low frequency (e.g., once a month) and when incidents occur [12,13]. These methods are costly, prone to data entry errors, and result in data sets that are too small for effective and successful project control [11]. To overcome the limitations of manual efforts, automated safety monitoring is considered one of the most promising methods for accurate and continuous monitoring of safety performance on construction sites [14]. Automated monitoring system can acquire data, convert it into structured data, and immediately deliver those data to project managers who can take action [15].

Among real-time project monitoring methods, a good number have strong applications for safety. The purpose of safety and health monitoring is to ensure there is effective measurement and management of construction workers safety practices against the existing safety plans and standards [7]. Unfortunately, the temporary nature of construction sites and project organizations makes the use of standard industrial monitoring systems impractical for construction [16]. Among other engineering application areas, automatically monitoring the location and trajectories of people can be useful for safety, security, and process analysis [11]. Wearable technologies in particular may enable the continuous monitoring of a wide range of vital signals which can provide early warning systems for workers with high-risk health issues [17,18].

2.2. Systems and sensors for wearable technology

Wearable technologies are based of different systems ranging from radio-frequency identification (RFID), magnetic field, radar, ultra-wide band (UWB), ultrasonic, sonar, Bluetooth, Global Positing System (GPS) (from Global Navigation Satellite System (GNSS)), laser, video and static camera, electrocardiogram (ECG/EKG), and electromyography (EMG). Sensors like galvanic skin response (GSR), accelerometers, gyroscopes, and magnetometers constitute a body sensor network. The evolution of digital and mobile technology has transformed many aspects of our lives with many examples that demonstrate the current and potential uses of wearable technology in the field of healthcare [19]. Innovations in sensor technology have been essential to the implementation of body sensor networks and have been combined with progress in short-range communication technologies such as ultra-wideband radio technology and Bluetooth which have enabled the implementation of wearable computing devices [20].

2.3. Wearable technology in other industries

Different categories of wearable technology have been applied across industries such as health care, manufacturing, mining, and athletics. Some of these technologies have shown signs of positive benefits [21] and efforts are being made by both researchers and industry experts to improve on these technologies and learn from their initial implementation.

With the advent of computing platforms with low power consumption and low cost sensors, wearable technology has been increasingly used in health-related research to promote physical activity [17]. Significant progress in computer technologies, solid-state micro sensors, and telecommunication has advanced the possibilities for individual health monitoring systems to collect and analyze human physiological metrics. A variety of compact wearable sensors are currently available [18,22]. Advances in miniature sensors and wireless technology have made available a new generation of monitoring systems that allow one to record physiological data from individuals carrying on daily activities in the home and outdoor environments [23]. Similarly, remote patient monitoring allows people to keep track of their health while avoiding unnecessary visits to the doctor.

In the business sector, several companies took inspiration from the seminal work achieved by researchers at the National Aeronautics and Space Administration's Jet Propulsion Laboratory (NASA-JPL) and developed systems-based body sensor networks for commercialization [18]. One such device provides wellness applications, wireless activity monitors, and health tracking devices that continuously track data such as heart rate, activity, respiration, body temperature, and posture in order to lower healthcare costs and increase productivity [24,25]. These applications are geared toward increasing knowledge transfer, productivity, and security within business operations including controlled access, customer services, remote supervision, and stock allocation [22,26].

In sports and fitness, wearable technologies are being used widely for tracking performance through the smooth and unobtrusive measurements [27]. Wearable technologies such as the GPS watches, heart rate monitors and pedometers are commonly used to obtain real-time information about performance [27,28]. Wearable technology is being incorporated into a multitude of equipment used by professional athletes to monitor not only their performance, but also their safety [29]. For example, sensors are used in the helmets of National Football League (NFL) players to detect concussions and smart compression shirts that have been wired to measure arm movement and technique to determine a pitcher's effectiveness in Major League Baseball (MLB). Also, wristband wearable GPS sport watches are commonly used in the game of golf during practice sessions to improve swing mechanics [21]. Others existing applications of wearable technologies in sport and fitness sector are related to an active lifestyle, including fitness monitoring, outdoor navigation, body cooling and heating, virtual coaching, and sport performance [22].

In security applications, police officers, firefighters, and paramedics are testing wearable technologies to provide remote communication support and feedback with the ability to access information hands-free while carrying out essential tasks [30]. Additionally, for personal security, lighting technologies and protective clothing are being used to enhance visibility and attract attention.

In the mining industry, a proximity warning system (PWS) based on the GPS and peer-to-peer communication was also developed to prevent collisions between mining equipment, small vehicles, and stationary structures [31]. The concept of GPS-based proximity warning for mining equipment entails the use of differential GPS receivers so that the equipment operators are aware of other vehicles or workers nearby.

Wearable technologies are also increasingly influencing people's daily activities in terms of gaming and in the tools used to operate household devices or other gadgets used in communicating [27]. This involves applications related to interacting with computing resource, including data/media access, interactive gaming, responsive learning, and shared experience [22].

2.4. Wearable technology in construction

As opposed to other industries, the application of wearable technology in construction is at the nascent stage. In fact, there are very few documented cases of application of wearable technology in the construction industry [6]. One of the very few application was the evaluation of a method for testing proximity detection and alert systems to promote safety on construction sites [32–34]. Also, hands-free systems were employed to monitor workers and increase their situational awareness by continuously collecting data on the jobsite, detecting environmental conditions, and the proximity of workers to danger zones [35]. The lack of wide-spread implementation is due, in part, to a lack of reliable data supporting their potential benefits.

Recently, the construction industry has begun to use mobile devices to access and share project data from remote work sites [36]. Although, the construction industry may be slow in adopting trends in mobility