Sensing technologies for construction productivity monitoring

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Abstract. Construction is a complex and dynamic industry that requires constant monitoring and evaluation to ensure project success. In recent years, the need for accurate and real-time performance data has become more pressing, making traditional evaluation methods based on manual data collection and direct observation less effective. To address this challenge, sensor technologies have emerged as a promising solution for construction performance monitoring. The objective of this article is to present a comprehensive overview of the current state of sensor applications for construction performance monitoring, including recent advancements in this field. Additionally, the article will examine the advantages and disadvantages of sensor technologies in the context of construction performance monitoring.

1 Introduction

The issue of construction productivity has become increasingly pressing in recent years. Conventional methods of performance evaluation in construction, which are based on manual data collection and on-site observations, are both time-consuming and susceptible to human error. To address this problem, the utilization of sensor-based monitoring and documentation technologies has gained significant attention in the construction industry and academic circles [1].

Sensing technologies refer to a range of devices and systems that can be used to gather and transmit data from construction sites. These technologies include wireless sensors, GPS systems, laser scanning devices, and computer vision technologies. They work by capturing data on various aspects of construction, such as material movement, machine operation, and human activity. This data is then processed and analysed to provide valuable insights into construction performance [2].

Historically, activity performance information has been gathered manually through the use of stopwatches and manual observation, or by analysing recorded video footage of the operation. These manual methods are tedious, time-consuming, and susceptible to errors. Additionally, with the advent of new construction and assembly techniques, previous data becomes obsolete and additional manual effort is required to collect new cycle time data. Automated activity monitoring methods can greatly reduce manual effort in data collection

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and provide support for effective production planning and monitoring systems. The establishment of an automated activity monitoring and classification system requires the capability to recognize activities occurring in each work area [3]. The hardware for activity classification includes components such as accelerometers, gyroscopes, magnetometers, Bluetooth, battery, Wi-Fi, memory, GPS, and light and temperature sensors. While combining sensors can improve accuracy, it also increases the cost of the hardware [4]. Automated progress monitoring frequently entails incorporating information from various sensors and sources based on the final goal [5].

The physical condition of the workers can be monitored through various sensors, such as electromyogram, electrocardiogram and heart rate can be checked using electrodes, body temperature using adhesive sensors, breathing rate using piezoelectric or piezoresistive sensors, body movement using accelerometers, body orientation using accelerometers, sweat levels through galvanic response sensors, oxygen saturation using pulse oximeter [6]. In the one hand, construction worker fatigue leads to decreased productivity, reduced service quality, and potential accidents, therefore understanding workers' physiological aspects is crucial for improving both safety and productivity [7]. In the other, implementing electronic performance monitoring for workers comes with the challenge of meeting GDPR standards [8]. Before monitoring, workers should be informed and trained on the use of the devices to be used. They must also give their consent for the collection of data regarding their performance during daily tasks, as required by legal and ethical guidelines [4].

In order to increase the success rate of sensor applications, electronic data collection devices must fulfil numerous requirements, such as durability and resistance, return on investment (ROI), energy efficiency and independence, ergonomic size and weight, user-friendly design, scalability, reliability, high data transmission rate, minimal communication infrastructure and data storage, and secure data handling [9]. There are two main methods for recognizing construction equipment activity, which depend on how the primary sensors are utilized. The first approach is called the "active sensor-based approach," where sensors are attached to the equipment or worker being monitored. The second approach is the "passive sensor-based approach," where sensors are not mounted on the equipment being tracked but are external, such as using video and audio information to classify activities [3]. Furthermore, most of the case studies, proposed methods that includes the integration of these technologies with Building Information Modelling (BIM). This state of affairs provoked that the construction industry is presently investing and will continue to invest in three key technologies in the near future: analysis models for BIM dimensions, sensing technology, and business information models. This emphasizes the importance of using sensing techniques and model-based methodologies to achieve better business results [4].

Despite the existence of sensory approaches relating to productivity, there is still a significant gap between the available sensor technologies and the understanding of their application in terms of construction performance evaluation. This gap has not been thoroughly examined, and as a result, there is still a poor understanding of sensors application in construction. Therefore, the aim of this article is in-depth examination of the modern sensing technologies and techniques used for monitoring productivity in construction projects. It provides a classification of sensors, systems, their advantaged and disadvantages, and approaches used for real-time monitoring in both indoor and outdoor construction environments.

2 Methodology

A review of the scientific literature was conducted to create a summary of all sensor-based technologies suitable for real-time monitoring of construction. The Web of Science electronic database was used as the main source, with the main keyword for this article being "Sensing technologies." The search was refined in three steps: 1) setting journal selection criteria to choose the most recent articles from 2013 to 2023; 2) adding the keyword "Construction" to the search to focus on technologies used in the construction industry; 3) using the keywords "performance monitoring" and "productivity monitoring" because they are related concepts that are equally important for the success of a construction project. This review only uses open access articles without limitations on language or science category, and documents were identified and selected based on their relevance to this study. The initial search generated up to 135,398 results due to the broad concept of "Sensor technologies," but after the refining steps, 109 articles remained.

During the in-depth review phase, content analysis and interpretation were carried out to reflect the latest developments in the field of sensing technology and fulfill the purpose of the article. After that, only the technologies that were used to monitor construction process productivity, workers, and machines were selected for detailed analysis.

3 Sensing technology classification

Classifying sensing technologies can be difficult due to the diversity of techniques and methods involved, as well as the variety of applications and contexts in which they are used. Additionally, many sensing technologies overlap and can be used in combination with each other, further complicating the classification process. As a result, it is important to have a clear understanding of the specific sensing needs and requirements for a given application in order to select the appropriate technology. The study conducted by A.S. Rao et al. provides a comprehensive overview of the different sensing technologies and techniques utilized for real-time monitoring of construction projects [5]. The authors used this classification as a basis for future analysis and summarized it in a Figure 1.

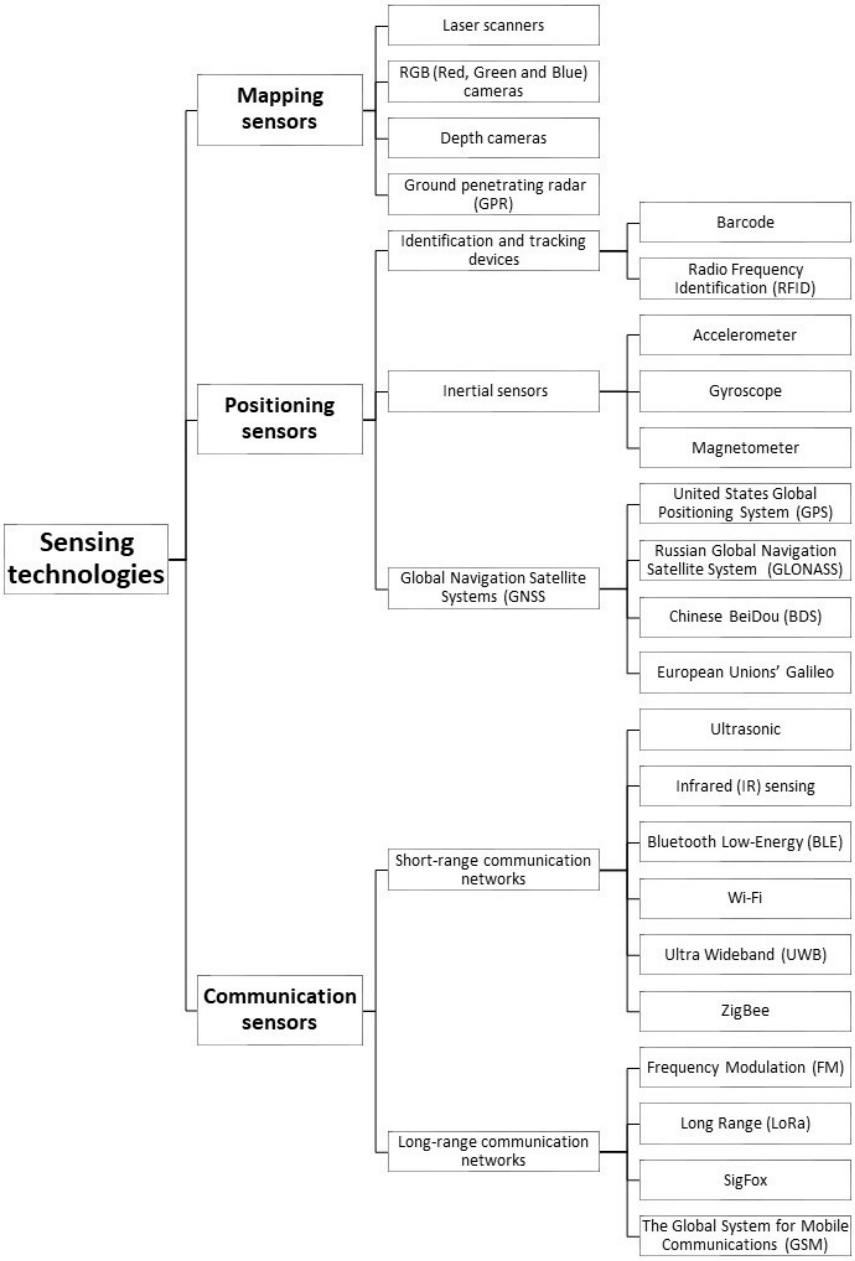

Fig. 1. A summary of sensor-based technologies for real-time monitoring of construction.

Since this article deals primarily with the issue of construction productivity, the authors selected and reviewed only those technologies that, according to the literature, is mainly used in the case studies for the purpose of monitoring the performance and productivity of construction. These sensing technologies are included in Table 1 with an analysis of their advantages and disadvantages in relation to construction productivity monitoring.

Table 1. The detailed overview of selected sensing technologies.

Sensing technology	Reference	Description
Inertial Measurement Unit (IMU)	[5, 10, 11, 12, 13]	IMU is commonly composed of gyroscopes for measuring and transmitting angular rate data, along with accelerometers for measuring and transmitting specific force data. Advantages: • gyroscopes are utilized for measuring angular rate, • accelerometers are utilized for measuring specific force or acceleration, • small size of data Disadvantages: • requires attaching sensors to each resource involved in the activity. • problem of error accumulation, that leads to considerable drift over time • sensitivity to magnetic interference.
Bluetooth low energy (BLE)	[14, 15, 16, 17]	BLE sensor technology is a tag/beacon that can operate for many months on a coin cell battery. This technology, can be complemented by online mapping tools, for indoor and outdoor tracking options at reasonable prices. Furthermore, devices can be moved from one place to another at the end of the project or can be easily replaced. Advantages: • low power consumption, • extended range, • compact size, • reduced latency, • superior energy efficiency, • infrastructure flexibility. • cost-effectiveness and ease of installation. Disadvantages: • vulnerable to rapid fading and significant fluctuations in the received signal strength, • need for relocating • measured data size is too large.
Light Detection and Ranging (LiDAR)	[18, 19, 20, 21, 22, 23]	LiDAR employs laser light pulses to gauge the distance between the sensor and an object by measuring the time it takes for the light to reflect back. The laser pulses, which are emitted in nanoseconds, enable the rapid scanning of regions and the generation of detailed, precise 3D images that can be used to produce elevation maps. Advantages: • quick data collection, • can be mounted to vehicles, • can survey inaccessible areas, • 3d models can be created from scan data, • get accurate measurements within the general scenes of the site. Disadvantages: • too inflexible for indoor use, • objects and weather can interfere with scanning, • does not work well with difficult shape of objects, • point cloud data registration process cannot be done automatically, • high cost of purchasing and deploying.
RGB-Depth	[18, 20]	RGB-D is a technology that combines both color RGB (Red, Green, Blue) and depth information to provide a more comprehensive 3D view of the environment. It is commonly used in computer vision, robotics, and augmented reality applications. Advantages: • provides both depth (D) and color (RGB) data, • better visibility in low-light conditions or areas with visual obstructions. Disadvantages:

		• equipment cost, • limited range, • privacy concerns.
Radio frequency identification (RFID)	[18, 20, 24, 25]	RFID is an example of RSSI-based tracking technology, that utilizes radio waves to recognize and track individuals or items. Can be used for material and tool tracking in indoor construction sites to enhance productivity and control processes. Advantages: • able to detect the presence of objects through walls • can be used indoors. Disadvantages: • chip sensitivity, • metal shielding, • restricted read range, • not suitable for intricate environments, • limited to presence detection or localization, • not allow determining the construction progress status.
Ultra-Wideband (UWB)	[14, 26]	UWB is a technology that uses low power radio waves to transmit and receive data over short distances. It has a high level of accuracy in tracking the location of objects, people, and equipment within indoor and outdoor environments. Advantages: • high read range, • low power consumption, • the ability to function both indoors and outdoors. Disadvantages: • material-dependent propagation, • Limited range (up to 100 meters), • multipath interference, • sensitivity to line-of-sight, • difficulties in deploying systems in dynamic environments.
Global Navigation Satellite System (GNSS)	[27]	GNSS is a technology that uses a network of satellites to determine the precise location of objects, people, and equipment. It is commonly used in construction productivity tracking to provide accurate location data for equipment and personnel. Advantages: • large coverage area, • provide high-accuracy positioning data, • real-time monitoring, • cost-effective, • easy to install and maintain, • non-intrusive. Disadvantages: • high equipment cost, • limited indoor coverage, • require a significant amount of power to operate.

ZigBee	[5, 14, 28, 29]	Wireless technology based on the IEEE 802.15.4 standard that is used for low-power, low-data rate communication between devices. It is commonly used in the Internet of Things (IoT) and building automation. The introduction of ZigBee wireless networks made it possible to control on-site construction resources. This technology has various applications such as tracking and monitoring the activities of workers on construction sites; tracking resources in indoor construction environments; reducing the risk of accidents due to falling objects to improve safety and prevent accidents. ZigBee consists of three main devices: 1. Coordinator (ZC) - the central device that manages the network and coordinates communication between devices. It selects a channel and network number to initiate network operation. If the Coordinator is not present, the network can still operate normally. 2. Router (ZR) - a device that relays data between other devices in the network. 3. End Device (ZED) - a device that is connected to the network but does not forward data to other devices, such as a sensor or light switch. It does not need to maintain the network structure. Advantages: • low-power, • low-data rate. Disadvantages: • limited by battery life, • line-of-sight issues, • primary appropriate for outdoor use.

4 Results and Discussion

One of the key advantages of sensor technologies is that they can provide real-time data that is much more accurate and reliable than manual data collection methods. This is particularly important in the construction industry, where labour costs are a major factor. Also helps to reduce the risk of human error and enables construction managers to make more informed decisions. Furthermore, the use of sensors can help to improve safety on construction sites, by monitoring hazardous conditions and alerting workers to potential dangers. Additionally, the use of sensors allows for remote monitoring of construction sites, making it possible to obtain real-time information from anywhere, at any time [3].

Despite the many benefits of sensor technologies, there are also some disadvantages to consider. One challenge is the cost of installing and maintaining these systems. The intricacy and dynamism of construction sites, resulting from high levels of worker and material movement, and variations in building types and locations, present significant challenges for tracking technology, both in terms of hardware and algorithmic requirements. There are various limitations of sensors from a hardware perspective, for instance signal strength fluctuation, range, interference, measurement accuracy, and cost. While the cost of sensors has come down in recent years, they are still a significant investment for many construction companies. Additionally, there may be some resistance from workers and construction managers who are used to traditional data collection methods and are hesitant to adopt new technologies. These limitations hinder the deployment of tracking systems in real-world construction environments. The algorithmic perspective of tracking technology may entail the fusion of data from several sensors, the application of noise filtering on the data, and the incorporation of environmental changes. Furthermore, some tracking techniques demand a time-consuming offline configuration phase for the initial system setup and depend on stable environments to ensure consistent tracking [14, 30].

Regardless of this disadvantages, researchers continue to develop frameworks for the application of sensors in construction. For example, automated equipment tracking framework have been proposed by Ergen et al. [31], which utilize radio frequency

identification (RFID) and global positioning system (GPS). Vahdatikhaki and Hammad [32] further enhanced this framework by incorporating motion data with equipment location to identify activities. Furthermore, both shallow and deep machine learning methods have been applied to identify equipment activities using IMUs [3].

A hybrid-tracking system, which incorporates Bluetooth Low Energy (BLE) technology, motion sensors, and Building Information Model (BIM), has been developed by Park et al. The study leverages the unique characteristics of each tracking information source, where BLE beacons offer absolute position information but can be impacted by high levels of noise, motion sensors provide relative position information but are susceptible to drift, and building geometry information represents a novel type of knowledge that can enhance tracking accuracy. The tracking system's motion sensor component is not exempt from operational limitations. During position tracking, the motion sensors in mobile devices that are freely reoriented by the user produced noisy data, making it challenging to obtain reliable heading direction and step counts. As a result, in the experiments, the test subjects were instructed to maintain a fixed position and orientation of the mobile device with respect to the body by using a belt clip or an armband throughout the study [14].

Bao et al. [33] utilized long-sequence videos to automatically detect, identify, and track activities performed by an excavator and a dump truck. Additionally, unsupervised classifiers were used to expand the bag-of-video-feature-words model into the construction domain, allowing for the learning and classification of labour and equipment activities [3].

Worker activity recognition has been approached using both active and passive methods, much like equipment activity recognition. Worker's velocity, gravitational forces, and orientation can be determined by electronic devices equipped with a battery or power source and a combination of sensors such as accelerometers, magnetometers, and gyroscopes [4]. However, the leading deep learning method for this task uses large complex neural networks to process data from wearable devices [12]. For instance, in an experimental setup, Akhavian et al. [35] employed machine learning methods and mobile sensors to recognize the activities carried out by a human crew. Nath et al. [34] also utilized mobile technology and machine learning techniques for the automated assessment of ergonomic risk posed to workers. Additionally, a framework based on motion tensor decomposition using IMU was suggested to identify the awkward postures of workers [3].

Rashid et al. conducted a study that presented a system for identifying activities through audio signals. The findings of the research highlight the potential of the proposed system to be utilized for automated monitoring and data gathering in modular construction factories, along with other recognition frameworks that are based on inertial measurement units (IMU) or computer vision (CV) [3].

Cheung et al. developed a system that merges Building Information Modeling (BIM) and Wireless Sensor Networks (WSN) to visually monitor safety conditions on construction sites through a spatial, color-coded interface. The system is capable of automatically eliminating hazardous gases. Numerous wireless sensor nodes were deployed on an underground construction site to collect data on hazardous gas levels and environmental conditions (temperature and humidity). The sensor nodes consist of a gas sensor, temperature and humidity sensor modules, a system main board, a Zigbee wireless transmission module, and a power supply module. In the event of an abnormal status detection, the BIM model will trigger an alarm and activate a ventilator on-site to alert and eliminate the hazard [36].

As tools advance and become more costly, tracking the status of mobile and compact devices is becoming increasingly crucial. However, existing sensors alone cannot intelligently extract meaningful information from their collected data. Thus, the data must be transmitted to the cloud for further processing, resulting in increased communication power requirements, detection latency, and heightened security and privacy concerns [12]. Another conclusion is that much of the research is focused on identifying hazardous conditions at

construction sites. Safety is often given more priority over performance and quality in the construction industry as unsafe conditions pose immediate risks to workers, and it's easier to detect and address them. This observation is supported by other sources, including [5]. However, balancing safety and performance is crucial for the success of a construction project, as high-quality work is important to meet client expectations and avoid costly mistakes and delays.

5 Conclusion

Sensor technologies have the potential to revolutionize the way construction performance is monitored and evaluated. By providing accurate, real-time data, they can help to improve decision-making, reduce labour costs, and improve safety on construction sites. However, there are also challenges that must be overcome, such as the cost of implementation and data privacy and security concerns. To fully realize their benefits, they must be used in combination with other tools and methods, such as process optimization and project management software. Furthermore, it is important to carefully consider the specific needs of each construction project and select the sensor technologies that are best suited to those needs. Nevertheless, the future of construction performance monitoring is likely to be heavily influenced by sensor technologies. The use of sensor technologies is a promising step forward for the construction industry and is likely to become increasingly important in the years to come.

Acquiring data from a construction site in real-time is just the initial challenge. The next challenge is to interpret and analyse this data. Manually reviewing this data is unrealistic and there is limited domain knowledge. Hence, there is a pressing need to create automated, sturdy, and scalable data analysis methods to extract crucial information from big data for Internet of Things based construction industry applications. Future research should focus on developing advanced data analysis methods specifically tailored to the construction industry. This includes techniques such as machine learning, artificial intelligence, and data mining algorithms that can automatically process and interpret the sensor data collected from construction sites. These methods should be scalable and able to handle big data generated by Internet of Things (IoT) applications. Furthermore, as the use of sensor technologies increases, it is imperative to address data privacy and security concerns. Future research should focus on developing robust security protocols and encryption methods to ensure the integrity and confidentiality of the collected data.

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