A Review of IoT based Construction Site and Labour Safety Monitoring Systems

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***Abstract*— To monitor the labours in the construction field, many supervisors were appointed. Since labours are scattered in the field, it will be difficult to monitor them by the supervisors. Real-time locating and tracking technologies are used in construction safety for automated monitoring of the location and direction of onsite resources, specifically workers and equipment in order to prevent hazard exposures and potential accidents. If it is a high-rise building construction, it will be difficult to locate the labourers at a given time and to communicate any information to them. Real-time locating systems (RTLS) are used for better site safety. IoT based RTLSs have aided safety management process in eight major research streams including safety monitoring, accident prevention, behavior-based safety, safety alerts and warnings, ergonomics analysis and physiological status monitoring, communication-based safety, performance evaluation of the developed RTLS-related technologies and on-site safety training. This paper reviews the existing methodologies and challenges in the field of construction safety. The main contribution of this review lies on providing a more comprehensive knowledge of the current utilization and further development of IoT based RTLS systems on improving construction safety management.**

Keywords*— *IoT, Civil worker safety monitoring, location monitoring system, RTLS, RFID.

I. INTRODUCTION

Fatal accidents have been occurring more frequently at construction sites due to the increasing size, height and complexity of building construction. In response of the accidents in the construction industry, it is essential to install smart technologies such as the Internet of Things (IoT), drones and closed-circuit television (CCTV) in reinforcing safety for construction workers could argue that the rise in occupational accidents has resulted from the increased scale of building construction made possible by technical advancements and the subsequent input of a larger number of construction workers, this issue has not to be mitigated by safe training and dispatch of safety officers alone [1]. Technology has been developing faster in recent days. It has become quite easy to get access to relevant information at anytime and anywhere. With smart gadgets users can easily have access to a vast amount of information wherever they are through the use of the internet on these devices. The IoT means interconnection via the internet of computing devices embedded in everyday objects, enabling them to transmit data. Long-term benefits could include energy savings by a platform that controls smart devices and appliances. The most common injuries on the job site are slips, electrocution, and crashes [2]. To fix these issues, IoT is now being used on the construction site Devices and sensors mounted on construction equipment assist managers in tracking and monitoring the fleet's position via GPS, identifying use trends, idle time, and other metrics, avoiding misuse, theft, or fuel pilferage, and effectively planning and scheduling a job based on constantly changing variables on the job site [3]. Wearables that monitor and provide continuous information about the body and health criteria are used by IoT to ensure the safety of construction workers. It sends out warnings when a dangerous/hazardous zone is approaching, and it notifies site managers of any unexpected changes in the local area, allowing them to better manage labour productivity.

II. RELATED WORK

A. Internet of things (IoT)

The Internet of Things (IoT) is a system of interrelated computing devices, mechanical and digital machines, objects, animals, or people that are provided with unique identifiers and the ability to transfer data over a network without requiring human-to-human or human-to-computer interaction. The IoT was initially inspired by members of the RFID community, who referred to the possibility of discovering information about a tagged object by browsing an internet address or database entry that corresponds to a particular RFID or Near Field Communication technology [4]. Among them, RFID is the foundation and networking core of the construction of the Internet of Things. The IoT enabled users to bring physical objects into the sphere of the cyber world. This was made possible by different tagging technologies like NFC, RFID, and 2D barcode which allowed physical objects to be identified and referred to over the internet. IoT, which is integrated with Sensor Technology and Radio Frequency Technology, is the ubiquitous network based on the omnipresent hardware resources of the Internet, is the Internet contents objects together. Table 1. lists the sensors and systems for construction safety monitoring. It is also a new wave of the IT industry since the application of computing fields, communication networks, and global roaming technology had been applied [5]. It involves in addition to sophisticated technologies of computer and communication network outside, still including many new supporting technologies of Internet of Things, such as collecting information technology, remote communication technology, remote information transmission technology, sea measures information intelligence analyzes and controlling technology, civil construction site monitoring, etc. An application of IoT for monitoring site and workers in civil construction field is illustrated in Fig.1[6].

Table 1. Sensors and Systems for Construction Safety Monitoring

Sl.no.	Sensing	Construction Site Hazards	Metrics	Sensing Technologies
1	Physiological Monitoring	Falls from height	Body posture	Gyroscope, Accelerometer, Magnetometer
		Slips and Trips	Body posture, Body speed, Body rotation and orientation	Gyroscope, Accelerometer
		Stress	Heart rate, Blood Pressure, Respiratory rate	ECG/EKG, Infrared, Radar
		Heat or cold	Body temperature	Thermistor
2	Environmental Sensing	Fire and explosions	Smoke and fire detection	Infrared
		Noise	Noise level	Noise sensor
3	Proximity Detection and Location Tracking	Caught-in or -between	Proximity detection	RFID, UWB, Infrared, Radar, Bluetooth
		Cave in	Location tracking	GPS, RFID, UWB
		Struck-by object	Proximity detection, Location tracking	RFID, UWB, Infrared, Radar, Bluetooth, GPS
		Electrocution	Proximity detection, Location tracking	RFID, Infrared, Radar, Bluetooth, GPS, RFID, UWB

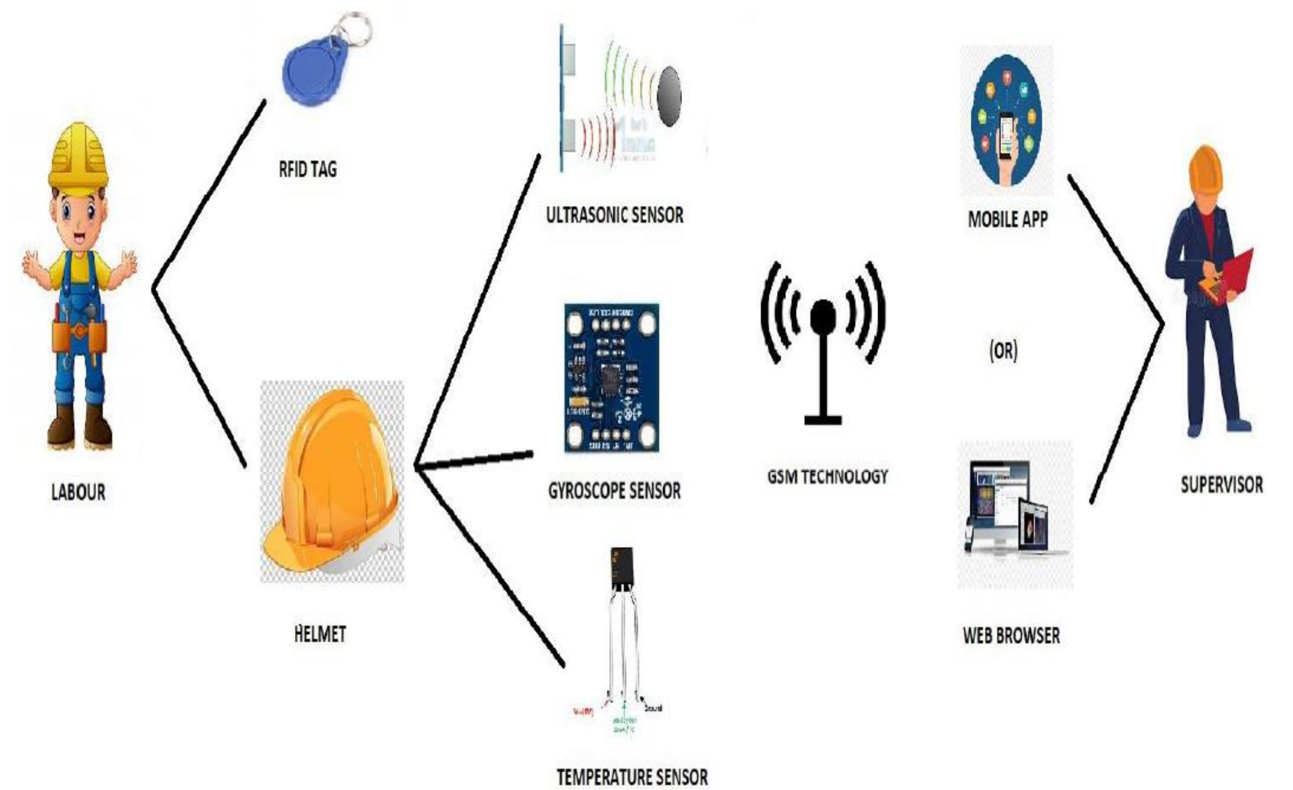

Fig.1 Construction site monitoring system [6]

B. Location monitoring system

There have been significant research efforts applying location tracking or visualization technology for a systematic construction safety management. These efforts focused on directly managing workers and objects to improve safety performance by proactively capturing site information [7] developed pro-active-real-time safety technology using radio frequency wave spectrum to improve the safety of a work zone by alerting workers. In 2012, Hallowell et al. identified the potential barriers and enablers associated with integrating sensing technologies within existing safety management strategies by interviewing safety managers [7]. In 2010, Chae and Yoshida applied Radio Frequency Identification (RFID) technology for prevention of collision accidents with heavy equipment [8]. Nadh et.al. in 2017, presented an automated object identification method using standard video cameras on construction sites [9]. In 2016, Park et.al proposed a real time locating system (RTLS) based tracking for the purpose of tracking the real-time location of workers. This section describes the RTLS hardware configuration and localization methods [10]. In 2021, Jayanthi et.al proposed a system that localizes, and warns site laborers. PIR sensor was used to detect the human entry. RFID reader is placed in every floor of the building which reads the RFID tag from the labour. This is used to find the location of the labour. Using RFID ,PIR sensor and Wi-Fi technology, the location of the civil worker confirms [6].

C. Labour safety monitoring

Kanan et.al in 2018 developed an IoT-based autonomous system for workers' safety in construction sites with real-time alarming,monitoring, and positioning strategies [11]. It was proposed for tracking construction assets such as materials and equipment by combining radio and ultrasound signals. Likewise, Chung et. al in 2020 implemented IoT-based application for construction site safety monitoring [12]. Outhwaite et. al in 2019 proposed a methodology for worker-driven monitoring and redefining supply chain monitoring to improve labour rights in global supply chains [13]. Chae et. al in 2010, explored the applications of RFID in the construction industry including automated tracking of pipe spools and other valued items, and an on-site inspection support system and explored the influence of combination manners of RFID and interior decorating materials on RFID system recognition [14]. Mehata et al. 2019 proposed IoT Based Safety and Health Monitoring for Construction Workers [15]. In 2021, Jayanthi et.al proposed an autonomous system that monitors, localizes, and warns site laborers. The system helps in saving project time and cost [6]. The authors developed a low cost integrated system that alerts the supervisor with two signals, one for the helmet usage and another for the idle time of the labour. The labours may not be able to use the existing communication device during the working hours. The present invention alerts the emergency call information from the supervisor. The supervisors receive the location information of the particular labour through this intelligent system if necessary [16]. In order to ensure the safety of labours the helmet is provided with a sensor, which senses and informs the supervisor through alarm if the labour is not wearing the helmet during working hours. This method will comparatively produce low cost with the benefits of sensor monitoring so that the working hours of the labours can be effectively reported through the idle time calculation. Working time of labours can be made effective by calculating the idle time of the labours, as a result of idle time calculation the wastage of working time can be prevented. To ensure the safety of the labour the helmet is provided with the sensors as shown in the Fig.2. Using gyroscope and temperature sensors the angle and temperature variation of the helmet is detected. When the labour tries to remove the helmet an intimation will be sent from supervisor from web browser to RFID tag.

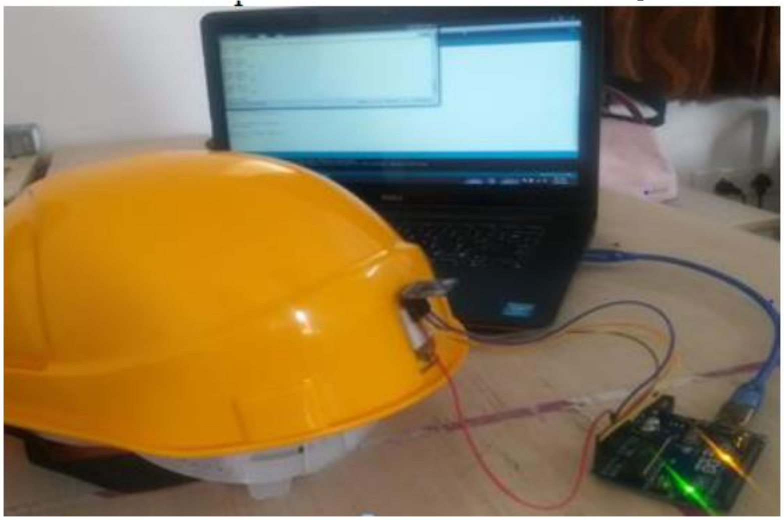

Fig.2 Helmet is provided with a sensor [6]

D. Alarming system

Alarm technology is applied to send warning signals to alert a worker when he or she approaches a dangerous area i.e. unsafe condition. The alarming system is composed of an alarm transmitter and a receiver [17]. The transmitter receives alarm signals from the RTLS engine and delivers it to the alarm receiver, which then sends it to the worker on site. The alarm transmitter and the receiver are attached to the RTLS engine and each tag respectively, as these attachments are highly suitable for use on work sites. Once a worker's location coordinates are sent to the concerned authority. Fig. 4 shows the alarm signal transmission algorithm.

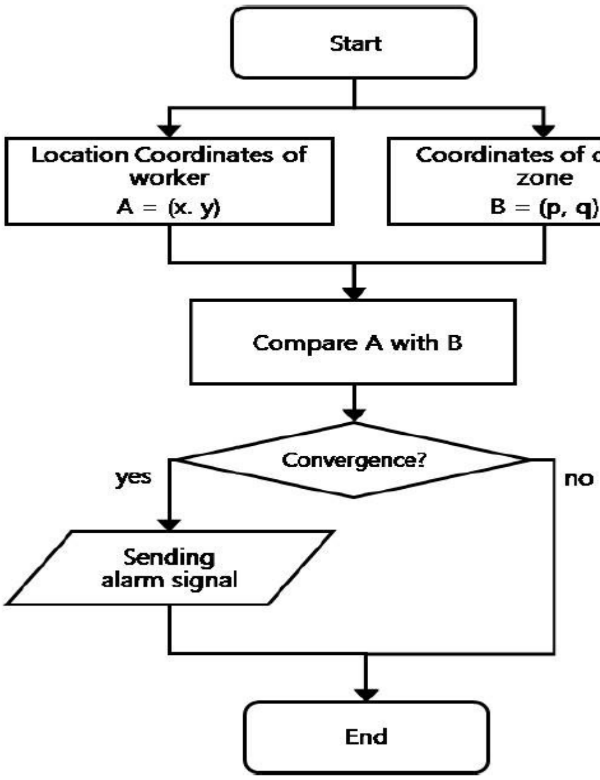

Fig. 3. Alarm signal transmission algorithm

III. CHALLENGES FOR IOT ADOPTION IN CONSTRUCTION

Some of the key capabilities that leading IoT platforms must enable are simple and secure connectivity, privacy, and security i.e. reduced risk of data loss, power consumption i.e. energy sustainability, wearability, and interoperability. For instance, some IoTs are required for monitoring construction workers' safety and collecting sensitive information such as the user's physiological data, absolute location, and movement activities that compromise the user's privacy. This information must be protected during the processes of storage or communication [18]. For instance, a protocol could be developed that limits the type of information that is transmitted through the IoT platform, thereby ensuring that workers have primary control of certain important, yet private health-related information. Furthermore, a non-punitive, opt-in-based system that provides some wellness benefits to workers should be considered. To mitigate the risk of cyber-attacks on IoT [19], there is a need for a strong network security infrastructure for short- and long-range communication. Careful precautions are desired in each passing layer of the system from the wearable sensors to the gateway devices to the cloud, and to ensure users' privacy and security. The heterogeneity of connected wearable devices and the multi-dimensionality of safety data [20] that can be collected and generated to make the demand for interoperability very high. Interoperability is the essential issue for crossing layers of the physical device, communication protocol, and spectrum utility, function, and application.

Workers should have primary control of certain important details like health-related and personal information. A holistic approach is required in addressing and solving the interoperability of IoT devices and services at several layers. Largescale service deployment of new technologies needs to be framed within a set of standards [21]. Because IoT spans multiple industries with many manufacturers and differs broadly in application scenarios and user requirements, large-scale commercial deployment of related IoT services seems very challenging [22]. IoT itself currently lacks theory, technology architecture, and standards that integrate the virtual world and the real physical world into a unified framework. Developments and coordination of standards and proposals will stimulate the effective expansion of IoT infrastructures and applications [23], services, and devices including WSDs. In general, standards developed by a concerted effort of multiple parties, information models, and protocols in the standards, shall be open [24]. It should be noted that global standards are typically more relevant than any local agreements.

For technologies of IoT to be accepted by end-users, their effectiveness, applicability to operations, and value-adding impact as identified and discussed in this study must be continuously evaluated and established. The application of IoT is expected to foster proactive and active construction safety management strategies for reducing injuries, illnesses, and fatalities on construction sites [25]. Further research efforts should be directed toward identifying factors and developing tools that can drive the effective application of these technologies whenever they are deployed on construction sites.

To enhance the diffusion of IoT in construction, there is a need to further evaluate some of the challenges facing their widespread adoption as identified and discussed in this study, particularly, users' inherent concerns with respect to privacy and security, interoperability, and standardization of the technologies.

IV. CONCLUSION

This paper provides a review of the potential applications of IoT for the continuous monitoring of construction workers' safety metrics to mitigate safety hazards and health risks on construction sites. The study evaluated wearable sensors and systems that can be used for physiological monitoring, environmental sensing, proximity detection, and location tracking of a wide range of construction hazards and vital signals which can provide early warning signs of safety issues to construction workers. The schematic model presented in this study can be used by manufacturers of IoTs as a tool for integrating wearable sensors and systems into a single device for interoperability and multi-parameter monitoring of construction safety metrics. This review has unlocked areas for further in-depth research studies on how to enhance the application of the IoT for proactive and active construction safety management. The evaluation of the adoption, adaptation, and infusion of IoTs in construction; evaluation of commercially available IoTs in construction; and development of prototypes of construction-specific wearable IoTs are subjects of further research currently being undertaken by the researchers involved in this study. Additionally, more research is required in understanding the resistance of construction employees to the latest technologies.

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