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Research on the Data Collection Methods for Pavement Maintenance Based on the Internet of Vehicles

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Abstract. *Under the background of technology of Internet of Vehicles, many passenger vehicles of our country have been equipped with intelligent terminals with GPS, vehicle condition survey, wireless communication and other functions. Hence, it is easy to collect the road vibration data with an additional vibration sensor. Combining the road vibration data with GPS/Beidou Satellite positioning data, the average road vibration data chart can be generated, which can be used to forewarn the road maintenance authorities when such data is abnormal. The automatic pavement maintenance data collection method based on the Internet of Vehicles and its system architecture are put forward in this paper, and the vehicles' vibration characteristics are analyzed in different scenarios, including non-road excitation, smooth road excitation, broken road excitation and common road excitation. Experimental results show that this method is expected to effectively reduce the data collection cost and significantly improve the collection efficiency.*

Keywords: The Internet of Vehicles; Road maintenance; Data collection; Levelness; Automatic survey

1. **Introduction.** As the road traffic mileage of China enters the top list in the world, information collection has become one of the key issues with respect to pavement maintenance. Though remarkable achievements have been made in the establishment of pavement maintenance management system and information system, we still have a long way to go including detection methods of road maintenance, data collection, mining, analysis and application for information system [1]. In addition, with the increasingly extensive application of the Internet of Vehicles (IoV), most of passenger vehicles in China have been equipped with intelligent IoV terminals with the function of satellite positioning, vehicle condition detection, wireless communication and others. Because these passenger vehicles have the characteristics of wide coverage and relatively fixed routes, it is possible to collect road vibration data with the accelerated speed displayed on a gyroscope or additional vibration sensors. Combined with data from GPS/Beidou Satellite, the pavement maintenance data like average vibration charts can be generated, which may be used as the basis for early warning to the road maintenance department when abnormal information occurs and as reference for their decision on maintenance. By doing this, the majority of pavement maintenance data in China can be collected automatically, which is hopeful to improve the efficiency of maintenance and management for road facilities drastically, and reduce the detection cost meanwhile.

2. Latest Development of Pavement maintenance data Collection.

2.1. Latest Development of Pavement maintenance data Collection in China and Abroad. With the development and improvement of computer technology and automatic control technology, pavement detection technology has greatly developed, from manual to automatic, detrimental to scatheless, and low speed and accuracy to high speed and accuracy. Since the 1970s, many countries abroad have made a series of achievements on the study of detection system, such as Way Link developed by the Research Institute of Transportation, University of Arkansas (US), PAVUE developed by Road Traffic Research Institute of Sweden and Royal Institute of Technology (Sweden), Road Crack (a new survey system for pavement data collection developed by CSIRO Laboratory from Australia), and PSI (a multifunctional detection system for pavement data collection from America),etc [1]. Accordingly, detection system also has made great progress in domestic, such as CT-501A high-speed laser pavement detection vehicle from Chang'an University, SINC-RTM on-board, intelligent and automatic pavement detection system from Wuhan University and intelligent road detection vehicle from Nanjing University of Science and Technology [2–4]. Although all these detection systems vary in the detection technique and research method due to different requirements, but all realize several basic functions like analyzing the shape, roughness and damage degree of road by using pavement images from specific road testing car [5,6], but limited to the maintenance of high-grade roads. In addition, because of the constraints in geography, funds, demography and other aspects, the information of rural roads, which owns the longest traffic mileages, mainly relies on the manual patrol.

2.2. Main Problems. The problems in the application of mainstream pavement maintenance data collection methods are mainly as follows [7–10]:

1. Dependency on specialized detection vehicles and personnel;

The pavement maintenance data now is obtained by special detection vehicles or personnel, which may be difficult in the case of the absence of relevant personnel or special vehicles.

2. Expensive instrument and equipment, which are inapplicable to daily road maintenance;

The majority of special pavement detection vehicles and instruments are imported from abroad, which is expensive, trivial to maintain, and need high professional requirements on operators; additionally, the data processing equipment used in the office are to be separately procured, and the server be separately installed, which increases the cost and feasibility of a collection system.

3. The geographic location information in pavement maintenance data cannot be generated automatically;

4. It is impossible to collect data from all the countryside roads;

5. The integrated and rapid storage of pavement maintenance data and geographic location is unachievable due to the defects of existing pavement maintenance data in loading geographic location labels. Therefore, the mining of pavement maintenance data cannot be realized despite the current trend of big data mining.

2.3. Characteristics of Pavement Maintenance Data Collection System Based on the IoV. Generally speaking, the traditional information gathering solutions for pavement maintenance usually have several shortcomings like low efficiency and poor cost-performance. This paper proposes a method, which brings road users, common passenger vehicles into the pavement maintenance information system by using the technology of IoV to collect pavement maintenance data, especially road roughness, and provides data support and pre-warning for the road department in road maintenance. In addition, thanks to separation collecting terminal from processing terminal, it not only reduces the costs of information gathering, but also simplifies the equipment maintenance, which better adapt to the demand of the rural road maintenance, therefore.

1. Realizing the convenient and real-time collection of pavement maintenance data using the common passenger vehicles;

Different from the traditional scheme using special test vehicle to collect pavement data, the method in this paper, utilizing common passenger vehicles, has advantages in many aspects, such as convenient information collection, sufficient sample data, low collection cost and wide road coverage.

2. Realizing the storage and mining of a high volume of pavement data using the cloud computing platform;

Compared with the traditional pavement maintenance information system, the difference from the system provided by this paper lies in the information processing platform. The former usually tailors a corresponding processing platform for the project, however, the latter is inclined to use cloud computing platform to store and mine vast amount of pavement information. As the front terminal, a computer with the basic computing function and the Internet only are what it needs, which has incomparable advantages in erection practice, cost and the project replicability.

3. Realizing the pavement maintenance information services based on the location information;

Better than the traditional pavement maintenance information system that cannot provide location information, this method is proposed to provide pavement maintenance data based on GPS information by combining with the GPS information of common passenger vehicles, providing support in road maintenance decision-making.

4. Providing the real-time road network information including road maintenance diagnosis information.

Distinguish from the traditional pavement maintenance data system that only provides information for several particular roads, this method provides the maintenance information of roads passed by the common passenger vehicles using the pavement maintenance data provided by them and provides the real-time maintenance information of the entire road network.

3. **Architecture Design for Automatic Road Maintenance Data Collection System.** During recent years, combined wireless sensor, GPS with wireless transmission technology, the IoV technology has gained rapid developments, the combination of wireless sensor, satellite GPS position and wireless transmission technology brings some new application services. As shown in Figure 1, relatively stable road vibration waveform is formed by selecting the road vibration data of floating car on the driven route. The waveform could reflect the maintenance level of the road.

3.1. **Basic Structure of the System.** Basing on the IoV technology, information collecting system for road maintenance usually gathers maintenance information by pavement evenness detection equipment installed in the passenger vehicles. The system mainly consists of the *On-Board Road Levelness Feedback System* and the *Data Mining Processing System*.

1. On-board levelness feedback system

Road levelness could be taken as a standard for measuring the road maintenance level, and could also reflect breakage condition of pavement, especially bumps and hollows.

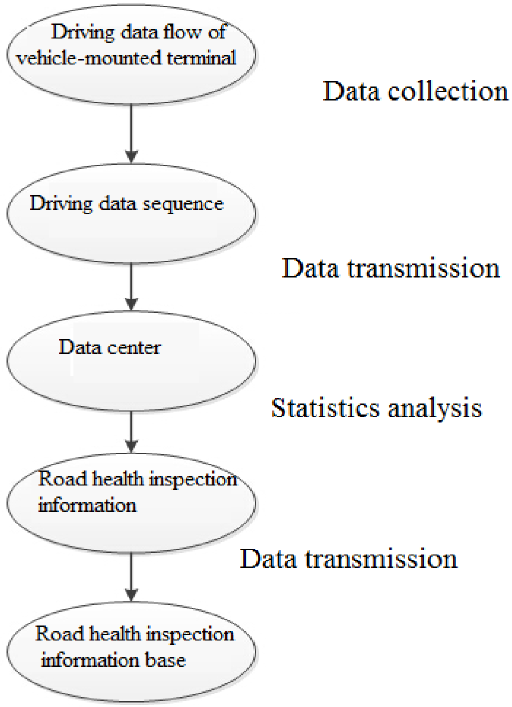


FIGURE 1. Flowchart of Collecting Method for the Information of Pavement maintenance

During research process, combined with on-board GPS, the system is able to generate roughness information rapidly by detection equipment collecting vibration information continuously.

2. Data mining processing system

The main point data mining processing system research is how to filter out interference factors, like: different vehicle types and capacities, and to obtain reliable information about road levelness after gaining the road basic data by the on-board system. Particularly, the system can comb the numerous data, produced during driving, and form relatively stable standard model for road levelness, finally produce warning information based on change of road levelness information timely when changes occur..

3.2. **Pavement Maintenance Data Collection Mechanism.** The vehicle itself is a vibration system with mass, spring and damping. Affected by uneven road, vehicle, a complex vibration system, could be simplified to a SDOF (single degree of freedom) system by only studying vertical vibration, namely Z-axis vibration of the vehicle, i.e,:

$$m\ddot{x} + c\dot{x} + kx = f(t) \tag{1}$$

m———mass
k———rigidity
c———damping
t——— time
$f(t)$——excitation function
$x(t)$——response function

When driving on specific sections (undamaged), suppose the excitation function f (t), when driving on deteriorated roads, random vibration g(t) is caused by the damaged road, then f(t) is :

$$\dot{f}(t) = f(t) + g(t) \tag{2}$$

The abnormal spectrum caused by damaged road could be filtered out by contrasting the vibration spectrum of driving on normal section and specific section.

3.2.1. *Calibration for measuring instruments.* When collecting pavement maintenance data, the *On-board Vibration Measuring Instrument* self-developed uses the vibration information collection equipment to obtain the acceleration data. The equipment could collect the acceleration data of three directions "X, Y, Z" and notes only takes on the Z axis only. The acceleration collection range of Z axis is ±4g (g is acceleration of gravity), the corresponding sampling value is -32768 to +32768, wherein 0 is the sampling value of 0g. Z axis of the measuring instrument shall be downward, thus, vehicle is only affected by acceleration of gravity when driving smoothly, and the collected acceleration is g, the corresponding sampling value is about 8192. If vehicle goes up or down suddenly during driving, hyper-gravity and hypo-gravity will appear in the Z axis, correspondingly, acceleration in Z axis will increase or decrease, and this is reflected on the change of the sampling value.

3.2.2. *Collection of vibration data.* During driving, the vibration collection equipment will return the vibration sampling value to data center at regular intervals (t). Vibration sequence $x_i =< t_i, A_i >$ could be gained based on the driving data, wherein i is serial number of vibration collection sequence, A_i is corresponding vibration value of t_i, acceleration of vehicle in Z axis (a_i) could be calculated out based on the sampling variation ($\Delta_i = A_i - 8192$):

$$a_i = (\Delta_i/8192) * g \tag{3}$$

i is the serial number of vibration collection sequence. By analyzing vibration sampling spectrum, instantaneous acceleration variation (a_i), threshold value (a_0), vibration sampling value variation (Δ_i) and threshold value (Δ_0) under different road affection could be calculated out.

3.2.3. *Collection of GPS data.* During driving, the GPS collection equipment will return the location, velocity and direction and other driving data of the vehicle back to data center with T time interval. Driving track sequence $X_i =< T_i, l_i >$ could be gained based on the driving data, wherein I is serial number of GPS collection sequence, l_i is location of vehicle at T_I, the driving path $path =< T_I, R_m >$ could be gained by matching the driving track sequence X_I and road network data set R, wherein R_m is the matched section at l_I time.

3.2.4. *Matching vibration data with GPS data.* As vibration collection and GPS collection belong to two different collection systems, and collection time interval is different ($t < T$), matching shall be conducted for vibration sampling sequence x_i and GPS sampling sequence X_i, thus obtaining driving data sequence $M_i =< t_i, \Delta_i, l_I, R_m >$, wherein $t_i \in [T_I, T_{I+1})$.

3.2.5. *Vibration data analyzing process.* Vibration sampling data Δ_i extracted from the driving data sequence M_i is more than location information l_I of the vibration threshold value Δ_0 and section R_m, and road grade $\delta_m(\delta_m = \sum_{i=1}^{n} \delta_{\Delta_i})$, of updated section R_m, wherein δ_{Δ_i} is the corresponding weight of Δ_i. The threshold of distress rating δ_i could be obtained based on the experiment for specific sections, if $\delta_m > \delta_s$, the road is deemed as damaged, and the distress rating is s, and at last, show differently rated sections in the road maintenance map with different colors.

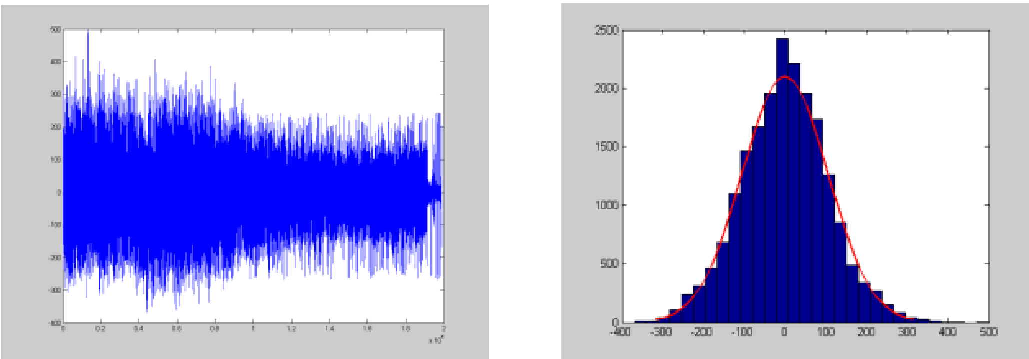
4. **Experiment and Data Analysis.**

4.1. **Analysis of Vibration Data.** In the experiment, Bus No.308 of Fuzhou Minyun Public Transportation Co., Ltd is used for data collection, which installs tri-axial acceleration meter researched and developed independently, among which, Z-axis is perpendicular to chassis while X-axis and Y-axis is level to chassis. Road vibration spectrum information and Vehicle GPS information can be collected when the vehicle is traveling.

(1) Data analysis when vehicle in the idle state

When the vehicle is under idle state, sampling vehicle vibration value without road excitation can be collected.

In the experiment, let Bus No.308 in idle state for 30 minutes, and collect sampling value of the vehicle vibration system road excitation. And then Vibration Spectrum, sampling frequency distribution histogram and probability distribution function curve of vibration system can be acquired, as shown in Figure 2.a and Figure 2.b. It is thus clear that under the condition that the confidence level is 0.95, and there is no road excitation, the sampling value of vehicle vibration system $|\Delta_i| < 500$.



(a) Vibration Spectrum (b) Probability Distribution

FIGURE 2. Vibration Characteristic under the State without Road Excitation

(2) Data analysis for vehicle travelling on the smooth pavement

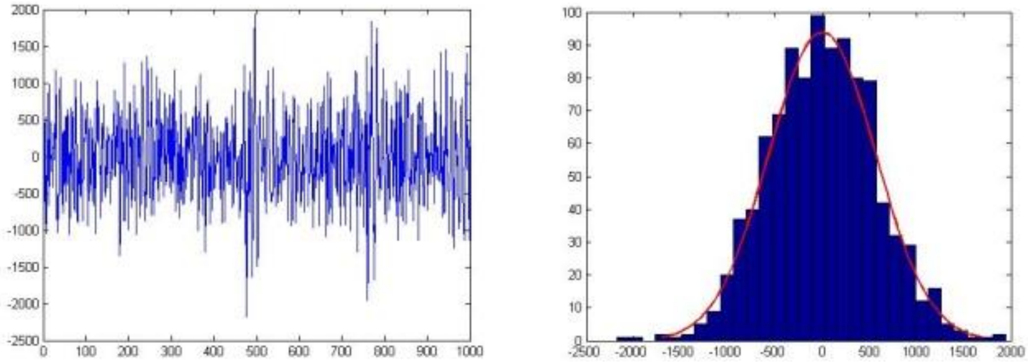
When travelling on the smooth pavement, in addition to the excitation produced by the vibration system, the vehicle also has the excitation caused by smooth pavement on it.

To collect excitation of smooth pavement, the new-built Mingde Road in the University Town is chosen for the experiment, to collect the sampling vibration value of Bus No.308 traveling on the smooth road. Vibration Spectrum, sampling frequency distribution histogram and probability distribution function curve of vibration system can be acquired. As shown in Figure 3.a and 3.b, it is thus clear that under the condition that the confidence level is 0.95, and with smooth road excitation, the sampling value of vehicle vibration system $|\Delta_i| < 2000$.

(3) Data analysis for vehicle traveling on damaged road

When travelling on the damaged pavement, in addition to the excitations produced by vibration system and smooth road, the vehicle also has the excitation produced by damaged pavement on it..

A damaged road is chosen for the experiment. Bus No.308 passes through a gully repeatedly at speed of 60km/h, collecting the 6-second variation sampling values before and after the bus passing through the gully, about 100 items in total. Sampling threshold vibration value may be acquired by analyzing sampling vibration values for the vehicle passing though the gully. Figure 4 shows the vibration spectrum of the Bus No. 308



(a) Vibration Spectrum (b) Probability Distribution

Figure 3. Vibration Characteristic under Smooth Road Excitation

when it passes through the gully for four times. It is thus clear that when the bus passes through the gully, the instantaneous amplitude $|\Delta_i| > 4000$.

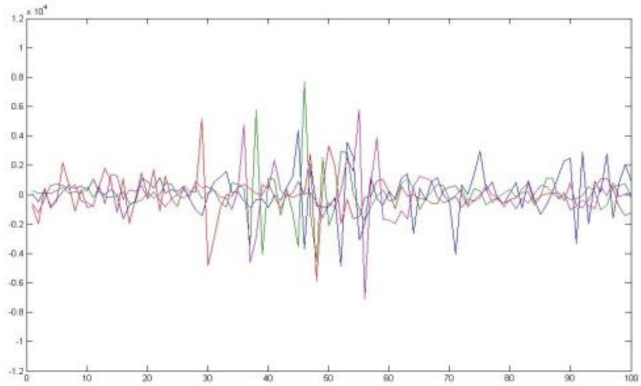


Figure 4. Vibration Spectrum When Passing through the Gully (four times)

(4) Data analysis for vehicle travelling on the common pavement.

When a vehicle traveling on a common road, road excitation consists of smooth road excitation and damaged road excitation.

The experiment collects daily operational data of the Bus No.308. Because the operational route of the bus is fixed, and all roads are common pavement, including information of damaged pavement. Abnormal vibration data of the vehicle can be separated and acquired by analyzing vibration spectrum when it travels on the damaged pavement. Figure 5 shows the vibration spectrum of the Bus No.308 for one operation.

Known from the experiment analysis of smooth pavement, the sampling varied vibration value within the range of the two red lines in Figure 5$\Delta_i < 2000$, that is to say the condition of road pavement is so good that need not to maintain. For amplitude beyond the range of the two red lines, it indicates that the road excitation plays a bigger role, that is to say the roads are damaged to different extents, and need tomaintain.

4.2. **Generation of Pavement Maintenance Data.** (1) Grading of abnormal vibration data

Only until the damage of pavement reaches to a certain level, the relevant department will carry out maintenance on the pavement. Therefore it is need to divide damages into different grades according to damage degree. In the experiment, abnormal vibration data

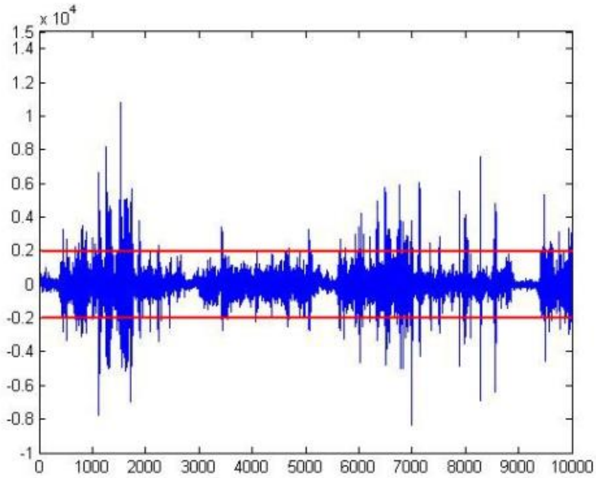


FIGURE 5. Vibration Spectrum under Common Pavement Excitation

has been divided into two classes, Class I is slight damage $4000 > |\Delta_i| \geq 2000$, Class II is damaged road $|\Delta_i| \geq 4000$, and different classes are endowed with different weights

The operational route of the Bus No.308 can be obtained from GPS information. Then generate operation sequence by matching vibration data and GPS. Coordinate position and road section corresponding to the abnormal sampling vibration value can be acquired directly. Analyze one-week operation data of Bus No.308 and generate road network maintenance data.

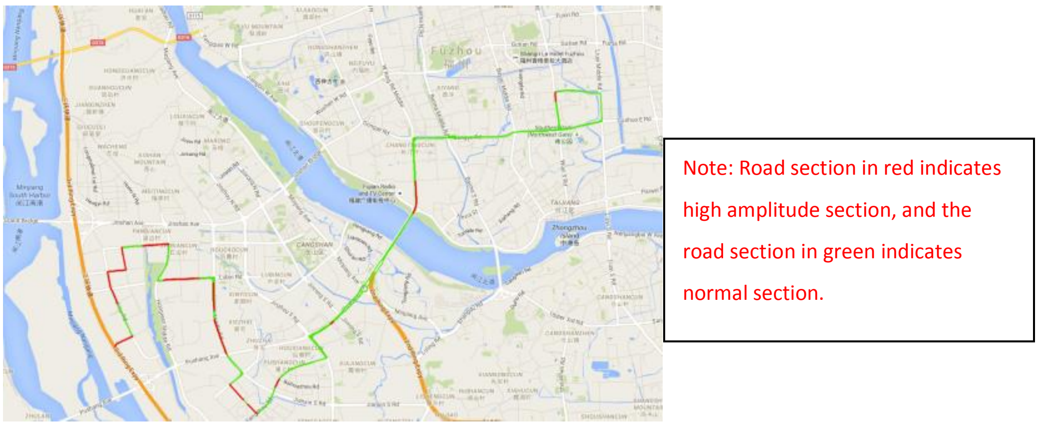


FIGURE 6. Schematic Diagram of Application Effect of Road Maintenance Condition

Combining measured data with layer, the results are shown in Figure 6. Abnormal amplitudes appear in several places including Jinju Road, Jianxin Middle Road, the ends of Youxizhou Bridge in second ring, etc. After field reconnaissance, many potholes are exist on Jinju Road and Jianxin Middle Road; In addition, as for Youxizhou Bridge in Second Ring, due to abutment's large gap, it is easy to reform 'skip' and result abnormal vibration. And what worth mentioning is that all test results are in conformity with actual situation.

5. **Conclusion.** Passenger vehicles are users of roads and also the ones providing road condition feedbacks. Through vibration characteristics of the passenger vehicle, the paper analyzes excitation of unpaved, smooth, damaged and normal roads, and makes a systematic study of the method for dynamic generation of pavement maintenance data.

The experiment results indicate that the method is feasible, and it may reduce the cost of pavement maintenance information collection and improve data collection efficiency. In addition, similar methods may also be applied to relevant fields such as air quality testing along roads.

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