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

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Abstract: In recent years, an intelligent vibratory roller with adjustable mode has become the leading direction for the development of compaction equipment that can obtain the state of the pressed material during the compaction operation and then control the working parameters and 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 a compaction operation monitoring system for an intelligent vibratory roller based on the Internet of Things. Firstly, a hardware system for real-time compaction operation monitoring was established, including the selection of a sensor module and signal conditioning module. Secondly, a method for real-time compaction monitoring data evaluation and analysis of compaction was proposed and a detailed analysis process of the compaction data was designed. Finally, the compaction operation monitoring prototype system based on the Internet of Things technology was designed and constructed.

Keywords: vibratory roller; compaction; real-time compaction monitoring; industrial Internet of Things

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1. Introduction

Road compaction is a basic process in the construction industry. Effective compaction is critical to the service life of a road. In recent years, with the rapid development of global engineering infrastructure, the requirements for compaction are getting higher. The vibratory roller as an important road-building machine is particularly important for improving the degree of compaction of the earthworks. In the meanwhile, the wide application of electronic technology, sensor technology, computer technology and automatic control technology has promoted the development of a vibratory roller in the direction of automation and intelligence [1]. However, the existing vibratory roller cannot adjust the parameters of the roller in real time according to the state of the material to be compacted because of the lack of an effective real-time monitoring technology, which makes it difficult to ensure compaction quality and efficiency, and wastes resources and energy. Thus, research into the compaction monitoring technology of an intelligent vibratory roller is becoming more and more urgent [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 GPS, various sensors, a computer system and IoT, the intelligent vibratory roller can measure the compacted material's stiffness and the equipment's running state in order to achieve the best compaction effects [3,4]. Therefore, this paper proposes a compaction operation monitoring system for an intelligent vibratory roller based on IoT, as shown in Figure 1.

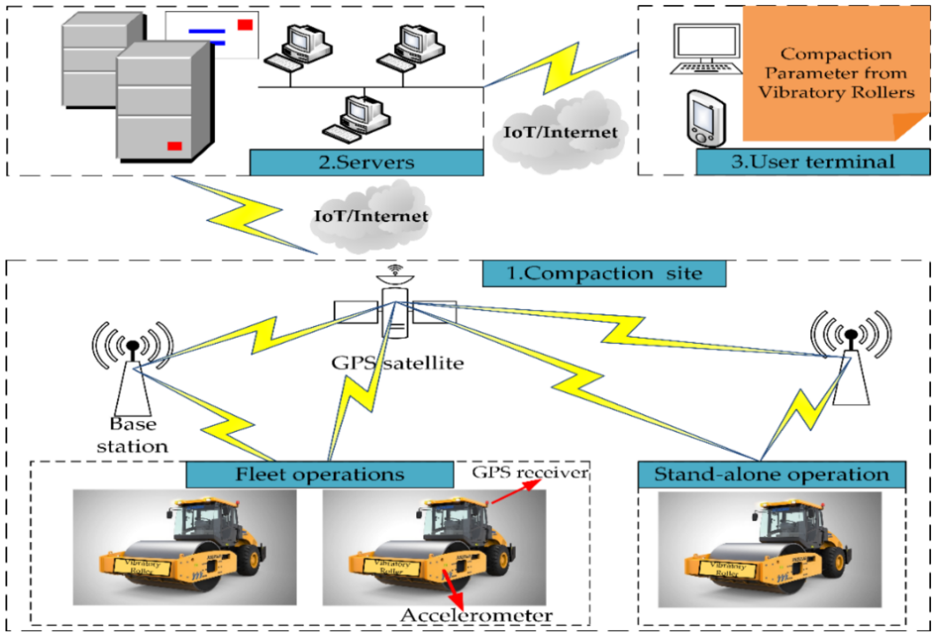

Figure 1. Overall framework of compaction operation monitoring system for an intelligent roller based on Internet of Things.

2. Hardware Design of Compaction Operation Monitoring System

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 showed that the vertical vibration acceleration of the vibrating wheel was closely related to the degree of compaction of the compacted material when the vibratory roller performed the compaction operation. Therefore, the degree of soil compaction can be reflected by collecting, analyzing, and processing the vertical acceleration signal of the vibratory roller wheel [6].

Based on the above theoretical analysis, a hardware system for real-time monitoring of the degree of compaction was 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 monitoring of the compaction operation, the vertical 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 and maximum measurement value. For the acceleration sensor used on the vibratory roller, its vibration frequency range also needs to be considered.

A sensor with high sensitivity is very sensitive to changes in acceleration. The larger the output voltage range is, the more accurate the obtained acceleration data will be. 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 15 g, 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 advantages such as high sensitivity, high measurement accuracy and anti-interference. The main technical parameters are shown in Table 1.

Table 1. Main technical parameters of ULT1006 sensor.

Model	Sensitivity	Frequency Range	Resonant Frequency	Output Impedance	Temperature Range
ULT1006	200 mV/g	0.3~8000 Hz	30 kHz	150 Ω	−40~120 °C

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 it 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. In order to make the output voltage of the sensor and the input voltage of the ADC device on the same level, an amplifier is required. in 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 and 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.

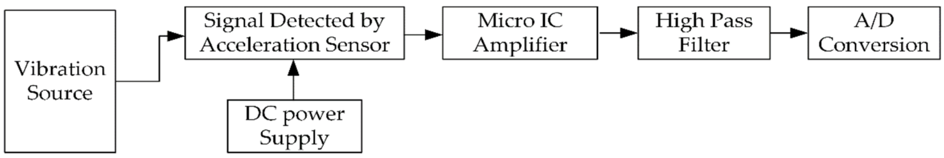

Figure 2. Acceleration signal processing diagram.

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 is obtained 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. The main technical parameters are shown in Table 2.

Table 2. Main technical parameters of AD7799BRUZ type digital-to-analog converter.

Model	Number of Pins	Resolution	Working Voltage	Throughput Rate	Input Channel Number
AD7799BRUZ	6	24 Bits	2.7~5.25 V	470SPS	3

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

In the hardware system of real-time compactness monitoring, the vertical acceleration signal of the vibratory wheel is monitored by sensors. Then, the acceleration signals are adjusted by a 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. The 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 an FWD (falling weight deflectometer) test in the compaction area [10]. Thus, we can compare the rebound modulus value which is monitored 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.

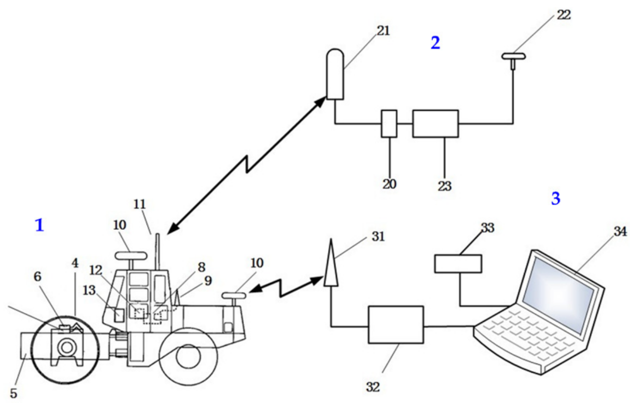

Figure 3. Composition diagram of compaction evaluation analysis system (revised from [11]).

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

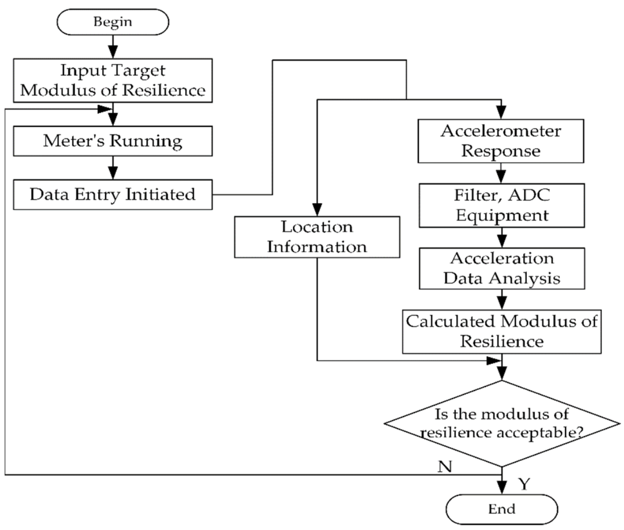

Figure 4. Real-time testing data evaluation and analysis process of compaction.

1. Inputting the target resilience modulus value in the compaction operation range obtained by the FWD test into Computer 34.
2. The roller compresses and the test begins.
3. Recording the compaction data. Transmitter 8 obtains the acceleration of vibratory wheel 4 and rack 5 from accelerometer 6 and 7 of vibratory wheel 4 and rack 5.
4. The GPS receiving module 10 on 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 vibration wheel 4 and rack 5 is sent to 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 compaction data transmitting and receiving device 13.

3. Software Verification of Compaction Operation Monitoring System

The monitoring system software is programmed by C# and uses browsers and servers to receive and display data. It mainly includes three functions, the intelligent compaction monitoring system client, the intelligent compaction of big data analysis system and the server module. In addition, the monitoring system software uses Microsoft SQL Server 2017 to store compaction data.

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

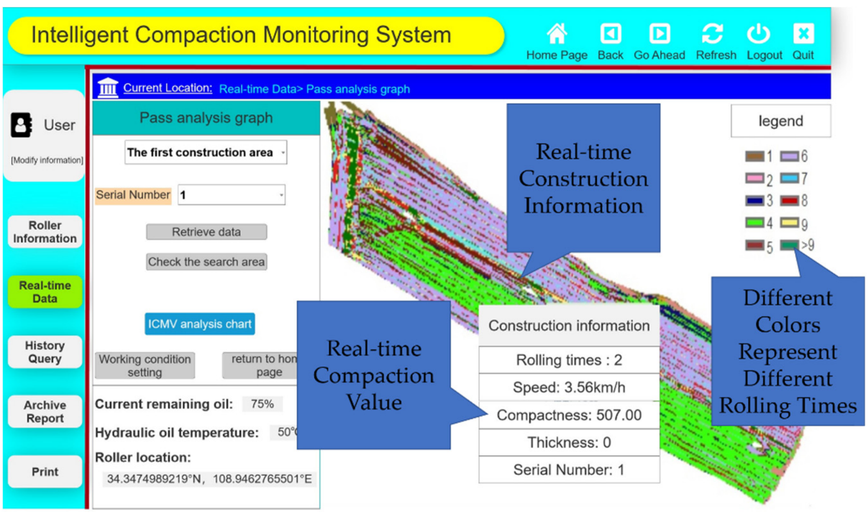

Figure 5. Real-time testing data evaluation and analysis process of compaction.

4. Conclusions

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

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

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References

1. Zhang, D.; Hu, D.; Xu, Y.; Zhang, H. A framework for design knowledge management and reuse for Product-Service Systems in construction machinery industry. *Comput. Ind.* **2012**, *63*, 328–337. [CrossRef]
2. Wang, G.F.; Hu, Y.B.; Zhu, W.Q.; Bao, Z.Y.; Chen, Z.J.; Huang, Z.H.; Wang, W. *The Design of a Compaction Parameters Management System for Intelligent Vibratory Roller*; IEEE: New York, NY, USA, 2017; pp. 634–638.
3. Qiao, H.H.; Ma, H.X.; Hu, H.Y. Analysis of IOT Application in the Field of Engineering Machinery. *J. Shijiazhuang Tiedao Univ.* **2015**, *28*, 81–85.
4. Wei, J.C.; Chen, X.S.; Ni, L.; Wang, A.L.; Xu, G. IoT-based design for construction machinery monitoring systems. *Chin. J. Constr. Mach.* **2014**, *12*, 364–366, 371.
5. Woodhead, R.; Stephenson, P.; Morrey, D. Digital construction: From point solutions to IoT ecosystem. *Autom. Constr.* **2018**, *93*, 35–46. [CrossRef]
6. Du, S.Q. Analysis on the signal sampling from real-time testing and control of vibratory roller. *Road Mach. Constr. Mech.* **2004**, *8*, 47–49.
7. Zhou, X. Application status and development of construction machinery Internet of Things. *Constr. Mach. Maint.* **2014**, *4*, 82–83.
8. Behnam, A.; Wickramasinghe, D.C.; Ghaffar, M.A.A.; Vu, T.T.; Tang, Y.H.; Isa, H.B.M. Automated progress monitoring system for linear infrastructure projects using satellite remote sensing. *Autom. Constr.* **2016**, *68*, 114–127. [CrossRef]
9. Wei, H.Y.; Xie, W.B.; Zhou, W.F.; Li, Y.Y. Research on Real-time Monitoring System for Construction Quality of Road Pavement Based on Internet of Things. *Technol. Highw. Transp.* **2015**, *1*, 23–35.
10. Yang, H.Y. Progress and Trend of Construction Machinery Intelligence. *Constr. Mach. Technol. Manag.* **2017**, *30*, 19–21.
11. Wang, W. Study on Intelligent Monitoring Technology of Vibratory Compactor Compaction Operation. Master's Thesis, Chang'an University, Xi'an, China, 2018.