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Application of Internet of Things (IoT) Technology in Smart Compaction System

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***Abstract*— This paper introduces the application of IoT technology in the smart compaction system and its utilization in water conservancy construction projects. By equipping essential compaction equipment with information control panels, automatic positioning modules, and corresponding IoT sensors, the system enables comprehensive monitoring of the entire dam compaction process, ensuring construction quality and safety. By integrating the latest IoT, computer technology, and dam compaction construction techniques, the system realizes unmanned compaction construction, effectively enhancing construction quality and accelerating the construction progress**

***Index Terms*— Smart compaction, dam, Internet of Things (IoT), water conservancy engineering**

I. Introduction

The technique of roller-compacted concrete dam construction has rapidly developed in China, with nearly two hundred roller-compacted concrete gravity and arch dams built to date, some exceeding a hundred meters in height. During this process, the dam construction field in China has accumulated rich practical experience and formed design and construction standards for roller-compacted concrete. However, challenges have also been encountered, including difficult-to-control construction problems. Traditional manual compaction methods lack the ability to obtain construction data, leading to issues such as uneven compaction, missed compaction, incorrect compaction, and over-compaction, posing significant risks to dam construction. Additionally, the labor intensity of construction personnel is high, with repetitive tasks and the adverse effects of machine vibrations on human health. These issues collectively affect the engineering quality of roller-compacted concrete dams [1].

By employing new technologies such as IoT, BeiDou navigation satellite system (BDS), 5G, and cloud computing, compaction machinery can be intelligently transformed, data can be collected, and analysis can be performed through a collaborative platform and management backend. This ensures quality control throughout the compaction process and not only guarantees the quality of roller-compacted concrete but also significantly improves its construction efficiency.

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II. Smart Compaction Concrete Dam System

2.1 Smart Compaction System Overview

The smart compaction concrete dam system consists of a central control center, wireless network, on-site sub-control station, GNSS reference station, and compaction machinery monitoring equipment. The overall configuration of the system is depicted in Figure 1.

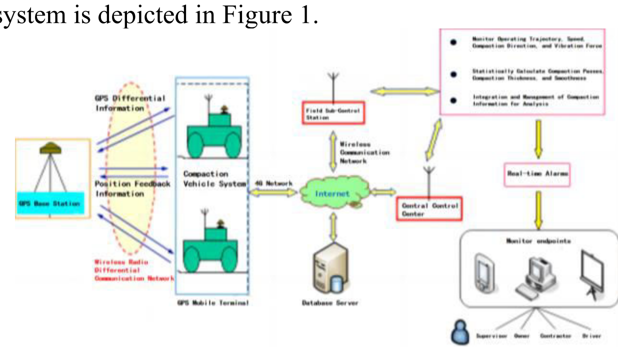

Figure 1: Smart Compaction Concrete Dam System Topology

(a) Central Control Center Design

The central control center is a core component of the GNSS monitoring system for compaction quality. It includes server systems, database systems, communication systems, security backup systems, and on-site monitoring application systems.

(b) Wireless Communication Networking

The 5G mobile wireless network technology is adopted to achieve complete coverage of the monitoring network in the operational area.

(c) On-Site Sub-Control Station Design

The on-site sub-control station should be established in a secure area near the construction dam surface and its location adjusted according to the construction progress.

(d) GNSS Differential Reference Station Design

The GNSS differential reference station serves as the "position standard" for the entire monitoring system.

(e) Compaction Machinery Monitoring Equipment

Monitoring data, including the position of the mechanical device in the dam construction process, pre- and post-compaction elevations, travel speed, and number of compaction passes, is collected by GNSS receivers installed on the compaction machinery and paving machinery.

(f) Visualization and Analysis

The results of automatic analysis and calculation are visualized. Managers can supervise the construction process in real-time.

(g) Smart Compaction Process Monitoring
Key digital indicators such as compaction speed and vibration status of the compaction machine are equipped with threshold values. Real-time analysis and warnings for compaction omissions and exceedances are provided, aiding decision-making.

2.2 System Operation Principle
Real-time monitoring of compaction machinery in the construction process is achieved by installing BeiDou navigation satellite system (BDS) positioning monitoring devices, industrial display devices, and vibration frequency acquisition devices on the compaction machine. The data collected is associated with compaction quality. The methods for obtaining data on compaction machine travel speed, number of passes, and pavement thickness are as follows: High-precision positioning data collected at regular intervals form a series of points that create a compaction trajectory, direction, and speed, which, combined with the compaction equipment width, define the coverage area. The number of times the coverage area is passed converts into the number of compaction passes. By analyzing the difference in elevation of the coverage area, the pavement thickness is determined.

III. Case Study of Smart Compaction Concrete Dam System

3.1 Project Overview
A roller-compacted concrete dam: The construction of a new roller-compacted concrete gravity dam with a crest length of 293 meters is described. The dam crest elevation is 145 meters, the maximum dam height is 69 meters, and the crest width is 10 meters. The main body of the dam is constructed using roller-compacted concrete. The construction process involves a combination of static and vibratory compaction methods to ensure uniform compaction and quality.

Figure 2: Smart Compaction Concrete Dam Construction

3.2 Application Scenario
In the overflow dam section, the surface layer is made of regular concrete, while the interior is composed of roller-compacted concrete. The use of fixed steel molds ensures one-time molding. Concrete is transported using 10-ton dump trucks, and M630 tower cranes with $3m^3$ hoists are used for the pouring process.
According to the construction layout of the dam site, a BeiDou navigation satellite system (BDS) reference station is established in a suitable area to collect signals for information acquisition. On the front end of the five hydraulic-driven single-drum vibratory rollers used in the project, BeiDou mobile stations are fixed to collect working data. Car-mounted terminals, i.e., visual intelligent tablets, are installed in the control room to receive and visualize data, aiding operators in self-correction during the quality formation process. Video monitoring client servers are installed in the project office meeting room, main management personnel's office computers, and on-site duty rooms. These servers transmit construction dynamics through a 4G network, enabling real-time viewing of the construction site.
After system installation, calibration of the collected information is conducted based on compaction equipment performance parameters (vibration frequency, compaction force, travel speed, and compaction width). This ensures the accurate and effective utilization of data in normal equipment working conditions, guaranteeing information accuracy, validity, and sensitivity. Measured compaction data is collected and design parameters are input to calculate the area of compacted surfaces, allowing monitoring and control of the entire compaction quality process. After system debugging, rechecking and testing are performed. By comparing the data collected from the compaction test area with the sampled data after compaction, the quality is deemed acceptable and the system is formally put into use.
The visual intelligent tablet for compaction operators is directly installed in the compaction equipment's operator room. After equipment startup, operators use the 4G network transmission to receive compaction task assignments, real-time tracking of compaction trajectories, vibration status, and coverage areas. The system also provides real-time warnings about compaction quality and assists operators in self-correction during the construction process. Different colors distinguish between compaction methods and working statuses, aiding operators in adjustment. Compaction is performed with a static pass followed by six vibratory passes. Different colors represent different compaction cycles. Real-time compaction pass counts are recorded, preventing common issues such as missed compaction and improper overlapping.
Various managers can use video monitoring rooms set up in the camp or on-site to view the compaction situation in real-time or randomly. Managers can directly view compaction elevation, coverage area, and number of compaction passes through visual images. In case of non-compliance with design requirements (e.g., pavement thickness, insufficient compaction passes), warnings or instructions can be issued directly to operators for immediate correction, improving on-site construction quality management and control.
Furthermore, the smart compaction system collects process data during compaction and construction. By uploading this data to the blockchain, data tampering and quality data statistics are prevented, with three-dimensional visual querying capabilities reducing the workload of quality statistics and improving data collection efficiency.

Figure 3: Smart Compaction Concrete Dam System Equipment Hardware

IV. Conclusion

The intelligent construction technology of roller-compacted concrete integrates engineering informatization and automation. By applying new technologies, the project management objectives of intelligence, informatization, visualization, and reduced labor are achieved throughout the construction process. The main application values include:

1. Enhancing project comprehensive management efficiency, achieving cost reduction, quality improvement, efficiency enhancement in engineering construction, providing safety barriers, and supporting dual carbon goals.
2. Promoting the level of intelligent construction technology through new technology applications, facilitating the digital transformation and upgrading of construction enterprises.
3. Enabling intelligent safety monitoring and construction to effectively prevent safety accidents.
4. Through the application of the smart compaction concrete dam system based on IoT perception technology, a complete, convenient, and efficient smart construction system for compaction concrete is established, thereby enhancing the core competitiveness of enterprises.

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