Development and Application of Quality Control System for Highway Subgrade Construction

Tong Wang

Jiangsu Easttrans Engineering Detection CO., LTD, Jiangsu Province, 210000

*Corresponding Author: Wang Tong; Four Floors of Building A2, Zidong International Creative Park, Qixia District, Nanjing; njdjwangt@126.com

Abstract

The compaction quality of the subgrade is directly related to the service life of the road. Effective control of the subgrade construction process is the key to ensuring the compaction quality of the subgrade. Therefore, real-time, comprehensive, rapid and accurate prediction of construction compaction quality through informatization detection method is an important guarantee for speeding up construction progress and ensuring subgrade compaction quality. Based on the function of the system, this paper puts forward the principle of system development and the development mode used in system development, and displays the development system in real-time to achieve the whole process control of subgrade construction quality.

Keywords: *subgrade construction; compaction quality; control system; full process control*

Introduction

In recent years, our province has been developing rapidly in terms of expressway, national highway and municipal engineering construction. However, in the project quality management, due to the lack of necessary information technology means, the construction process of some important processes cannot be monitored in real-time. For example, the subgrade construction in the sandy soil distribution areas in the coastal areas of jiangsu province has higher requirements on the quality control of subgrade compaction, while the traditional construction mainly relies on the personal experience of the roller operator, which is easy to cause leakage pressure and overpressure, and the construction quality is difficult to be guaranteed. Specifically, the following problems exist:

(1)The construction management adopts the method of paper recording, the efficiency is low and the construction inspection data cannot be obtained and utilized in real-time, which is not conducive to the future engineering management and quality problem traceability;

(2)Subgrade rolling operation process completely depends on the operator's responsibility and driving experience, which can not guarantee the strict and accurate implementation of the rolling scheme;

(3)On-site supervision adopts the way of side stations for supervision, which lacks efficient and convenient supervision means and data support;

(4)Traditional subgrade compaction degree detection is point sampling inspection method, which has large workload and limited coverage, and has certain destructive effect on subgrade filling, so it is impossible to quickly judge unqualified areas of rolling compaction.

1. Overall structure design of the system

The real-time monitoring system for subgrade compaction quality of high-grade highway is mainly composed of beidou Corse reference station, rolling monitoring terminal, data and application server, remote (or on-site) monitoring client and on-site PDA (mobile phone). Using the Internet of Things and Internet technology to obtain the thickness of the subgrade during real-time rolling, the rolling speed, the number of passes and the CMV value of the road roller, and use the multivariate nonlinear regression method to establish the compaction degree prediction value (CEIC) based on these four indicators, finally the construction quality of subgrade compaction process is obtained. The overall architecture of the system is shown in Figure 1.

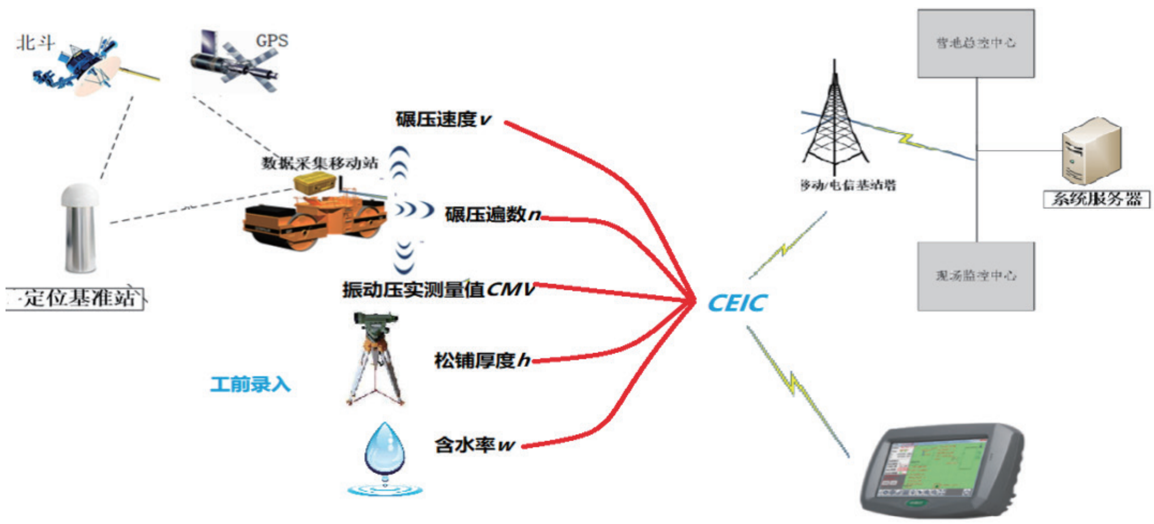

Figure 1 Overall framework of real-time monitoring system for compaction quality of high-grade highway subgrade

2. System composition

The system consists of subgrade construction data acquisition intelligent equipment, positioning system and subgrade construction quality control system.

2.1 Subgrade construction data acquisition intelligent equipment

During the rolling process, the eccentric mass block in the vibratory roller rotates, and the vibrating wheel begins to vibrate, generates vibration acceleration. The signal collected by the acceleration sensor is analyzed and processed, and the time-domain acceleration curve is obtained. In the initial stage of rolling of the subgrade, when the filling layer is loose, the vibration time domain curve is an ideal sinusoidal curve due to the small road stiffness. As the number of rolling passes increases, the filling layer becomes denser and its stiffness gradually increases. At this time, the subgrade filling layer begins to produce harmonic frequency, and the ratio of its amplitude to the fundamental frequency amplitude can be used as an evaluation index parameter for the compaction quality of the subgrade. ECV is obtained by spectral analysis of the acceleration of two or more vibration period of the vibratory wheel, the output value is the average of multiple. The indicator is related to the vibration wheel parameters (vibration wheel diameter and width) and the vibration wheel motion parameters (frequency, amplitude, speed), and it is a dimensionless parameter. As the stiffness of the compacted pavement increases, the vibrating wheel produces different harmonic components. The ECV can be used to monitor the dynamic response of the vibratory wheel compaction, reflecting the characteristics of the material being compacted. The calculation formula for ECV is:

$$ECV = \frac{A_{2\Omega}}{A_{\Omega}}$$

Type: ECV—— Quality index of continuous compaction;

A_{Ω}—— Acceleration amplitude of base frequency;

$A_{2\Omega}$—— Acceleration amplitude of the second harmonic component.

The intelligent equipment for data acquisition in subgrade construction adopts the embedded standard module structure system. The acceleration sensor is a preamplifier circuit that adopts a method of amplifing the charge. Generally, the output from the sensor end is the charge with weak signal and inconvenient to be monitored. The amplifier is to amplify its output charge, reduce the impedance, and convert the charge into a voltage (voltage is easy to measure) output for easy monitoring. The signal conditioning circuit module filters the acceleration signal. The A/D acquisition module can carry out A/D acquisition transformation for acceleration signal. The CPU module analyzes and processes the acceleration signal and velocity signal. Finally, the results and related content are displayed through the screen.

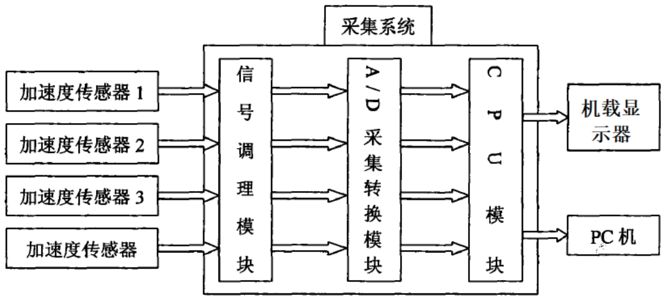

Figure 2 Design scheme of continuous intelligent compaction monitoring device

2.2 Positioning system

This system adopts beidou +GPS RTK high-precision positioning technology, which is a dynamic adjustment and difference real-time solution technology developed on the basis of beidou positioning technology and ordinary RTK positioning algorithm. According to the actual situation of locking satellites in the current environment, it conducts unified deployment and calculation, avoids the phenomenon of GPS signal instability in the domestic, and provides the carrier phase algorithm of beidou to obtain the centimeter-level positioning capability. Then, based on Beidou+GPS RTK high-precision positioning technology, the corresponding roller compaction trajectory algorithm and rolling pass algorithm are developed.

2.2.1 Research on roller track algorithm

The rolling track of the roller is composed of the line segments formed by the roller position at every 1s interval, and its rendering can be realized by Bresenham algorithm in line segment generation technology. The rolling area is a rolling strip formed by rolling track as the axis and extending vertically to both sides with half the width of the rolling wheel. It can be regarded as a line segment whose line width is equal to the width of the rolling wheel, and it can be drawn by using the moving brush method. The implementation method is as follows: a square brush is adopted, and the brush width is set to a value representing the width of the grinding wheel, and then move the brush center along the track segment to generate the corresponding rolling strip. In addition, the travel trajectories of different roller compactors are represented in different colors to facilitate differentiation.

2.2.2 Research on the algorithm of rolling pass number

The intelligent positioning speed measuring device is installed at the center position of the roller roof (ie, the center position of the rolling roller), assuming the roller width W. Figure 3 is a schematic diagram of the calculation of the number of rolling passes. Real-time determination of roller rolling region in t, namely rectangular region ABCD, then the coordinate of point A is (Xj, Yj+W/2) and the coordinate of point B is (Xj, Yj-W/2), that is, the width range of calculation of rolling pass is yj-w /2 to Yj+W/2.

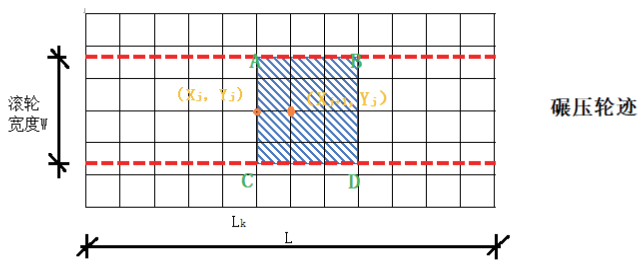

Figure 3 Schematic diagram of the calculation of the number of rolling passes

The specific algorithm is as follows:

(1) Obtain the beidou +GPS high-precision differential positioning data and determine whether it is valid. If the result is yes, store the valid data according to the time of collection and proceed to the next step. Otherwise invalid data will be deleted.

(2) The longitude and latitude coordinate data in the stored beidou +GPS high-precision difference positioning data are transformed from the spherical coordinate system to the plane rectangular coordinate system XOY.

(3) Based on the data storage time sequence, select the initial point M (Xm, Ym) in this batch of data, and calculate the point N (Xn, Yn) that is furthest from the initial point M (Xm, Ym) in this batch of data.

(4) The XOY plane rectangular coordinate system for calculating the number of times is established, and the beidou +

GPS high-precision difference positioning data in the XOY plane rectangular coordinate system is transformed.

(5) Project all the points in the rectangular coordinate system of the XOY plane to the X-axis or Y-axis, obtain the points on the coordinate axis (Xj, 0) or (0, Yj), and form one-dimensional data values.

(6) According to the observed length interval l set externally, the acquisition and test point l_k with equal spacing is set on the coordinate axis of the rectangular coordinate system of the XOY plane.

(7) The coordinate values (Xj, 0) and (Xj+1, 0) or (0, Yj) and (0, Yj+1) of the coordinate points of all adjacent moments are sequentially multiplied with l_k.

(8) Determine whether the coordinate values (Xj, 0) and (Xj+1, 0) or (0, Yj) and (0, Yj+1) of all adjacent coordinate points are distributed on both sides of the point according to the plus or minus of the multiplied values. If the product is negative, the two points are distributed on both sides of the acquisition test point, and the number of compaction times of the roller at the current section position is added by 1. If the product is positive, the two points are on the same side, and the number of compaction times of the roller at the current section position is unchanged. Traverse all points, obtain the road roller construction times of the road section passing the point l_k.

(9) Determine whether it is the last cross-section position. If the judgment result is yes, output the number of construction that need to observe the cross-section, and then the program stops and waits for the next start. Otherwise, the calculation of the next cross-section construction number is continued.

2.3 Subgrade construction quality control system

2.3.1 Design principle

(1) Suitability

"Data security" is the primary design principle. The architecture not only meets the industry's "data privacy requirements", but also meets the "functional requirements" such as simplicity and convenience of use.

(2) Stability

The system structure fully considers the stability of the system, and the design is guaranteed to ensure the stable operation of the system for 7×24 hours. Operation interface design, database design, module design, data structure design and so on should also fully consider the stability of the system.

(3) Openness

The system design follows the open principle, the system has a strong secondary development ability, can be further developed according to future development needs.

(4) Maintainability

The system structure is simple, modular programming technology is adopted, and the software configuration is simple and effective. All configuration actions have corresponding configuration interface and relevant description information, ensuring the convenience of system update, maintenance and upgrade.

(5) Flexible expansion

The system software adopts the structure system of layered development and multi-point network communication. The dynamic library is mainly connected between the functional modules in each device, forming the system running state of low coupling and high cohesion. Intelligent interface technology and reserved perfect data interface are adopted to realize the docking with other information systems. At the same time, the system will not destroy the stability of the original structure when it is extended and upgraded or function modified.

(6) High performance

Through the application of caching and load balancing technology, the maximum utilization rate of resources should be less than 70%, and the average utilization rate of resources should be less than 50% when the system is running within 7×24 hours. The WEB server can be accessed by 1000 users at the same time, and the WEB page access speed is no more than 3 seconds; The terminal positioning data upload interval of 5 seconds, the system has the processing capacity of 1500 pieces of positioning data information per second on average and 2500 pieces of positioning data information per second at peak.

(7) Load balancing

The system application adopts the distributed business processing and storage mode of multi-communication front machine and multi-service server, and the database adopts the horizontal partition mode to achieve load balance. And has the ability to expand the system capacity only by increasing the number of corresponding servers. Without having to make major adjustments and changes to the system.

2.3.2 System objectives and functions

System objectives

(1) On-line real-time monitoring of project construction quality.

(2) The integrated management of quality monitoring and progress information during highway construction provides information application and support platform for highway construction quality and progress control, as well as highway safety diagnosis.

(3) To achieve the owners and supervisors of the project construction quality of deep participation, fine management. Through the automatic monitoring of the system, not only the owner can rest assured of the project quality, effectively control the construction progress, but also can realize the rapid response to the highway construction quality and progress control.

(4) It provides an information integration platform for the completion acceptance, safety appraisal and future operation and management of highway construction.

System implementation functions

(1) The software is composed of monitoring center, field sub-control station, GPS reference station, network system and roller device monitoring terminal, etc. It mainly realizes the following functions:

(2) The digital model of highway section is established, and the rolling parameters and rolling area are monitored in real-time based on the digital model. Dynamic monitoring of subgrade rolling machinery track, speed and rolling height.

(3) Real-time automatic calculation and statistics of subgrade at any location of the rolling times, compaction thickness, etc., and in the subgrade construction digital map visualization display, at the same time for online query.

(4) When the roller is overspeed, the system automatically sends alarm information to the operator, site supervisor and construction management personnel. When the number of rolling times and compaction thickness are not up to the standard, the system will prompt the detailed content and the location of the coordinates that are not up to the standard, which will be reflected in the software platform of the control system, so as to timely instruct adjustment or rework, and write the alarm information into the construction abnormal database for future reference.

(5) After the construction of each layer, graphic report of rolling quality is output, including rolling track chart, rolling times chart, compaction thickness chart and compaction elevation chart, etc., which are used as auxiliary materials for quality acceptance.

The rolling quality information of all construction sections during the construction period is saved to the network database.

3. Display system

3.1 Rolling speed status

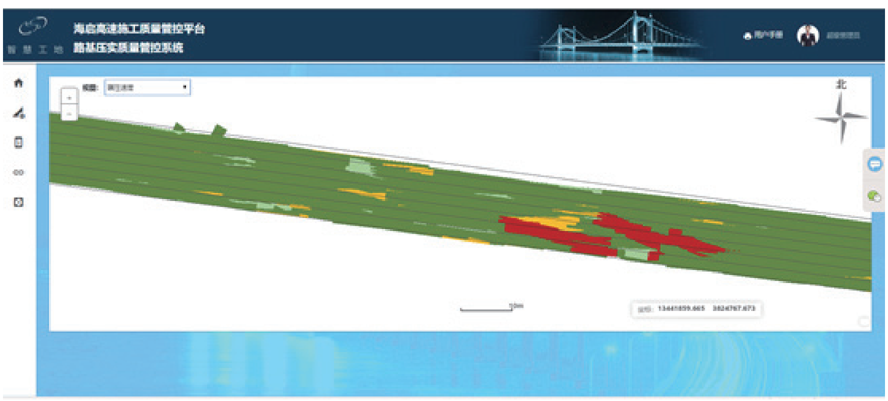

Figure 4 Rolling speed

3.2 Rolling times state

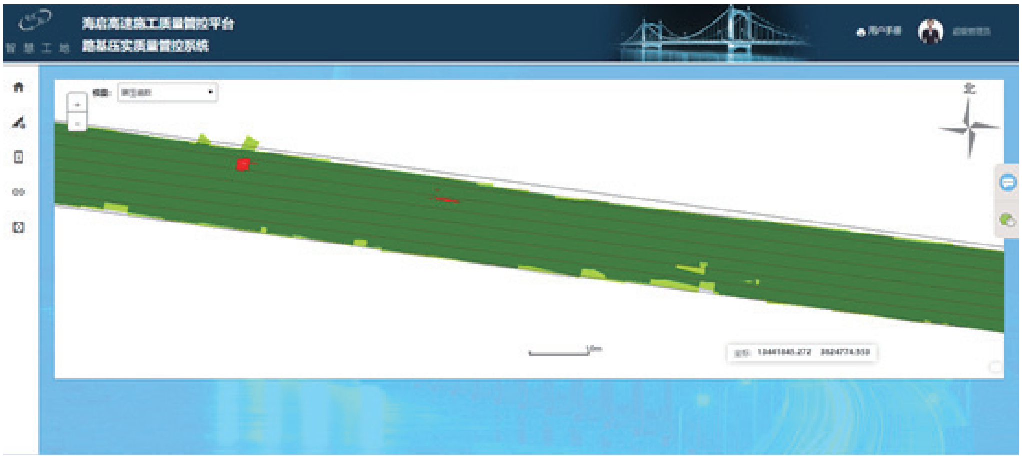

Figure 5 Rolling times

3.3 Compaction quality report

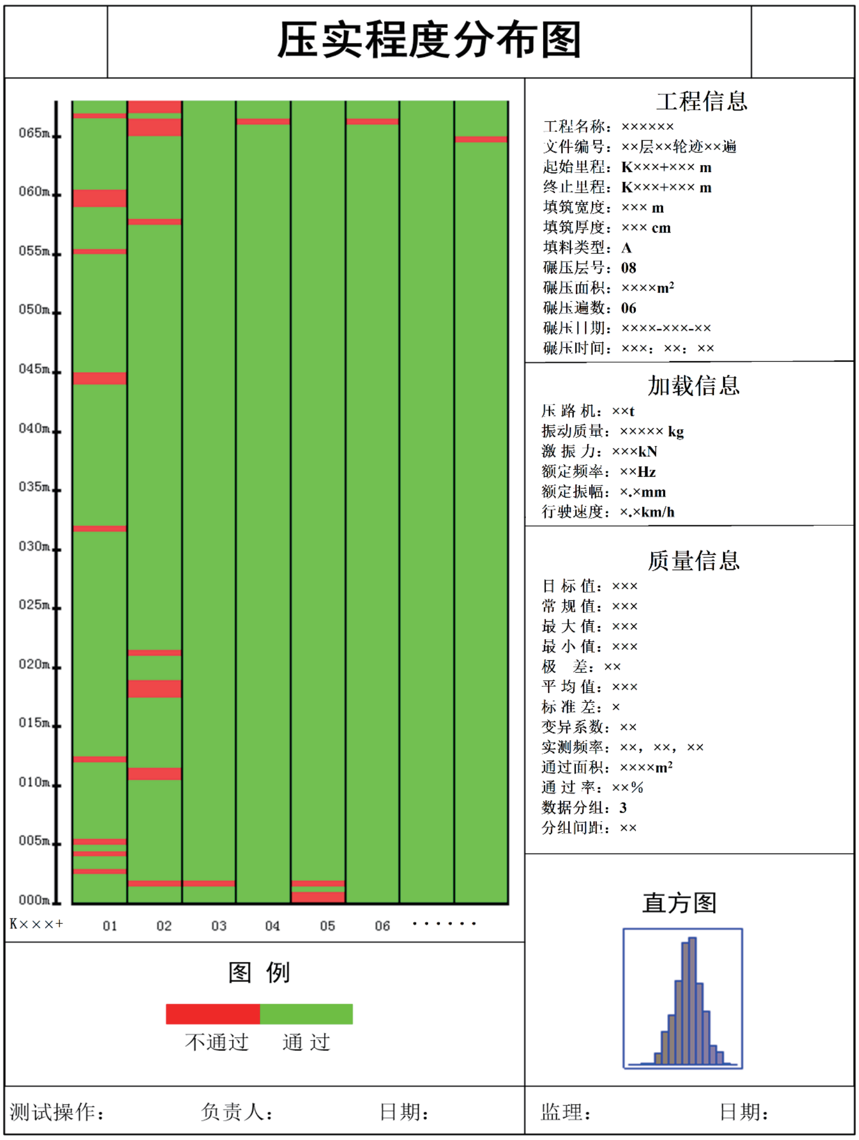

Figure 6 Compaction quality report

4. Social and Ecnomic Benefits

4.1 Ecnomic Benefits

Asphalt pavement is now the main form of highway pavement structure in China. Beacause of the insufficient bearing capacity of subgrade, net-shaped cracks, longitudinal cracks, subsidence rutting and other diseases appear. Pavement damage directly affects the safety of driving and leads to traffic jam. From the research, it shows that once the degree of compaction increase by 1%, the modulus of resilience of earth subgrade increase by 2.5%, thus we can know that the increase in degree of compaction will obviously increase the strength of the earth subgrade and improve the service life of the subgrade. For Expressways and Second Class highways, 1% decrease of the degree of compaction will lead to 0.5 years decrease in road life. For Expressways, the design life decreases by 3.3% for 15 years, for Second Class highways, the design life decreases by 4.2% for 12 years, and for tertiary highways, the degree of compaction decreases by 1%, the road life decreases by 0.3 years and the design life decreases by 3.8% for 8 years. This section takes expressway as the object of economic benefit analysis.

The cost of a single set of equipment in this system is 60,000 yuan, which can be reused many times (use 2 times as sample). Based on the calculation of 5 rollers on site, 5 sets of vehicle-mounted equipment are needed. The platform fee and maintenance fee of the expressway subgrade construction quality management and control system are 200,000 yuan per project. On calculation of half of the cost of a single set of equipment and the cost of system platform and maintenance, the total cost of the system is 5 x 3 + 20 = 350,000 yuan. According to the engineering experience mentioned above, it can be estimated that the economic loss is about 230,000 yuan per kilometer, accounting for 3.3% of the cost of road surface, for every 1% decrease in the degree of compaction of subgrade.

Table 1 Analysis of Influences of Subgrade Compactness on Full Life Cost of Asphalt Pavement

(Bi-directional and Six lane) Unit(10000yuan)

Cost per kilometer of Asphalt Pavement	The annual cost of a single kilometre based on 15-year life expectancy	The life of road that shortened once the compactness of subgrade is reduced by 1%	Economic loss per kilometer caused by 1% reduction of subgrade compactness
700	46	0.5	23

This set of Expressway subgrade construction quality management and control system can effectively reduce the economic losses caused by rework due to unqualified degree of compaction. Table 2 conservatively estimates the construction cost of subgrade per kilometre to be 380,000 yuan. If the loss caused by rework is considered, the rework cost per kilometre is 3080 yuan according to 1% rework rate. In the absence of this system, if the degree of compaction is increased by one percentage point by using this monitoring system, the benefit will be increased by 230,000 yuan per kilometer. Therefore, the total economic benefit of 10 kilometer long pavement will be (23+0.308)*10=23,308,000 yuan. The investment-benefit ratio (cost-effectiveness ratio) of the Expressway subgrade construction quality control system is 35/233.08=0.15.

Table 2 Estimation of unit price of subgrade construction(28m Wide) Unit(1000yuan/km)

Labor costs	Machinery fee	Charges	Construction cost per kilometre	Rework fee (Rework rate 1%)
5.6	5.6	19.6	30.8	0.308

4.2 Social Benifits

This compaction monitoring system focuses on process control, real-time display and record construction parameters such as rolling times, rolling quality, rolling detection date and time. In the construction process, real-time operation guidance is provided for the constructors. The constructors and supervisors can find out whether the construction process parameters meet the technical requirements of the construction specifications in real time, and correct the unsatisfactory operation parameters and operation modes in real time. They can do traditional detection in the compacted weak areas which will improve the qualified rate of one-time detection and save the cost of the inspectors. The use of this system can greatly improve the efficiency of compaction operation while ensuring the construction quality and by visual display interface, even drivers without rich construction experience can achieve precise control and shorten the construction time. It can also eliminate the rework caused by leakage pressure, less pressure and over pressure, reduce the waste of resources and time, and improve the quality of subgrade construction which can extend road service life and reduce the cost of later maintenance.

5. Conclusion

(1) Introduced the overall architecture design of the system and the hardware composition of the system, providing a basis for the development of the system.

(2) Starting from the function of the system, the whole process of monitoring data acquisition, storage and final application is analyzed, and the principle of system development and the development mode used in system development are put forward.

(3) The quality management and control system of expressway subgrade construction is developed. By inputting the thickness of construction loose and acquiring the ECV, rolling speed and rolling times in real time, the whole process of subgrade construction quality is controlled, and the remote real-time inquiry of rolling speed, rolling times and compacting quality can be achieved.

(4) Through the analysis of social and economic benefits, adopting the quality management and control system of expressway subgrade construction can bring remarkable social and economic benefits.

References

[1] Wu Yongping. Analysis of Intelligent Compaction Technology System[J]. Construction Mechanization, 2012, (6): 41-44.

[2] Gong Shutao. Development and application of real-time monitoring system for roadbed compaction quality of high-grade highway [D]. Tianjin University, 2014.

[3] Yu Liang, Zhang Zhiyuan. Discussion on GPS Measurement Technology in Road Engineering[J]. Science & Technology Vision, 2014, (4): 113-114.

[4] Tu Huiying, Pan Yinglong. Discussion on roadbed compaction[J]. Communications Science and Technology Heilongjiang, 2010, (11):31-33.

[5] Wang Haiyan, Yang Fangting, Liu Lu. Comparison and Application of Standardization Coefficient and Partial Correlation Coefficient[J]. The Journal of Quantitative & Technical Economics, 2006(09): 150-155.

[6] Jinsang Hwang, Hongsik Yun, Juhyong Kim. Development of Soil Compaction Analysis Software (SCAN) Integrating a Low Cost GPS Receiver and Compactometer [J]. Sensors, 2012, (12):2351-2353.

[7] Lee, H.K. An integration of GPS with INS sensors for precise long-baseline kinematic positioning [J]. Sensors 2010, 10:9424–9438.