Research on Digital Early Warning and Decision Support of Construction Safety Supervision

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Abstract: Traditional safety supervision methods have some problems, such as lagging information acquisition and insufficient risk identification, which can not meet the needs of modern complex construction environment. This paper proposes to build a digital early warning and decision support system based on the Internet of Things (IoT), big data, AI and BIM to realize real-time monitoring, data analysis and intelligent decision-making. The system collects construction site data by deploying sensors, cameras and other equipment, uses big data analysis and AI algorithm for risk identification and early warning, and pushes early warning information to relevant personnel through visual interface and mobile terminal. In addition, the system also provides a decision support module, which constructs a decision support model based on historical data and real-time data to provide scientific decision-making basis for safety supervisors. The research shows that the digital early warning and decision support system can effectively improve the efficiency and accuracy of safety supervision, reduce the accident rate and ensure the safety of the construction site.

1. Introduction

The construction industry is one of the important pillar industries of the national economy, but it is also accompanied by high security risks. In recent years, with the acceleration of urbanization and the increase of large-scale infrastructure construction projects, construction safety accidents occur frequently, which poses a serious threat to the safety of people's lives and property. The traditional construction safety supervision method mainly relies on manual inspection and empirical judgment, which has some problems, such as untimely information acquisition, incomplete risk identification and delayed emergency response, and it is difficult to meet the needs of modern complex and changeable construction environment.

The rapid development of digital technology provides a new solution for construction safety supervision. The application of Internet of Things (IoT), big data, AI, building information model (BIM) and other technologies makes real-time monitoring, data analysis and intelligent decision-making possible. By constructing digital early warning system and decision support system, the efficiency and accuracy of safety supervision can be effectively improved, the accident rate can be reduced, and the safety of construction site can be guaranteed. Therefore, it is of great theoretical significance and practical value to deeply study the digital early warning and decision support of construction safety supervision.

2. Analysis on the current situation of construction safety supervision

As an important pillar industry of the national economy, the safety management of the construction industry is becoming increasingly important. However, the traditional safety management mode has many shortcomings in information collection, processing and transmission, which is difficult to meet the needs of modern building construction [1]. Many supervisors have a wrong understanding of safety supervision, and think that the management of production safety is mainly the responsibility of the construction unit, which has little to do with supervision and can only play the obligation of social supervision at most. The management system of some engineering supervision units is not perfect, the supervisors lack safety awareness, and there is no special safety

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supervision plan and supervision rules, so the safety supervision system is not perfect [2]. The informatization degree of safety management in construction enterprises is unbalanced. Although some enterprises have introduced informatization technology, the application effect is not ideal, and there are problems such as information islands and inaccurate data [3]. The existing safety supervision system has insufficient ability to monitor and warn the safety risks on the construction site, and lacks effective means of data collection, analysis and processing, which makes it difficult to find and deal with potential safety hazards in time.

Data collection and integration through IoT, sensors and other technical means, all kinds of safety data on the construction site are collected in real time, and integrated through big data technology, providing comprehensive and accurate information support for safety supervision [4]. Intelligent monitoring and early warning uses AI algorithm to analyze the collected data, find potential safety risks in time, and send early warning information to relevant personnel through the early warning system to improve the response speed and efficiency of safety supervision. Based on historical data and real-time data, decision support model is constructed by using machine learning and other technologies to provide scientific decision-making basis for safety supervisors and optimize safety supervision strategies and measures. Strengthen the digital skills training of safety supervisors, improve their understanding and application ability of digital early warning and decision support system, and provide talent guarantee for the effective operation of the system. The present situation of construction safety supervision shows that the traditional safety management mode has been difficult to meet the needs of modern construction, and it is urgent to introduce digital early warning and decision support system to improve the safety management level [5]. Through data collection and integration, intelligent monitoring and early warning, decision support and personnel training and other measures, the efficiency and effect of safety supervision can be effectively improved, and the safety of building construction can be escorted.

3. Application of digital early warning technology in construction safety supervision

3.1 Early warning system construction

The architecture of the early warning system is shown in Figure 1. The data acquisition and perception layer collects the environmental parameters, equipment operation status and personnel behavior data of the construction site in real time by deploying various sensors and high-definition cameras. Tower crane tilt monitoring and deep foundation pit slope stability tracking all rely on sensors to realize dynamic capture [6]; At the same time, BIM technology is combined to simulate the construction process and help identify potential risk points. In addition, smart wearable devices can monitor the physiological indicators of workers, further expanding the data dimension.

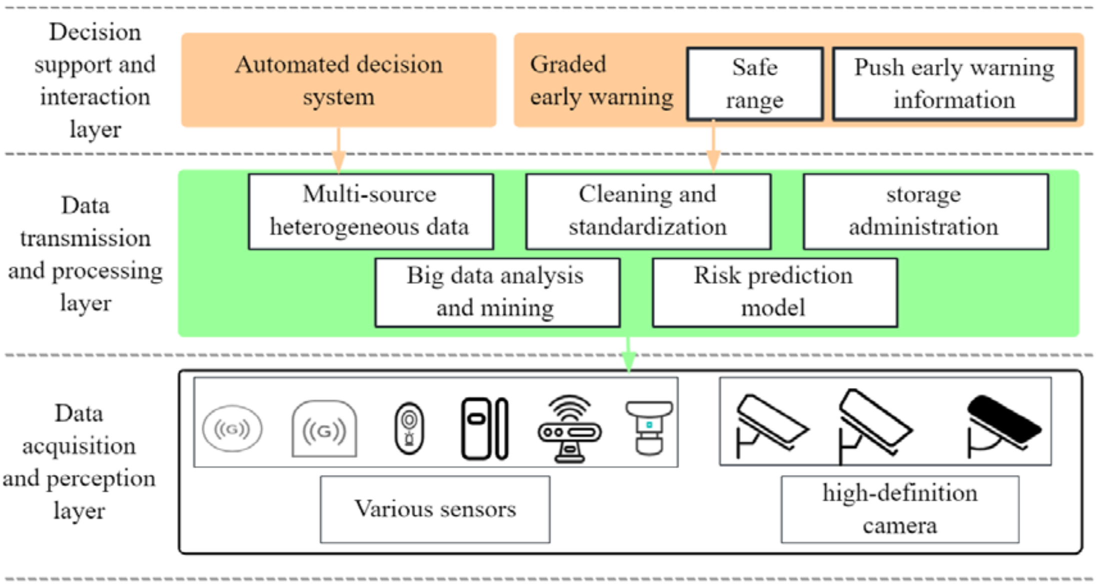

Figure 1 Early warning system architecture

The data transmission and processing layer integrates multi-source heterogeneous data by using IoT technology and cloud computing platform to complete cleaning, standardization and storage management. Mining historical accident laws through big data analysis, and establishing a risk prediction model based on machine learning algorithm. Trend analysis and anomaly detection methods are used to evaluate the possibility of structural deformation or progress lag [7], and the transition from passive response to active prevention and control is realized.

The decision support and interaction layer develops an automatic decision-making system and sets a threshold to trigger a hierarchical early warning mechanism. When the monitoring value exceeds the safety range, the system automatically pushes the early warning information to the mobile terminal of relevant managers and matches the preset disposal scheme. This level also includes visual interface design to visually display the heat map of risk distribution, temporal and spatial evolution trend, etc., and to assist users to quickly formulate scientific countermeasures.

3.2 Early warning index system

The warning indicator system covers four categories of indicators: human factors, equipment and facilities, environmental conditions, and management processes (as shown in Table 1), aiming to comprehensively evaluate and improve the safety level of construction sites. Human factors indicators quantify the safety awareness of individuals and teams through real name entry management and behavior analysis algorithms; Equipment and facility indicators utilize IoT technology to monitor key parameters such as lifting machinery, scaffolding, and fire protection systems, and set dynamic alarm thresholds to prevent energy safety hazards; Environmental condition indicators are combined with weather forecast APIs and on-site data to construct models, evaluate the impact of meteorological conditions on construction, and ensure the stability of temporary facilities [8]; Management process indicators use natural language processing technology to parse unstructured information such as supervision logs and response time for rectification orders, monitor system implementation, and extend to the supply chain collaboration level to ensure the safety and compliance of materials and storage environments.

Table 1 Classification and content of early warning index system

Category	Index content	Remarks
Human factor index	Construction personnel qualification certification, safety education and training records, and frequency of illegal operation	Real-name registration system admission management, behavior analysis algorithm, comparison standard action library, inspection efficiency of managers and closed-loop rate of hidden dangers
Equipment and facilities index	Stress load of hoisting machinery, looseness of scaffold connector, pressure value of fire fighting system, electricity overload and gas leakage	IoT terminal continuous tracking, dynamic alarm threshold, real-time monitoring
Environmental working condition index	Risk of falling objects from high altitude caused by wind speed exceeding the limit, foundation settlement caused by rainfall, load balance of temporary power lines, and overturning resistance of temporary facilities	Regional weather forecast API, field measured data, environmental sensitivity analysis model

Management process indicators	Integrity of supervision log, response time limit of rectification sheet, qualified rate of emergency plan drill, compliance of incoming materials batch, temperature and humidity control effect of storage environment	Natural language processing technology, analysis of unstructured information, automatic identification of missed items or delayed disposal events, collaborative monitoring of supply chain

4. Design of decision support system based on digital technology

4.1 System design objectives and core functions

Taking "dynamic monitoring-intelligent early warning-accurate decision-making" as the main line and integrating multi-source digital technology, a safety supervision decision-making support system covering the whole construction cycle (pre-planning → process implementation → post-resumption) is constructed to achieve the following objectives:

(1) Real-time perception Multi-dimensional dynamic data of man, machine, material, method and environment (5M1E) in the construction site are collected by IoT equipment;

(2) Intelligent early warning. Based on big data analysis and AI algorithm, potential security risks are identified, and supervisors are prompted by hierarchical early warning mechanism (red/yellow/blue level);

(3) Scientific decision. Provide auxiliary decision-making functions such as risk disposal scheme recommendation, resource scheduling optimization and historical case matching to reduce the risk of human misjudgment;

(4) Closed loop management. Form a closed loop of the whole process of "risk identification → early warning push → disposal tracking → effect evaluation" to improve the standardization and effectiveness of supervision work.

The core functional modules are shown in Figure 2:

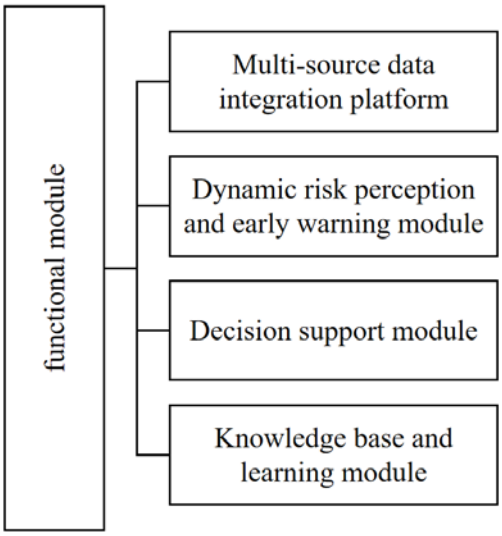

Figure 2 Core function module

Multisource data integration platform. Integrate BIM model data (structural parameters, spatial relationship), IoT sensor data (sensors are deployed in scaffolding, tower cranes, deep foundation pits and other key parts to collect displacement, load, wind speed, temperature and humidity, etc.), video monitoring data (AI cameras identify behaviors such as not wearing helmets and illegally entering dangerous areas), supervision logs and historical accident databases to build a unified "construction safety data lake".

Dynamic risk perception and early warning module. Risk identification automatically identifies explicit and implicit risks through rule engine and machine learning model; Early warning classification calculates risk value (R=P×S) according to risk probability (p) and consequence severity (s), and divides early warning grade according to threshold (red: stop work immediately; Yellow: rectification within a limited time; Blue: continuous monitoring), and through the mobile APP, audible and visual alarm and other channels to push [9].

Decision support module. Provide targeted disposal suggestions based on similar case matching or AI production model; Combined with GIS (Geographic Information System) positioning, intelligently recommend the location of the nearest emergency material warehouse and rescue team, and simulate the effects of different disposal strategies; Through digital twin technology (BIM+ real-time data mapping), the three-dimensional situation of the construction site is presented, and the risk hotspot map and equipment health status map are superimposed to assist the supervisor to intuitively grasp the global risk distribution.

Knowledge base and learning module. Built-in construction safety standards, typical accident case base and expert experience rule base, and continuously optimize the risk identification model through machine learning.

4.2 Key technical support

Relying on the integration technology of BIM and GIS, the early warning system realizes the integration of building component-level information and geographical environment data, and supports the collaborative analysis of microstructure security and macro-environmental risks. Through the combination of IoT sensor and edge calculation, the localization real-time monitoring and rapid response of high-risk factors such as scaffolding tilt, toxic gas and tower crane overload are carried out. Using AI algorithm, including supervised learning to identify violations, unsupervised learning to mine potential risk patterns and time series model to predict structural deformation or environmental anomalies, to improve the ability of risk prediction; At the same time, with the help of digital twinning technology, a virtual model synchronized with the physical site is built, which can map the construction status in real time and simulate the impact of risk disposal schemes, providing dynamic verification and optimization support for safety management decision-making.

4.3 System architecture design

As shown in Figure 3, the system adopts an "end-edge-cloud" layered architecture. The sensing layer (end) includes IoT sensor, intelligent camera and mobile inspection terminal (hand-held equipment for supervisors), which is responsible for data acquisition; The edge layer (edge) is an edge computing device deployed on the site, which performs local preprocessing and preliminary analysis on high-frequency and real-time data; Platform layer (cloud) stores multi-source data based on cloud computing platform, and runs risk analysis model, decision algorithm and visualization engine; The application layer is oriented to supervisors, project managers, security officers and other roles, providing interactive interfaces between Web and mobile terminals, and supporting functions such as early warning viewing, decision assistance and report generation.

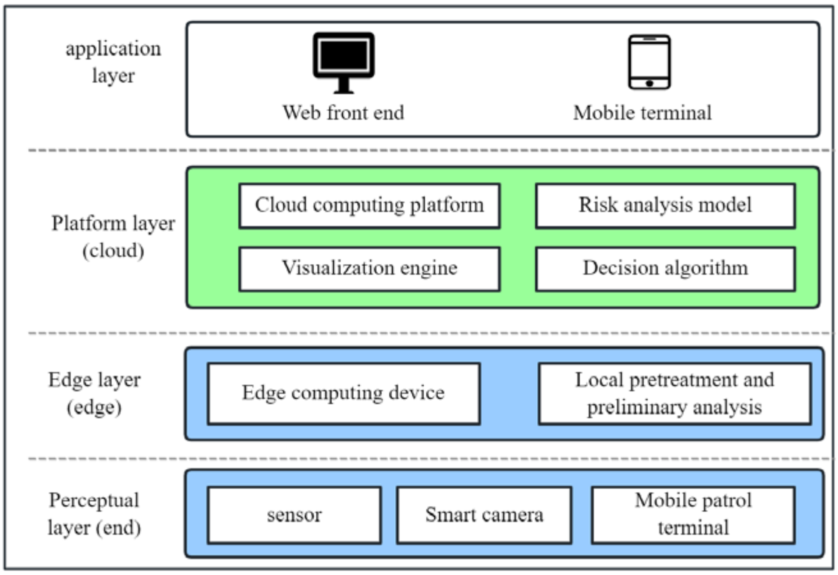

Figure 3 "end-edge-cloud" layered architecture

5. Conclusion

Based on the in-depth analysis of the current situation of construction safety supervision and the rapid development of digital technology, this paper puts forward a digital early warning and decision support system based on IoT, big data, AI and BIM. The system collects environmental parameters, equipment operation status and personnel behavior data of the construction site in real time, uses big data analysis to mine historical accident rules, and establishes a risk prediction model based on machine learning algorithm, thus realizing the transformation from passive response to active prevention and control. The digital early warning and decision support system of construction safety supervision not only improves the efficiency and accuracy of safety supervision, but also reduces the accident rate, which provides strong technical support for ensuring the safety of construction site. In the future, with the continuous progress of technology and in-depth application, the digital early warning and decision support system will play a more important role in the field of construction safety supervision.

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