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Proceeding Paper

Design of Intelligent Compaction Operation Monitoring System for Intelligent Vibratory Roller Based on Internet of Things †

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Abstract: In recent years, the intelligent vibratory roller with adjustable mode has become the leading direction of the development of compaction equipment, which can obtain the state of the pressed material in time in the compaction operation and then control the working parameters, the excitation mode of the whole machine according to the condition of the pressed material. The intelligent vibratory roller can better meet today's requirements for compaction. This paper proposes an intelligent compaction operation monitoring system for intelligent vibratory roller based on internet of things. Firstly, a hardware system for real-time compaction monitoring is established, including design selection of sensor module, signal conditioning module. Secondly, a method for real-time compaction monitoring data evaluation and analysis of intelligent compaction is proposed, and a detailed analysis process of compaction data is designed. Finally, an intelligent vibratory roller operation monitoring prototype system based on the Internet of Things technology is designed and constructed.

Keywords: vibratory roller; intelligent compaction; real-time compaction monitoring; industrial internet of things

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1. Introduction

Road compaction is a basic process in construction industry, and effective compaction is critical to the service life of the road. In recent years, with the rapid development of global engineering infrastructure, the requirements for compaction are getting higher. At the meanwhile, the wide application of electronic technology, sensor technology, computer technology and automatic control technology has promoted the development of compaction machinery in the direction of automation and intelligence [1]. The intelligent vibratory roller has become a front direction of road compaction equipment [2].

The application of the Internet of Things (IoT) in vibratory rollers is mainly reflected in operation monitoring, real-time positioning, and intelligent control. Instrumented with the GPS, various sensors, computer system and IoT, the intelligent vibratory roller can measure the compacted material stiffness and equipment running states, and automatically adjust the compaction mode and working parameters, so as to achieve the best compaction effects [3,4].

Therefore, this paper proposes an intelligent compaction operation monitoring system for intelligent vibratory roller based on IoT as shown in Figure 1. The remainder of this paper is organized as follows: The second part establishes a hardware system for real-time compaction monitoring, including design of sensor module and signal conditioning module. A method for real-time compaction monitoring data evaluation and analysis of intelligent compaction and detailed analysis process of compaction data are also designed. The third part constructs an intelligent vibratory roller operation monitoring prototype system based on the IoT technology. Finally, the forth part concludes this paper and points out the further work.

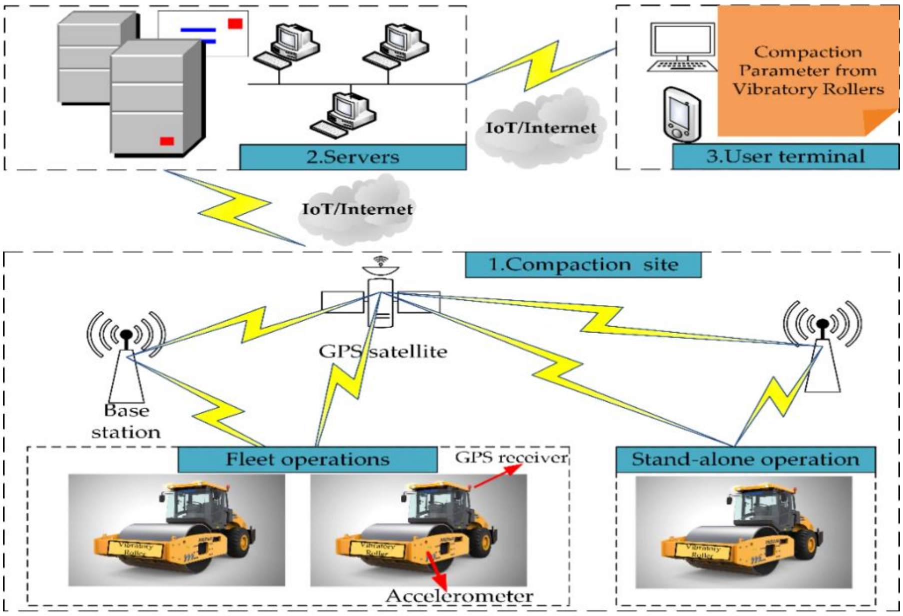

Figure 1. Overall frame of intelligent road roller based on Internet of Things.

2. Real-Time Compaction Degree Monitoring and Evaluation of Intelligent Construction

In the 1970s, Yoo and Selig studied a two-degree-of-freedom linear model and found that the acceleration of the vibrating wheel changes with the change of the stiffness and damping coefficient of the compacted soil [5]. A large number of construction practices also show that when the vibratory roller performs compaction operations, the vibration acceleration of the vibrating wheel is closely related to the degree of compaction of the compacted material. Therefore, the degree of soil compaction can be reflected by collecting, analyzing, and processing the vibration acceleration signal of the vibratory roller [6].

Based on the above theoretical analysis, a hardware system for real-time monitoring of the degree of compaction is designed. The hardware system mainly includes an acceleration sensor module and a signal conditioning module. The acceleration sensor module measures the acceleration signal related to the vibratory roller. The signal conditioning module adjusts the obtained acceleration signal and finally obtains the specific values of acceleration [7]. The obtained data is uploaded to the remote data management center through GPRS. Then the data management center analyzes and processes the data [8].

2.1. Sensor Module

2.1.1. Acceleration Sensor Module

In the real-time detection of compaction, the acceleration of the vibrating wheel is the main research object. The selection of the acceleration sensor is usually selected through the following technical indicators: sensitivity, number of measurement axes, and maximum measurement value. For the acceleration sensor used on the vibratory roller, its vibration frequency range also needs to be considered.

The sensor with high sensitivity is more sensitive to the change of acceleration. The output voltage range is larger, the acceleration data obtained will be more accurate. Regarding the number of measuring axes, generally two measuring axes can satisfy the acceleration measurement in most cases. For the maximum measured value, since the amplitude of the general vibratory roller is mostly between 0–15 g and the vibration frequency is between 15–50 Hz. Therefore, the range of the sensor should be more than 15g, and the frequency range should be greater than 15–50 Hz.

Based on the above standards and cost performance, this design uses the ULT1006 sensor developed by LANCETEC. It has the following advantages.

- High sensitivity and high measurement accuracy;
- Low impedance output, anti-interference, low noise;
- Stable and reliable, resistant to moisture and dust.

2.1.2. Signal Conditioning Module

The signals transmitted by the acceleration sensor on the vibratory roller are mixed with a lot of vibration noise, such as the noise generated by the engine or the oil pump. Therefore, a signal conditioning module is required to perform noise reduction processing on the transmitted acceleration to improve its signal-to-noise ratio [9].

Figure 2 presents the processing flow of the acceleration signal. The micro IC amplifier is built into the acceleration sensor and is an element that amplifies the signal output by the acceleration sensor. The signal from the acceleration sensor is of mV level. The input voltage of the ADC device for A/D conversion is of V level. Therefore, in order to make the output voltage of the sensor and the input voltage of the ADC device on the same level, the amplifier is required. At the meanwhile, A high-pass filter is also needed to adjust the signal. The function of the high-pass filter is to cut off low-frequency signals and output high-frequency signals, so that the filter can not only determine the low-frequency cut-off frequency of the detected acceleration signal, but also reduce noise and improve the signal-to-noise ratio.

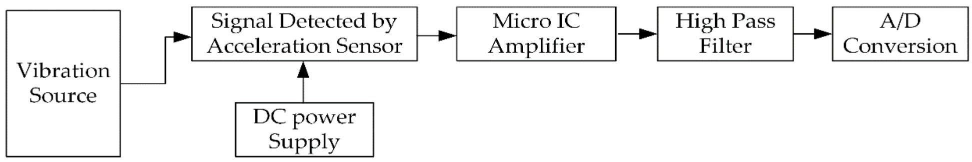

Figure 2. Acceleration signal processing diagram.

The noise is reduced and the signal-to-noise ratio is improved after the acceleration signal is adjusted and processed by the high-pass filter. What we get is still a voltage signal. The A/D conversion module converts the voltage signal into a digital signal. In this design, the AD7799BRUZ type digital-to-analog converter is used, which has the advantages of low noise and low power consumption.

2.2. An Evaluation and Analysis Method of Real-Time Compaction Data

In the hardware system of real-time compactness detection, the acceleration sig-nal of vibratory wheel and frame are detected by sensors. Then the acceleration signals are adjusted by signal conditioning system through A/D conversion. The feature values are extracted to obtain useful information. In addition, relevant data analysis methods are needed to analyze the data obtained.

The elastic modulus E is used to evaluate the compaction effect. Modulus of resilience is the ability of compacted material to resist vertical deformation within the range of elastic deformation under the action of Ground Reaction Force. E can be expressed as:

$$E = \frac{\sigma}{\varepsilon} \tag{1}$$

where σ is stress and ε is strain.

Before compaction, the target resilience modulus value should be calculated in advance through FWD (Falling Weight Deflectometer) test in the compaction area [10]. Thus, we can compare the rebound modulus value detected during the compaction process with the target modulus value to verify the compaction effect. Figure 3 presents the composition diagram of compaction evaluation analysis system.

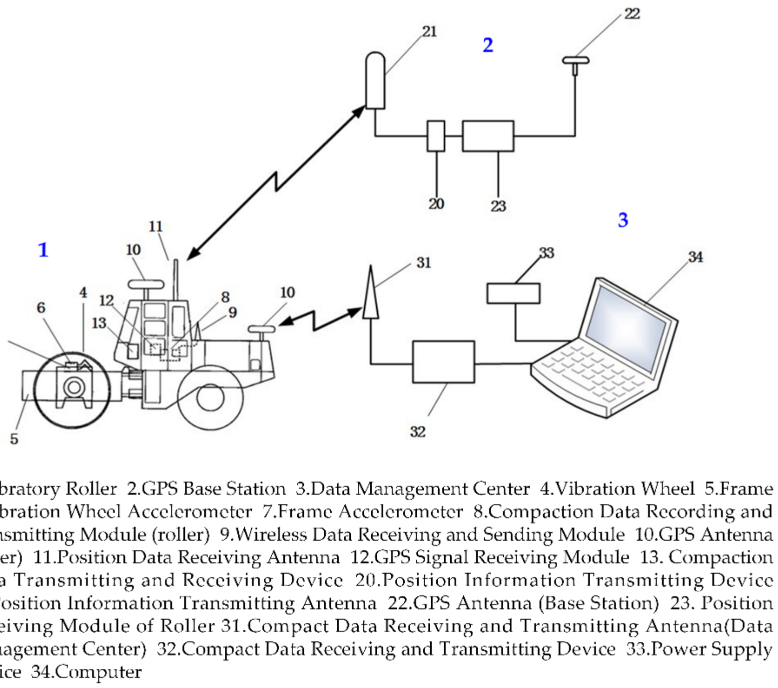

Figure 3. Composition diagram of compaction evaluation analysis system.

As shown in Figure 4, the specific process of real-time compaction testing data evaluation and analysis is described as follows.

1. Input the target resilience modulus value in the compaction operation range obtained by the FWD test into the Computer 34.
2. The roller compresses and the test begins.
3. Recording the compaction data. The Transmitter 8 obtains the acceleration of the Vibratory Wheel 4 and the Rack 5 from the Accelerometer 6 and 7 of the Vibratory Wheel 4 and the Rack 5.
4. The GPS Receiving Module 10 on the Vibratory Wheel 4 obtains the current position data of the roller from the GPS Base Station, the position information is sent to the Data Management Center 34 by the Wireless Data Sending Module.
5. The acceleration information of the Vibration Wheel 4 and the Rack 5 is sent to the Data Management Center 34 by the Wireless Data Receiving and Sending Module 9, the acceleration information is converted between the high-pass filter and the ADC to get the acceleration values for Vibration Wheel 4 and Rack 5. Through the analysis of the acceleration data in Computer 34.
6. After the acceleration information is obtained by the Data Management Center, the acceleration information is converted and processed by the high-pass filter and the ADC equipment to get the acceleration values of Vibration Wheel 4 and Rack 5.
7. The ground reaction force is judged.
8. The Data Management Center records the position information and the rebound modulus of the roller at every moment during the compacting process, and integrates the data.
9. The measured spring back modulus will then be displayed on the Computer 34 display and compared with the measured target modulus in the first step to evaluate

whether the current compaction process has been qualified or not. When the compaction state is not up to standard, Computer 34 instructs the roller to continue working through the Compaction Data Transmitting and Receiving Device 13.

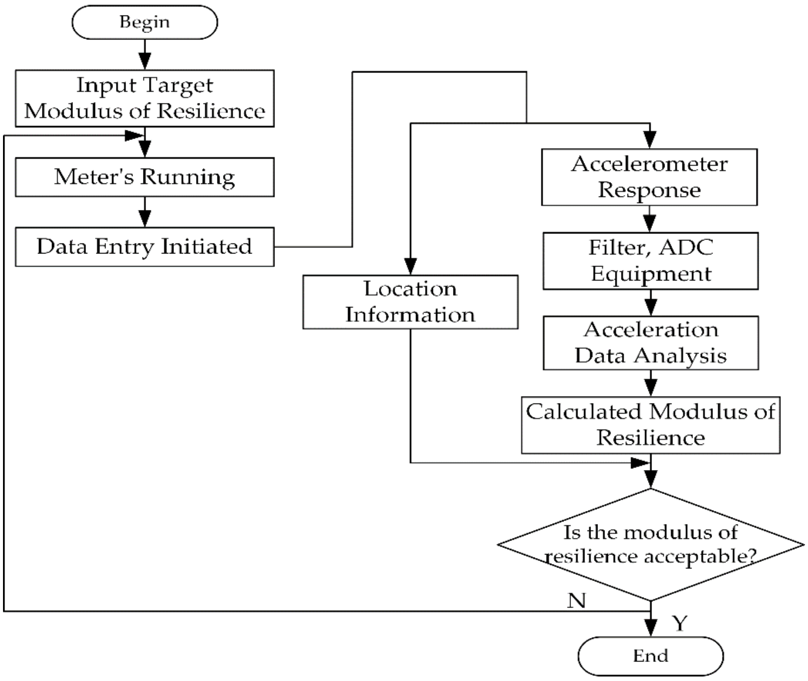

Figure 4. Real-time testing data evaluation and analysis process of compaction.

3. Software Verification of Compaction Operation Monitoring System

The monitoring system software mainly includes three functions, including the intelligent compaction monitoring system client, the intelligent compaction of big data analysis system and the server module.

Through the software, we can see the various parameters of the roller that is undergoing compaction operations. One of the most important functions of the monitoring software are real-time data viewing. The real-time data includes the current number of rolling passes and real-time compaction value, as shown in the Figure 5.

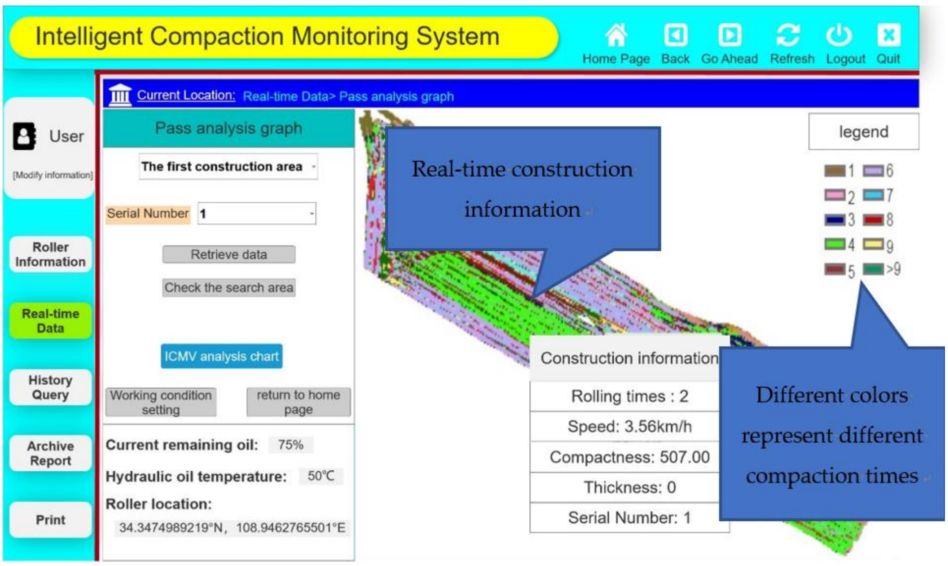

Figure 5. Real-time testing data evaluation and analysis process of compaction.

4. Conclusions

In this paper an intelligent compaction operation monitoring system for intelligent vibratory roller based on IoT is designed. Firstly, by acquiring the real-time data of various sensors in the compaction detection hardware system, a method for evaluating and analyzing the real-time compaction detection data for intelligent compaction is proposed, and a detailed evaluation and analysis process of the compaction data is given. Finally, the established intelligent compaction operation monitoring software was verified.

In the future, we will study to rely on new sensor technology and multi-information fusion technology to accurately and effectively obtain job quality data, and use new information processing methods such as artificial intelligence and deep reinforcement learning to deep process job quality big data.

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