Research on Foundation Pit Monitoring and Management System Based on BIM+GIS+IOT

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Abstract: Since traditional foundation pit monitoring methods cannot meet the overall safety requirements of engineering, a foundation pit monitoring and management system based on BIM+GIS+IOT was proposed in this paper. BIM, GIS and Internet of Things were applied in the system. ESP32 chip and ESP-IDF framework were used to develop the IOT to complete the real-time collection and transmission of monitoring data, and the BIM and GIS model data is integrated and displayed by linking the information of the monitoring points and BIM model. The system then is used in the construction of a subway station foundation pit for environmental monitoring and early warning monitoring.

1. Introduction

With the acceleration of urbanization, the scale of underground space in urban area continues to expand [1]. The foundation pit engineering is the base of underground engineering, and is quite different from above-ground engineering in construction. There are serious time-space effects and information islanding phenomenon in the construction process [2]. People have paid more and more attention to the structural safety risks in foundation pit construction, and thus the monitoring of changes in the soil, environment and surrounding buildings that may be caused during the construction of foundation pits has become an indispensable link. Traditional monitoring methods can barely meet the overall safety requirements of engineering. With the rapid development of civil engineering information technology, the need for informatization of environmental monitoring of foundation pits needs to be solved urgently.

In traditional foundation pit monitoring methods, two-dimensional drawings and data charts are mainly used to transmit information, and there are problems such as low automation level, low time efficient, and insufficient interaction between construction environment information and personnel operations. Building Information Modeling (BIM) can be used to transmit and share information-based building data throughout the life cycle of the project. Geographic Information
System (GIS) can be used to realize the conversion between different formats of data, and analyze a variety of data. The Internet of Things (IOT) technology can be used to complete the real-time collection of object information and realize data transmission between objects.

Therefore, a foundation pit monitoring and management system with intelligent perception and early warning monitoring is proposed in this paper. In the system, BIM, GIS and IOT are used to complete the 3D scene construction, BIM and GIS data integration as well as information collection and transmission, and to integrate the environmental monitoring module and early warning monitoring module by combining with the actual needs of on-site monitoring.

2. Design of the System

2.1. System structure
The B/S architecture is applied in the system, which consists of perception layer, data layer, service layer, and access layer from bottom to top. As shown in Figure 1.

2.1.1. Perception layer
In the perception layer, sensors are connected to the IOT, and information is transmitted to the cloud server. Settlement sensors, inclinometer sensors, temperature sensors and other sensors are arranged on site. These sensors can sense the status information and external environment information and upload the information to the server in real time, accurately reflecting the safety status of the foundation pit. Thus data acquisition is completed.

2.1.2. Data layer
The transmission of this layer is mainly through WLAN communication technology, which transmits the collected perception information on IOT, thereby realizing the interaction and sharing of information, and forming a network of collaborative perception.

2.1.3. Service layer
The open source database (PostgreSQL+PostGIS) is used to realize the storage and management of vector data and relational data, as a bridge to realize the data transfer between the data layer and the interface layer.

2.1.4. Access layer
The application layer is the interface between IOT and users, and is an application of system business functions. Based on WebGL, it realizes the display of the 3D model on the web side, and realizes the functions of system video monitoring, visual display, and warning display.
2.2. **System development environment**

(1) Use PHP as the main background development language.

(2) Adopt Git as a management tool for platform code version maintenance and control.

(3) Use React as the main framework, Ant Design as the UI framework, and react-router to organize and manage front-end routing; in terms of data flow processing, Redux is used as the JavaScript state container to provide predictable state management. Use Sass to preprocess language, so as to make the CSS organization clearer, effectively reducing code redundancy.

(4) The storage management of vector data and relational data is realized based on open source database (PostgreSQL+PostGIS).

3. **System application foundation**

3.1. **3D scene construction**

3.1.1. **BIM model of foundation pit**

Since foundation engineering is characterized with complicated environment, large scale, difficult technology and containing complicated supporting structures, conventional modeling methods can hardly meet the elaborate requirements of deep foundation. In this paper, Autodesk Revit is used to build the BIM model of the foundation pit. First, obtain the placement path according to the drawings; secondly, create adaptive family files such as piles, supports, anchors, waist beams and crown beams; finally, use the Dynamo program to place the adaptive family, and assign attribute information to each model to generate the final parameterized model. Adjust and repair the model artificially in some special areas.
3.1.2. Geography information model

Based on surveying and mapping, GIS is a technical system used to collect, manage, process, analyze and describe macro-geographic data and its attributes [3]. Applying GIS technology to the field of foundation pit monitoring can effectively solve various problems of data integration.

The oblique photography technology can perceive a wide range of high-precision scenes, which makes up for the shortcomings of traditional 3D modeling in terrain authenticity and surveying precision. The environmental images are obtained by taking pictures with drone, and recording the spatial positions and shooting angles of these are recorded. These images are processed into dense point model and an external GIS model of the foundation pit is built in Context Capture.

Excavate and flatten the topographic maps and oblique photographic models to make the GIS model to conform to the macro-geographical environment required by the BIM model of the foundation pit. Import the model into the GIS platform, associate the BIM model layer with the terrain layer and the oblique photography layer, and load the BIM model into the reserved position to establish a three-dimensional scene.

3.2. BIM and GIS data integration

IFC is a hierarchical and modular data definition architecture, which is a common data model standard in the BIM field. The IFC standard divides BIM data into four levels, including resource layer, core layer, sharing layer and professional field layer. These hierarchical structures define all the data information of the building entity through different information modules, including geometry
information, attribute information and space topological relations and so on [4]. CityGML is a format for data exchange and storage of virtual 3D city models. It defines most of the terrain in the urban area and geographic object models as well as their geometric, topological, semantic and appearance attributes, including aggregation between thematic types, relationship between targets and spatial attributes [5].

In this paper, GIS technology is used as a platform and FME software is used as a medium to transform IFC data into CityGML data. Use FME and a workflow to reconstruct the data model and transform it into the target data format. First, filter the semantic information to obtain the IFC entity geometry, and convert the IFC geometric information into the expressive form of CityGML. Integrate the geometric semantic information into CityGML according to certain semantic mapping rules, and enhance semantics of the mapped information to different degrees to obtain CityGML models of different LOD levels. The BIM model is graphically represented in detail, so as that the geometric information such as size, volume, height, and direction, and non-geometric information such as quantity and performance data can be directly read from the model.

| IFC          | CityGML               |
|--------------|-----------------------|
| IfcBeam      | Building Installation |
| IfcPile      |                       |
| IfcSlab      | FloorSurface          |
| IfcWall      | WallSurface           |
| IfcOpening   | ClosureSurface        |

3.3. Application of Internet of Things
The construction of the Internet of Things in this system can be divided into the acquisition layer and the network layer. The ESP32 chip and the ESP-IDF framework are used for the development of the Internet of Things, and the temperature and humidity of the construction site, the vertical displacement of the column, the axial force of the steel support, and the axial force of the concrete support are collected in real time. By using ESP32, the data collected by the sensors can be sent to the database server, and early warning message will be sent to clients when the collected data is abnormal. OpenWrt open source system is used for network routing, so as to ensure the timeliness and accuracy of data. The sensors based on IOT are used to monitor the construction sites in real time and are linked to BIM model, and thus the monitoring situation can be obtained in real time.

The acquisition layer is mainly composed of a MESH network (including a physical sensor and ESP32 chips), a GPS positioning device, and a video image acquisition device. Acquisition layer is the foundation of the Internet of Things system and guarantees the comprehensiveness, accuracy, and timeliness of data collection.

The acquisition layer can acquire signals. Since construction sites are large in area and many work sites are scattered, data collection routers need to be set up at each site. The router nodes in each construction site transmit sensor signals (such as pressure, temperature, displacement, stress, etc.) and location information to the database server through the construction site Intranet, and then the database server upload the information. In such case, the situation of the construction sites is accurately reflected in real-time.
The network layer mainly completes the reliable transmission of perception layer data between different terminal sensors and servers. It mainly uses Wi-Fi-MESH, RTSP (Real Time Streaming Protocol) and other communication technologies and communication devices such as cables and OpenWrt routers to transmit and exchange perception layer data through API interfaces, TCP and UDP protocols.

4. System Function Application
Based on OT, BIM, GIS and other technologies, the foundation pit monitoring system collects information automatically by arranging monitoring sensors on the construction sites of foundation pits, associate the acquired data such as temperature, humidity, dust, displacement and axial force with foundation pit information model and geographic information, and realize the integration of model information and monitoring data. According to engineering needs, it is divided into a foundation pit environment monitoring module and a foundation pit monitoring and early warning module.

4.1. Project Overview
A two-story underground subway station has a total length of about 153.6m and the width of the station foundation pit is 44.6m; the depths of the south and north end wells are 19.514m and 19.207m respectively; the standard section of the foundation pit is about 17.76m.

4.2. Foundation pit environment monitoring module

4.2.1. Temperature and humidity monitoring
The temperature sensors and humidity sensors which are set up inside the foundation pit transmit the on-site temperature and humidity monitoring data to the database server through the site intranet. Set an early warning threshold and send early warning information and report abnormal situations in time to the set client side if the temperature of the equipment exceeds or falls below the set threshold.

4.2.2. Dust monitoring
Too much dust on the sites will not only pollute the environment, but also seriously harm the health of workers, so it is necessary to monitor dust. The dust sensors which are set up around the foundation pits transmit the on-site dust monitoring data to database server through the site intranet. Set an early warning threshold and send early warning information to the client side if the dust concentration exceeds the warning threshold.
4.2.3. Video surveillance
Connect on-site cameras to the system and monitor the construction environment and operation in real-time, thereby realizing monitoring, operation and maintenance of the foundation pits.

4.3. Foundation pit monitoring and early warning module

4.3.1. Layout of monitoring points
There is a river passing above the subway station, the foundation pit is deep, and the surrounding environment is extremely complicated. Considering the characteristics of the foundation pit itself, the complicated surrounding changes and some safety issues that may occur in the foundation pit, the monitoring points are divided into the following two categories:

(1) The structure of the foundation pit: mainly including inclinometer, column settlement, steel support axial force, concrete support axial force, etc.

(2) Surrounding environment: mainly including surrounding ground settlement, surrounding building settlement, surrounding pipeline settlement, groundwater level, etc.

4.3.2. Visual display
In the BIM model, the monitoring result of the monitoring points are displayed to users with green, orange and red flashing lights, which indicate normal, warning and abnormal respectively. In addition, the monitoring points are connected with the BIM model. The information of the monitoring points
will be displayed when you click the point in the model, as shown in Figure 7.

![Figure 7 Visual display of the monitoring points](image)

**4.3.3. Warning display**
The monitoring results are shown on the right of Figure 8. You can check the real-time data and early warning conditions corresponding to each monitoring point. You can also click the BIM model to switch to the monitoring point and check the information.

When the monitoring data of a certain monitoring point of the foundation pit exceeds the early warning threshold, the platform will send early warning information to the person in charge, and the on-site personnel will be organized to rectify the problem.

**4.3.4. Statistical analysis**
As shown on the left of Figure 8, the system provides graphic reports, data analysis, etc., which separately counts the number of stress alarms, displacement alarms, and settlement alarms, summarizes alarm history, and completes alarm trend analysis.

![Figure 8 Early warning and monitoring](image)

**5. Conclusion**
In this paper, a foundation pit monitoring and management system based on BIM, GIS IOT was built. The system realized real-time data acquisition and transmission based on IOT and then integrate the foundation pit monitoring data with BIM and GIS data. What’s more, the functions of temperature and humidity monitoring, video monitoring, warning issuance and alarm statistics were achieved through
visual display. Therefore, the purpose of informatization and safety monitoring of the on-site construction of the foundation pit was achieved, and real-time and reliable monitoring of the foundation pit was guaranteed.

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