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EMBEDDED MACHINE FOR MEASURING PAVEMENT DEFLECTION BASED ON LPC2214

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ABSTRACT

In order to improve precision and efficiency of measuring pavement deflection in the transport area of China, a measuring machine based on embedded operating system μC/OS-II is designed with LPC2214 MCU. In the design, wireless communication technology, embedded technology, filter technology of software and hardware, anti-jamming technology and other advanced technologies are applied. The machine is divided into two parts: main-machine and sub-machine. The former is used to measure voltages from laser displacement, which will be sent to main-machine from wireless communication channel. The lather is used to calculate, store, display and print the deflection value. All the deflection heights and results will be sent to PC, which can be processed in further. Based on the machine, many experiments are carried out on different highways. The experiment results showed that error of road deflection was below 0.01mm and consuming time for each test was about 60 seconds.

Keywords: *Road Deflection, μC/OS-II, LPC2214, NRF24L01*

1 INTRODUCTION

Until the end of 2010, China's highway has covered about 65,000 kilometers, only next to the United States of America. Because the safety and comfort of passengers is decided by road, all the countries are very particular about road's targets. There are mainly three important targets for a road: road roughness, height of rut and pavement deflection. The first two are static targets, which reflect the actual working situation of road. The last one is a kind of dynamic target which characterizes bearing capacity of road. Pavement surface deflection measurements are the primary means of evaluating a flexible pavement structure and rigid pavement load transfer. Many characteristics of a flexible pavement can be determined by measuring its deflection in response to load [1]. For a newly constructed road, pavement deflection is the most important target to be checked. Therefore, how to measure the road deflection with high precision and efficiency is focused on by all the people in the transport area.

There are three broad categories of deflection testing equipment: static deflection equipment, steady state deflection equipment and impact load devices. Benkelman Beam, a kind of static deflection equipment, is a simple device that operates on the lever arm principle. The Benkelman Beam is used with a loaded truck. Measurement is made by placing the tip of the beam between the truck's dual tires and measuring the pavement surface rebound as the truck is moved away. The Benkelman Beam is low cost but is also slow, labor intensive and does not provide a deflection basin. Road rater, a kind of steady state deflection equipment, measures the dynamic deflection of a pavement produced by an oscillating load. The main advantage of such equipment can measure a deflection basin. But the cost of road rater is too high. Falling weight deflectometer (FWD), the most common type of impact load devices, delivers a transient impulse load to the pavement surface. The subsequent pavement response (deflection basin) is measured by a series of sensors. The FWD can either be mounted in a vehicle or on a trailer and is equipped with a weight and several velocity transducer sensors. To perform a test, the vehicle is stopped and the loading plate (weight) is positioned over the desired location. The sensors are then lowered to the pavement surface and the weight is dropped. The advantage of FWD over a steady state deflection measuring device is that it is quicker, the impact load can be easily varied and it more accurately simulates the transient loading of traffic. But it damages to the road surface, shortening the

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life of road [2, 3]. In China, Benkelman Beam is widely applied to measure pavement deflection.

The machine designed in this paper, comprising of main-machine and sub-machine, can measure not only pavement deflection, but also deflection basin. Laser beam is applied to measure deflection instead of lever arm, from which the radius of deflection basin can be expanded over than 10 meters, higher than the above equipments. All the functions, such as calculating pavement deflection, getting radius of deflection basin, saving record, printing results and so on, are accomplished automatically by MCU. Also, all the measuring data can be transmitted into PC, which can be further processed. Only one person, spending only 1 minute for each sampling measurement, is required to measure deflection if such kind of machine is used. Moreover, there are many other advantages for this machine, such as small volume, light weight, high measuring precision, easy to carry, low cost and so on.

2 WORKING PRINCIPLE OF MACHINE

A truck with 10-ton load stops on the test road. The sub-machine is set between the back dual tires. The main-machine is placed on the road 10 meters away from the sub-machine, which is the radius of deflection basin. A laser beam produced by main-machine beats to the sub-machine. When truck moves forward as the arrow direction, the sub-machine will move upward from position A to position B along with road surface. The displacement difference between position A and position B reflects the real rebound value of road surface.

The displacement difference multiplied by a stationary parameter is the real pavement deflection. In order to decrease the influence of temperature changing, double optical tablets technology is applied in the sub-machine design. During the test, sub-machine converts the two voltages from sensor and sends them from wireless channel to the main-machine when a sample signal happens every 1 second. The main-machine calculates the pavement deflection value based on the values of voltages received from sub-machine. And then the following operation will be achieved automatically, such as printing in real time, displaying from LCD, communicating and so on.

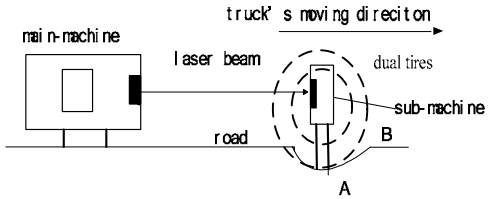

Figure 1: Working Principle Of Machine

3 SUB-MACHINE DESIGN

The sub-machine, placed between the back dual tires of truck, converts voltages from sensor and transmits them to the main-machine, which is composed of CPU unit, laser sensor unit, AD convertor unit, wireless communication unit.

CPU unit

In order to decrease the total power consumption, MSP430F1121 is used to design sub-machine. MSP430F1121 with 256 byte RAM and 4Kb FLASH, made by TI Corp., has many advantages, such as ultra-low power consumption, powerful data processing ability, multiple internal register, many addressing modes, concise instruction set and a lot of peripheral elements [3]. With such kind of MCU, providing program storage of Flash and JTAG technology, it is easy to develop product and program online.

Laser sensor unit

Laser sensor unit is made of laser displacement sensor (NY-101), which can convert the laser position into two voltages from 1V to 2V. The height of deflection at each sampling time is calculated based on the above voltages, from which the final deflection value and the total diagram of deflection basin will be drawn. Each height of deflection is calculated as the following formulas:

$$h=\frac{A}{B}\times\left[(2.5-A)\times 1.82+8.2+(35-T)\times 0.03\right]\times(1+|A|\times 0.05) \quad (1)$$

$$A=V1-V2 \quad (2)$$

$$B=V1+V2 \quad (3)$$

In Formula 1, 2 and 3, h is the deflection height at each sampling point (mm). V1 is the up voltage from displacement sensor (v). V2 is the down voltage from displacement sensor (v). T is the real temperature (℃).

AD converter unit

AD converter unit is made of ADS8341, which is a kind of successive approximation 16-bit AD

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converter. There are 4 input channels in ADS8341, among which two channels are used to convert the two voltages from sensor [4]. There are a lot of advantages for ADS8341, such as low power consumption, simple interface, high converting speed, and so on. So it is very suitable for connecting to MSP430F1121.

Operation amplifier OPA2277 is applied in this unit, which is designed as a kind of voltage follower [5]. The two voltages from 1V to 2V are connected to OPA2277. The outputs of OPA2277, whose voltages are equal to the input, are connected to input pins of ADS8341. The reference voltage of ADS8341 is 2V according to the real application. All the signal acquisition is accomplished by programming several pins of MSP430F1121, such as IC_CLK, IC_CS, IC_DIN and IC_DOUT.

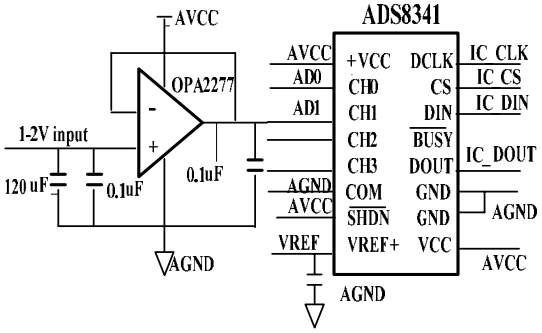

Figure 2: Ad Convert Unit Of Block Diagram

Wireless Communication Unit

From contrasting communication distance and error rate for several kinds of wireless modules, NRF24L01 is chosen as the wireless communication unit in the design. NRF24L01, working in ISM global frequency-2.4Ghz, has internal antenna, whose highest working frequency is 2Mbps [6]. Each NRF24L01 can be set different address in order to make communicate with the aimed sub-machine correctly. SPI bus is the interface between NRF24L01 and MSP430F1121, which is shown as the Figure 3.

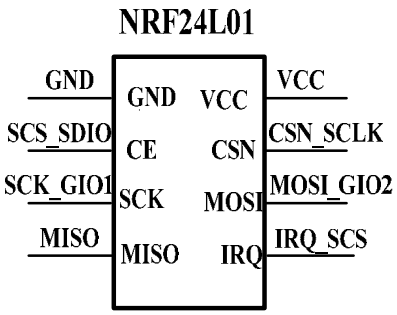

Figure 3: NFR24L01 Block Diagram

4 MAIN-MACHINE DESIGN

Main-machine is used to r transmit laser, receive wireless data, calculate deflection value, store data, communicate with PC and other functions, which is located at the distance of deflection basin radius away from the sub-machine. The main-machine is made of CPU unit, human-machine interface unit, data storage unit, communication unit and so on

CPU unit

In order to decrease the total power consumption, LPC2214 is used to design main-machine. LPC2214 is based on a 32 bit ARM7TDMI-STM CPU with real-time emulation and embedded trace support, together with 256kB of embedded high speed flash memory [7]. With their compact 144 pin packages, low power consumption, and up to 9 external interrupt pins, LPC2214 is particularly suitable for industrial control, medical systems, Access Control Unit and point-of-sale and so on. 256 Kb on-chip Flash Program Memory is used to store application program and embedded operating system μC/OS-II. With In-System Programming (ISP) and In-Application Programming (IAP) via on-chip boot-loader software, it is easy to finish software design.

Human-machine interface unit

Human-machine interface unit is made of LCD and keyboard, which is designed to exchange information between human and machine. Dot-array LCD is used to display Chinese, ASCII, number, picture and other information. Keyboard of 4*4-matrix is used to set configuration parameters and select working mode, working parameters and so on.

Data storage unit

Data storage unit is mainly made of SST39VF160 and PCF8563, which are designed to store important data and get real time information.

SST39VF160, a kind of 16 million bits flash memory, is used to store all the information for each test unit including road name, deflection radius, final deflection value, deflection height at each sampling time and so on. Data stored in SST39VF160 can be saved for over than 100 years when it loses power.

PCF8563, a kind of clock chip based on I2C bus, is applied to provide time and date information, which is very important to save the record [8].

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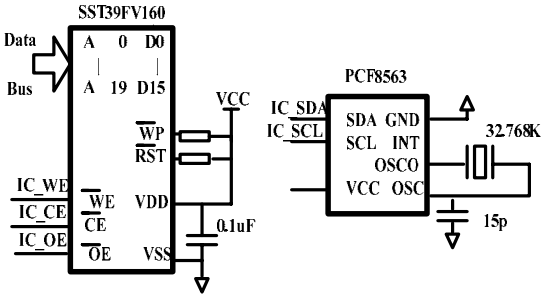

Figure 4: Data Storage And Time Unit Of Block Diagram

Communication unit

Communication unit is divided into two parts: wireless communication and wire communication. The former, responsible for receiving wireless data from sub-machine, is made of NRF2401, whose hardware design is the same as sub-machine.

The latter is responsible for not only communicating with PC but also printing data in real-time with serial-printer. Both functions are achieved through RS232 interface. Therefore, MAX202 chip, with two RS232 channels, is applied in the machine.

UART0 and UART1 of LPC2214 are connected to TXD00/RXD00 and TXD11/RXD11 of MAX202 respectively. TXD_0/RXD_0 and TXD_1/RXD_1 of MAX202 are connected to PC and micro-printer, which is shown as Figure 5.

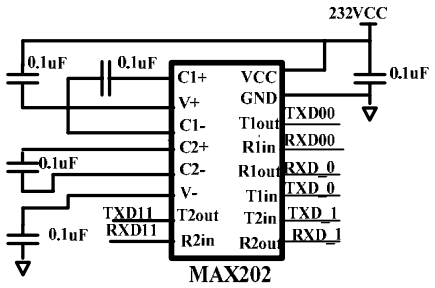

Figure 5: Communication Unit Of Block Diagram

5 SOFTWARE DESIGN

Transplantation of μC/OS-II operating system

Embedded operating system of μC/OS-II is applied in software design, whose code is open and programmed by standard ANSIC language [9]. So, it is very easy to transplant into LPC2214.

μC/OS-II operating system can be divided into 4 parts, that is application code, μC/OS-II set code, μC/OS-II key code, μC/OS-II transplantation code [10]. All the transplantation of μC/OS-II operating system are to program the above four kinds of codes. Structure of application code based on μC/OS-II operating system is shown as figure6 .

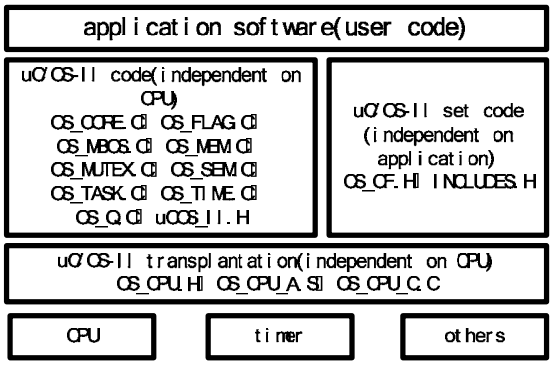

Figure 6: Mc/OS-II Structure

In order to make every unit of main-machine run harmoniously, system software is divided into several tasks, every one of which accomplishes specific function.

Begin-task is designed to initialize all the chips of main-machine and establish other tasks, which is made by main function.

```
int main (void)
{
    ……
    OSInit();   // initialize
    OSTaskCreateExt(Begin-task, (void *)0,
&task0_stack[2999], TART_PRIO,
    START_ID, &task0_stack[0], 3000, (void *)0,
0);// stablish task
    ……
    OSStart();  //start multi-task operation
} ;
```

Pavement-Count-Task is programmed to calculate deflection, in which the final deflection value is calculated based on the wireless data. Each deflection height can be calculated as Formula 1.

Communicate-Task is programmed to communicate with PC and micro-printer, from which all the test data can be processed in further.

Human-Machine-Task is programmed to display results, deal with keyboard, store test record and other operation.

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Design for application program

It can be seen from the above tasks that Pavement-Count-Task is the main code of application program, which will be produced in detail as the following contents.

The truck moves at the even speed of 3Km/h. The deflection basin radius is supposed as 10 meters [11]. According to real requirement, 40 sampling points is set during test, which means the interval time between two sampling points is about 0.25 second. For NRF2401 module, 0.046 second is needed to communicate with main-machine and sub-machine at each time. So, 5 times communication between the two machines can be achieved at each sampling point, from which filter function can be applied to develop accuracy of test. The key flow chart is shown as the Figure 7.

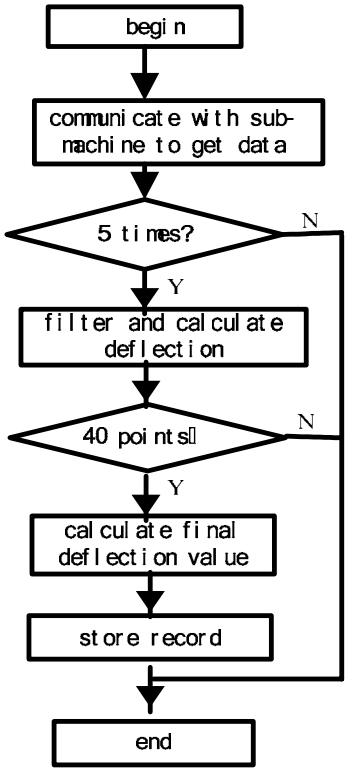

Figure 7: Flow Chart Of Key Program

6 EXPERIMENT DATA AND ANALYSIS

On September 27 of 2011 , the machine is applied to measure pavement deflection value on Xi'an-Tongchuan highway at the same position. The highway was completed in 1989, whose surface is very hard. The standard pavement deflection value is 0.366mm at this point. Measure the deflection value with such machines for 10 times at the same point, whose results is shown as table I.

Table I: Pavement Test Results On Real Highway

Sequence Number	Final Deflection Value (Mm)	Consuming Time (S)
1	0.370	60
2	0.359	59
3	0.365	58
4	0.373	57
5	0.371	60
6	0.366	58
7	0.358	59
8	0.358	60
9	0.376	59
10	0.357	55

The results show that test error of deflection value is less than 0.01mm. The consuming time for each measurement is within 60 seconds. The difference among consuming time for each measurement is mainly caused by different time of aiming laser before the truck is moving forward. It is well known that laser's transmission in the air is influenced by temperature, humidity, atmosphere pressure, air flow and other parameters. So, all above parameters should be measured to revise the final result in order to improve precision.

7 RESULTS

Embedded technology, wireless communication technology, displacement sensor of laser is applied in both main-machine and sub-machine to solve a lot of problems during measuring pavement deflection value.

The size of main-machine is 40cm×30cm×30cm, whose weight is 2.5Kg. The total power consumption is less than 30W. The price is only a tenth of the same product abroad. μC/OS-II operating system is applied in the design to manage all the tasks, from which the real-time problems during traditional operation can be resolved. The accuracy and efficiency has been developed greatly. The machine is at the market promotion stage now.

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