

An IoT-Based Early Warning System for Settlement Monitoring Using Differential Pressure Static Level

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Abstract— This paper presents an IoT-based automated settlement monitoring system that aims to meet the diverse requirements of applications and the increasing demand for settlement monitoring. The system consists of a perception subsystem, data transmission layer, IoT cloud platform, and application terminal. The differential pressure static level sensor transmits the sensor serial port raw data to the 4G DTU through the RS-485 bus interface. Then, the 4G DTU converts it into a 4G network and transmits the data to the IoT cloud platform via the MQTT protocol. The IoT cloud platform analyzes and processes the collected data to generate reports, visualize data to generate curves, and perform real-time anomaly identification on the data. Finally, it implements viewing of settlement monitoring data and curve changes, as well as monitoring status warnings at the application terminal. The practical engineering application results show that this system can provide effective safety monitoring and an early warning scheme for slope, tunnel, bridge, and building safety monitoring.

Keywords— IoT, Differential Pressure Static Level, Settlement Monitoring, MQTT, Early Warning System, Cloud Platform

I. INTRODUCTION

At present, China's highway construction mainly focuses on the central and western regions, most of which are mountainous areas. When structures are built in areas with harsh environmental conditions, higher requirements are placed on the timeliness and accuracy of settlement monitoring. Existing conventional monitoring methods have limited applicability, poor monitoring accuracy, are easily affected by human and environmental factors, and cannot meet the needs of automated and intelligent management of monitoring data. For instance, the interferometric synthetic aperture radar (InSAR) technology is possible to use at any time and in any atmospheric condition, but the technical implementation is difficult and the spatial and temporal resolution is low [1]. The global positioning system (GPS) can measure in a highly automated manner and does not require a direct line of sight between stations, making it cost-effective. However, vegetation cover, buildings, or other types of infrastructure can cause signal scattering, which can reduce

GPS accuracy [1]. The Global Navigation Satellite System (GNSS) can achieve millimeter-level positioning [2], but the cost of monitoring equipment and the requirements for environmental use are high [3]. The settlement information monitored manually is both expensive and limited. At the same time, these records exhibit lagging effects and cannot provide real-time instructions for on-site construction [4].

With the continuous advancement of Internet of Things (IoT) and cloud platform technology, the communication network architecture design in the field of settlement monitoring has been further optimized and improved. Meanwhile, due to the advantages of the differential pressure static level, such as its simple structure, low cost, strong environmental adaptability, high monitoring accuracy, high degree of automation, and the ability to realize all-weather high-frequency and long-time settlement monitoring [3, 5], it has been widely used in the safety monitoring work of various types of engineering and architectural bodies, such as subgrade, foundations, bridges, and tunnels.

In summary, in order to meet the diverse needs of applications and the increasing demands for settlement monitoring, and to achieve automated management of structural settlement monitoring, this paper designs and develops an automated settlement monitoring and early warning system based on differential pressure static level and Internet of Things technology.

II. DESIGN OF SETTLEMENT MONITORING SYSTEM

The IoT-based automated settlement monitoring and early warning system designed and developed in this study consists of the perception subsystem, data transmission layer, IoT cloud platform, and application terminal from the bottom up. The overall architecture of the IoT-based automated settlement monitoring and early warning system is shown in Figure 1.

A. Overall System Design

The sensor (differential pressure static level) transmits the raw data from the sensor serial port to the 4G DTU through RS-485 bus interface, then the 4G DTU converts it to the 4G

network and transmits the data to the IoT cloud platform through the MQTT protocol, and the IoT cloud platform analyzes and processes the collected data to generate reports, generates curves by visualization processing, and identifies real-time anomalies of the data. Finally, the application terminal realizes the view of settlement monitoring data and curve changes and the warning of monitoring status.

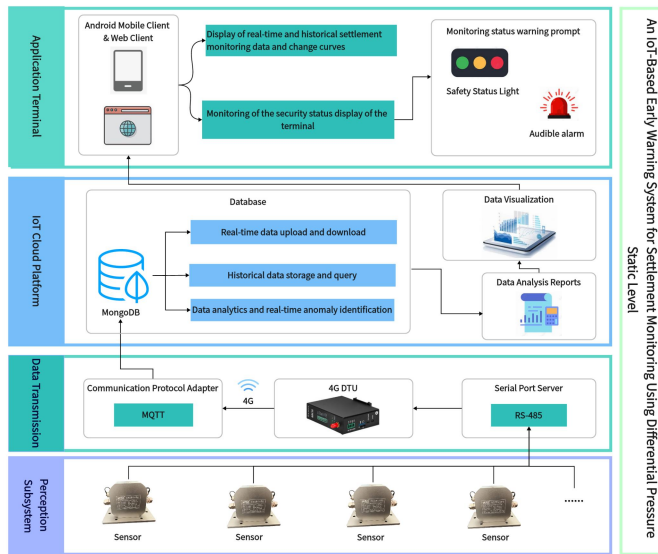


Figure 1. Overall architecture of IoT-based automated settlement monitoring and early warning system

B. Perception Subsystem

The perception subsystem mainly consists of the differential pressure static level to accomplish settlement data acquisition. The pressure differential static level used in the system is model PTH-SZY100, which features small size, high accuracy, and wide applicability. In the actual settlement monitoring process, it can meet the monitoring requirements of different temperature regions, achieve automatic temperature compensation, and has ultra-short response time, ultra-high monitoring resolution, and effective waterproofing capabilities. The appearance of PTH-SZY100 differential pressure static level is shown in **Figure 2** and its technical parameters are listed in **Table 1**.

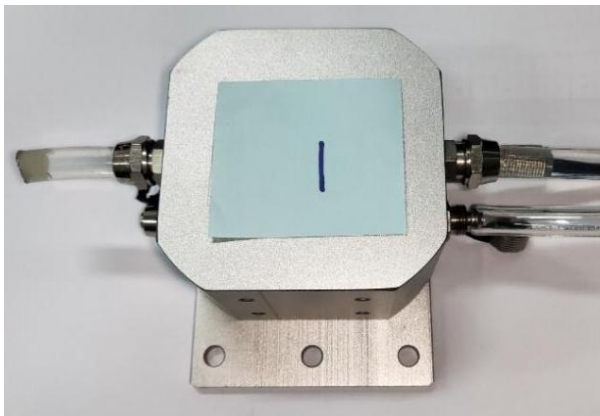


Figure 2. PTH-SZY100 differential pressure static level appearance

TABLE 1. PTH-SZY100 DIFFERENTIAL PRESSURE STATIC LEVEL TECHNICAL PARAMETERS

Technical Parameter	Specification
Measuring Medium	Fluid
Pressure Range	0~1mH ₂ O
Working Temperature Range	-40~100°C
Comprehensive Accuracy	0.02~0.1%FS
Display Resolution	0.01mm
Fieldbus Type	RS-485
Power Supply Requirement	12V DC(7-30VDC)
Response Time	≤5ms
Waterproof Rating	IP68

C. Data Transmission

The data transmission layer is mainly composed of 4G DTU and the RS-485 bus interface. The 4G DTU obtains the raw data from the serial ports of various sensors through the RS-485 bus interface, converts it into a 4G network for transmission, and adopts the MQTT publish/subscribe messaging protocol [6] to improve data scalability and stability.

D. IoT Cloud Platform

In view of the functional requirements of the software side of the settlement monitoring and early warning system, the system component architecture of the IoT cloud platform is designed, in which the main functions of the database include the following three requirements:

- 1) Real-time Data Uploading and Downloading:** Real-time uploading of information entered into the field sensing subsystem and mobile terminal; fault tolerance and fault clearing mechanisms for data collection; real-time docking of monitoring data; and support for exporting and downloading data in the form of an Excel table.
- 2) Historical Data Storage and Query:** Under the premise of ensuring that the monitoring data processing, analysis, and early warning are not affected, the storage capacity of the data is controlled, and users are supported to call and query the historical data of the monitoring targets through the application terminal.
- 3) Data Analysis:** After preprocessing the monitoring data, such as data cleaning, data correction, and real-time anomaly identification, intelligent monitoring and early warning judgments are made, and the results are promptly feedback.

Compared to other databases, if all tests that do not include scanning workloads are considered, which are composed of scanning operations, MongoDB is the database with the best execution time [7]. MongoDB has strong performance, large aggregation capabilities, fast storage of extremely complex data, powerful query capabilities, and support for data replication and failure recovery.

In conclusion, the main framework of the IoT cloud platform is developed using Python language, and uses MongoDB database to store, analyze, process, predict, and judge monitoring data, providing users and administrators

with a powerful real-time monitoring visualization, controllable, and queryable monitoring system.

E. Application Terminal

The application terminal mainly includes a web client and an Android mobile phone client, which is a system integrating the functions of monitoring equipment control, data presentation, chart display, warning display, etc., and can truthfully present the information of project settlement monitoring. Through this system, users can understand the real-time status and development trend of monitoring targets over time.

III. REAL IMPLEMENTATION

In practical engineering applications, this monitoring and early warning system can also work with other sensors. This study focuses on the application of differential pressure static leveling for settlement monitoring.

A. Measurement Point Deployment

After determining the construction program according to the actual situation of the project to carry out the deployment of measurement points, the deployment of measurement points as shown in **Figure 3**.

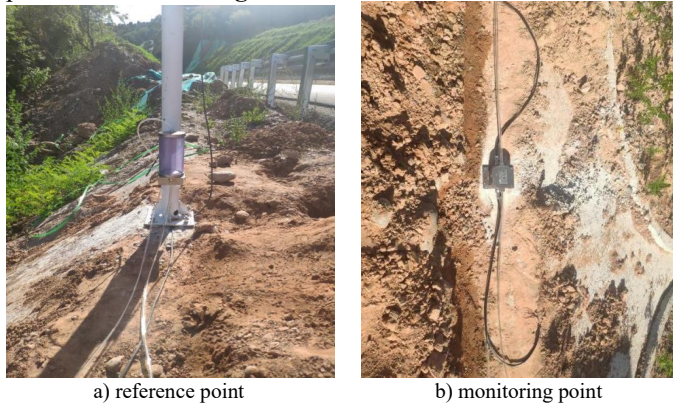


Figure 3. Measurement point deployment

B. Monitoring Warning Value Settings and Alerts

After completing the installation of equipment and measurement point deployment, according to the specification and the actual engineering design requirements to set the pre-warning indicators, different warning states will be used to take different emergency measures.

The main forms of early warning prompts include the display of the security status of the monitoring terminal and the status and early warning display of the monitored object.

The monitoring terminal's security status display is a simple and intuitive way to display the security status of the monitored objects in the scheme on each monitoring terminal, aiming to enable each requester to directly grasp the status of the monitored objects they need to view in the shortest possible time. Through the monitoring end of the screen, intuitively view the safety status lights to grasp the safety of the project to be monitored, with green, yellow, orange, and red colors to indicate the different safety status; different

colors correspond to different sounds; and the client's color changes while emitting different sounds to warn the monitoring personnel. This allows monitoring personnel to understand and control the status of the monitored object more quickly and directly. The correspondence between the safety status and the safety indicator color is listed in **Table 2**.

TABLE 2. SAFETY STATUS ALERT

Safety Status Light Color	Safety Level	Treatment Measures
Red	Very dangerous	Emergency evacuation and remedial measures
Orange	Moderately dangerous	Remediation and elimination of hazardous conditions at the site
Yellow	Slightly dangerous	Strengthen monitoring of the site and take the necessary measures
Green	Safe and stable	-

The status warning display of the monitored object refers to the process of reflecting the monitored dynamic process through the monitoring platform, predicting it to a certain extent, and providing early warning processing for the safety status of the monitored object. When there is a dangerous situation, the monitoring data can be provided according to the needs and conditions on the spot, so as to provide the latest deformation monitoring information and feedback to all parties on the spot. At the same time, the alarm log can be viewed in the system, as shown in **Figure 4**.

Figure 4. Alarm log interface

C. Monitoring Information Query

Users, through the equipment address of this study in the mobile phone or web terminal system, can complete the system login, enter the platform at all levels of the interface to view project information, monitoring information, etc., and at the same time generate a static level settlement curve that can be viewed arbitrarily retrospectively, which can satisfy all parties to know about the project site conditions and to ensure construction safety in a timely manner. As shown in **Figure 5**, the user can query the historical settlement data by selecting the DTU, monitoring point location.

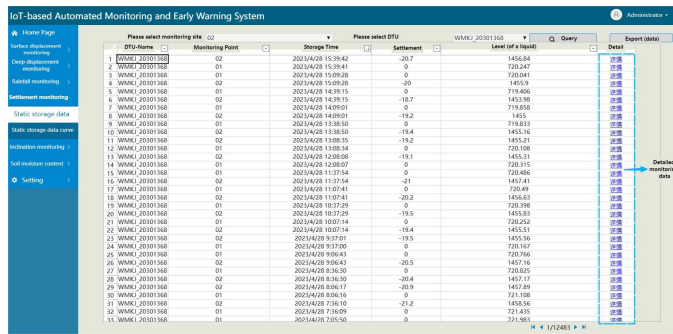


Figure 5. Historical data view interface

Each perception subsystem collects real-time monitoring data from the construction site, which is processed in real time by the IoT cloud platform subsystem and presented in the form of visualized data and curves in the application terminal system. In terms of real-time data display, the monitoring system categorizes and numbers all the perception subsystems in the project and displays the real-time data of each system independently. In this way, users can view the real-time status of each device in a timely manner, as well as quickly select the real-time monitoring results of the perceptual subsystems that need to be focused on, which facilitates the deployment and arrangement of equipment at the key monitoring points of the project. The user can query the historical settlement change curve by selecting the DTU, the monitoring point location, and the start time and end time, as shown in Figure 6.



Figure 6. Static level settlement change curve

IV. CONCLUSIONS

In order to overcome the limitations of existing traditional monitoring methods with limited applicability, low monitoring accuracy, susceptibility to human and environmental factors, and inability to meet the needs of automated and intelligent management of monitoring data, this study developed and designed a set of automatic settlement monitoring and early warning system based on differential pressure level and Internet of Things (IoT) technology, which realised remote, real-time, high-precision monitoring and early warning during the construction and operation of structures under harsh environmental conditions, and was able to provide effective safety monitoring and an early warning scheme for slope, tunnel, bridge, and building safety monitoring.

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