

Dynamic grouting monitoring with a novel multi-channel distributed system

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SUMMARY

With the development of engineering construction, the construction of underground space with complex geological structures is increasing, resulting in more potential engineering problems (e.g., water inrush). Grouting, as a technology for prevention and control, has been widely used in engineering applications such as tunnel construction and pile foundation engineering. To the best of our knowledge, a trenchless visualization method, which can effectively control and evaluate grouting fluid filling of underground space for energy saving, environmental protection and reliable construction quality, is underexplored today. To this end, a novel distributed wireless sensor network-based solution is proposed in this paper. Specifically, metal electrodes are first inserted into the ground in the grouting area to collect data from underground space during the grouting process. Then, by leveraging resistivity inversion imaging software, an effective dynamic monitoring can be achieved so that the grouting effect can be evaluated accurately by observing the grouting diffusion, filling range and evolution process in the underground. Finally, the proposed distributed system can collect multiple profile data in quasi real-time by flexible wireless networking mode, leading to comprehensive and effective monitoring of underground filling for grouting engineering. Experiments on lossy clay area show the effectiveness of our proposed distributed system for engineering monitoring in the field of grouting.

Keywords: Grouting monitoring ; Resistivity ; Multi-channel ; Distributed system

INTRODUCTION

Grouting is an effective method of injecting a solidifiable slurry into voids, fissures and pores in soil or rock strata, to improve their properties, especially to reduce permeability (Y. Chen et al. 2016; D. Wang et al. 2020; Q. Wang et al. 2019), increase formation strength, reduce deformation, and prevent foundation settlement (P. Gao et al. 2020).

At present, grouting detection methods are mainly divided into four categories: analytical method, hole inspection method, excavation sampling method and physical detection method. The available detection methods are also divided into two types, lossy monitoring and nondestructive monitoring methods. One of the most commonly used lossy monitoring methods is digital borehole testing (follow-on drilling) (A.H. Hoiem and B. Nilsen 2014), which requires drilling after grouting and collecting cores for analysis (Q.i. Wang et al. 2021).

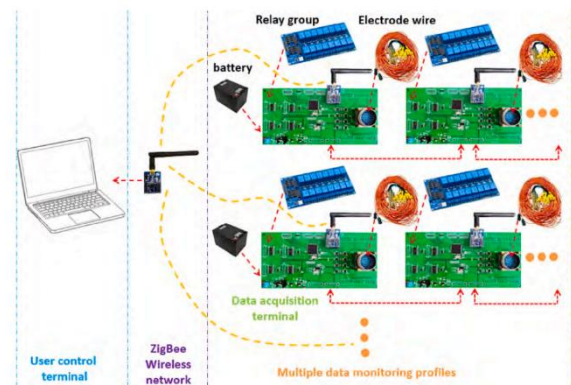


Figure 1. Structure of monitoring system. (The system uses computers and upper computer software as user control terminals, and each data collection is cascaded by multiple data collection terminals. The zigbee module is connected to the computer through USB, allowing the user control terminal to control multiple data collection terminal hosts through the zigbee network for data collection.)

In summary, the contributions of this paper are as follows:

- 1) After analyzing the existing grouting detection methods, multichannel dynamic data acquisition is proposed for the first time. The ad-hoc network

grouting detection system can greatly improve detection efficiency, accuracy and flexibility.

2) Established a wireless communication network based on ZigBee application layer, which can transmit data through user control terminals and multiple data acquisition terminals. Then, the multidata acquisition terminal can be controlled by the monitoring software running on the computer, so as to realize the long-term automatic monitoring of multi-profile lines.

3) Laboratory simulation experiments were carried out to verify the performance of the distributed resistivity monitoring system. A small-scale physical grouting experiment is carried out, and the inversion results verify the accuracy of the system design and the effectiveness of the method.

This article is organized as follows: Test methods and system structure, hardware design, software design, experiment and field test. Finally, we give a conclusion for the paper.

TESTING METHODS AND STYLES STRUCTURE

The ERT method is one of the array exploration methods (U. Mukhwathi and F. Fourie 2020) in which a large number of electrodes are inserted into the surface during monitoring.

The system hardware design

The ZigBee module is connected to a computer's USB port and the QT-based monitoring software runs on the computer for human-computer interaction.

The data acquisition terminal, which serves as the core unit of the distributed monitoring system, utilizes the STM32F103ZET6 at 72 MHz with 32-bit Cortex-M3 manufactured by STMicroelectronics.

Electrodes A and B in the electrical resistivity tomography method are used as electrodes to power the ground. Both A and B are connected to two relays which control the electrode as electrode A connected to the positive terminal of the battery, or as electrode B connected to the sample resistance, or as a dummy electrode.

Software design

This section introduces the monitoring system programme flow including the user control terminal, the data acquisition terminal and the ZigBee network module program.

Experiment and test

System performance test: The stability of the data acquisition system is of paramount importance, so the performance of the system was tested by linking pins AIN6 and AIN7 together and the inputs of AIN8 and AIN9 together, setting the ADS1263 sampling rate to 1200 SPS.

Grouting simulation test: In order to test the performance of the grouting monitoring system, the process of grouting simulation evolution was tested.

The grouting and filling process has been tested, and the field can be seen in Figure 2.



Figure 2. Filed testing.

The inversion imaging results of the three profiles in the field experiment are shown in the Figure 3 below.

This experiment mentioned above simulates grouting filling with geological characteristics of cavities such as karst, so the mechanical properties of rock stratum are the mechanical properties of grouting materials. We have tested the mechanical properties of the cement-based grouting material used in the experiment, which fully meets the requirements of engineering strength and environment.

CONCLUSIONS

This paper proposes, experimentally tests and verifies a distributed dynamic monitoring system for grouting. The system includes a user control terminal and one or more data acquisition terminals. Then, the data interaction between the user control terminal and the data acquisition terminal is carried out via ZigBee network according to the acquisition process. Simulated grouting experiments in the field showed that the monitoring system can monitor the apparent resistivity changes in multiple underground areas by controlling multiple data acquisition terminals through the user control terminal. The collected data clearly reflect the changes in the underground resistivity abnormal

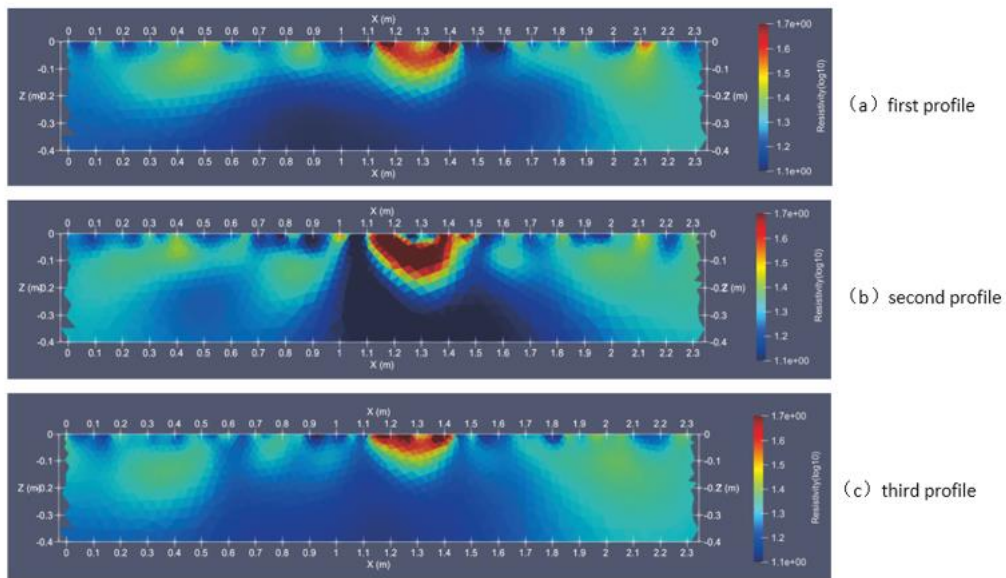
areas after inversion imaging by inversion software, thus providing a reference for the actual grouting process control and effect evaluation. Due to the scalability of the ZigBee network, in future work, more sensor nodes will be added to the current ZigBee network to extend the monitoring of parameters, including grouting volume, grouting pressure and slurry density, so as to realize multi-physics monitoring of the grouting project and complete the quantitative control and real-time evaluation of the grouting process.

ACKNOWLEDGEMENTS

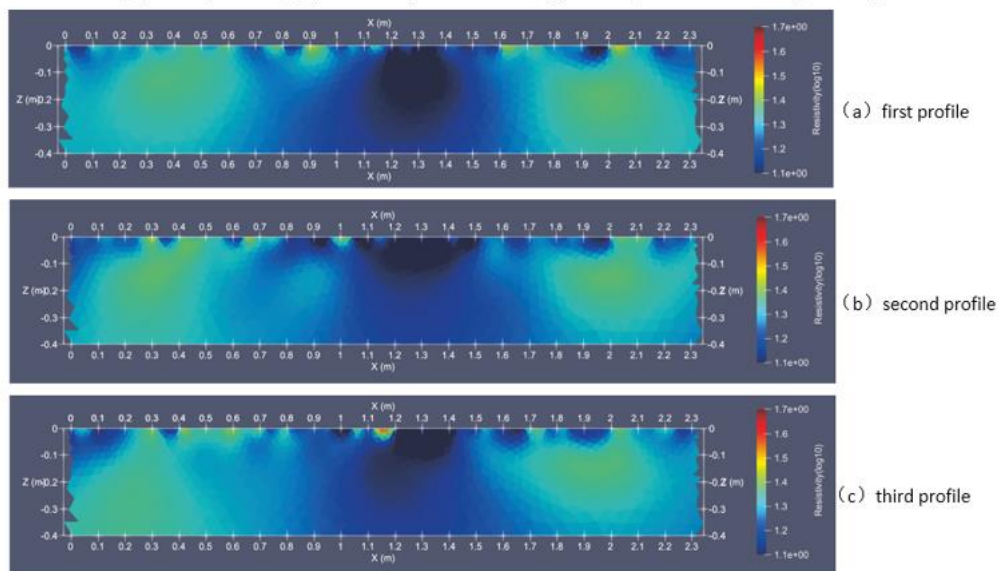
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The apparent resistivity distribution of three profiles in the grouting area
(a)first profile, (b)second profile and (c)third profile before grouting



The apparent resistivity distribution of three profiles in the grouting area
(a)first profile, (b)second profile and (c)third profile after grouting

Figure 3. Inversion comparison of three profile.