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Design of an Intelligent Bridge Structure Health Monitoring System

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Abstract. This paper designs an intelligent bridge structure health monitoring system (BSHMS) based on ZigBee wireless sensor network. Based on 3G wireless transmission technology and ZigBee technology, it serves as a wireless monitoring platform with a multi-level network architecture composed of data acquisition node, centre node (gateway) and remote server. In this paper, system hardware circuit and software system are redesigned, CC2530 is applied in the Contiki operating system. Then, various modules of the entire system are tested and debugged online. The test shows that the system can run stably and capture various data accurately before transmitting it to the rear server, thus meeting the design requirements.

1. Introduction

As the throat and junction of ground traffic, bridges are frequently eroded and deformed due to long-term traffic loads and damaged by nature factors, further affecting its bearing capacity, normal usage or even endangering vehicles or people on them (Adhikari et al., 2014). Therefore, BSHMS is of great social, economic and scientific significance.

In special weather or under specific traffic conditions, the bridge service condition, reliability, durability and carrying capacity are intelligently assessed through non-destructive bridge structure diagnosis and warning signals will be sent in case of serious abnormalities, providing guidance for maintenance and support for decision-making (Alampalli et al., 2008).

With the development of information technology, the monitoring system has also become more and more intelligent (Balocco et al., 2015). Technically, internet of things, wireless sensor network technology and big data analysis technology all facilitate the development of the intelligent real-time wireless BSHMS (Chen et al., 2014). Since wireless transmission and safety prediction are main trends in future intelligent monitoring system (Elzarka et al., 1999), in view of the composition and function requirements, we design the BSHMS as the further application of wireless sensor network technology in the new field.



2. Overall Design of the System

The system is designed like this: first, a wireless sensor node is designed to ensure the accurate acquisition of bridge data from the monitoring points; then, a wireless sensor network is automatically set up and data collected is sent through it to the center node, which finally transfers the data through Ethernet to the remote server for user's access (Li et al., 2016).

Thus, the ZigBee-based intelligent wireless road and bridge monitoring system is constructed with wireless sensor technology, ZigBee technology and 3G communication technology. It is composed of front data acquisition node, center node (gateway node) and server.

In this system, the front data acquisition node collects bridge structure data by its different sensors. The node is assigning unique network address based on the link layer address, which actively searches the next hop address for a shortest destination route. After the shortest and optimized network is constructed, the node will send the data received from the sensor module to the destination through it (Liao et al., 2016).

As hub of the whole monitoring system, the center node (gateway node) obtains data collected by each data acquisition node module, and transfers it to the rear server through 3G network after simple processing (Li et al., 2015), i.e. encapsulating data into IPv6 packets.

Once a data request sent from the remote login client is received, the master server will establish a connection with the client and send the data there (Metni and Hamel 2007).

Please refer to Figure1 for working principle of the intelligent BSHMS.

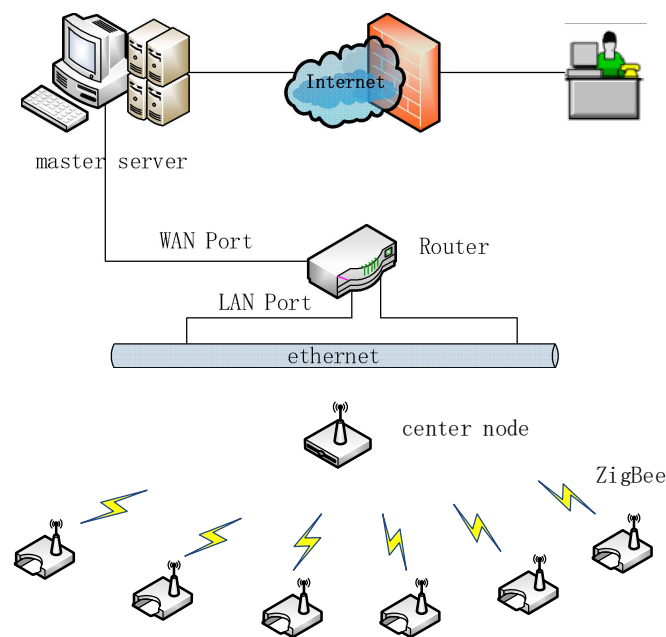


Figure 1. Block diagram of the system

3. System Hardware Circuit

3.1. Block Diagram of the Overall System

The system hardware circuit includes center node hardware circuit, wireless sensor node hardware circuit, and power supply system hardware circuit. Please refer to Figure2 for diagram of the overall system hardware.

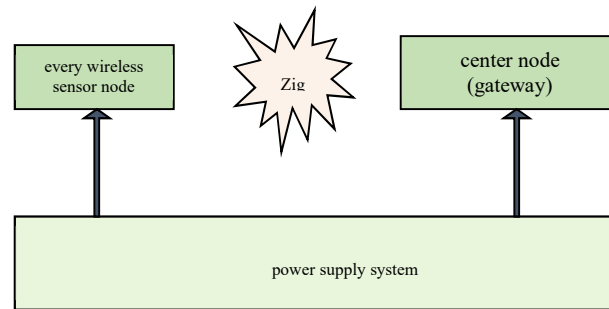


Figure 2. Diagram of the overall system hardware

3.2. Center node (gateway) hardware circuit

The center node(gateway) receives various data sent by wireless sensor nodes before transferring it through the 3G module to the rear server. It's hardware includes wireless communication module, master processing unit, and 3G module, as is shown in Figure3.

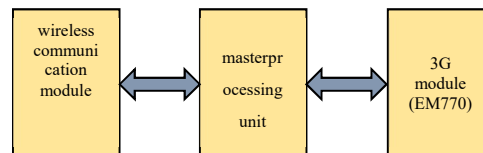


Figure 3. Center node(gateway) hardware structure

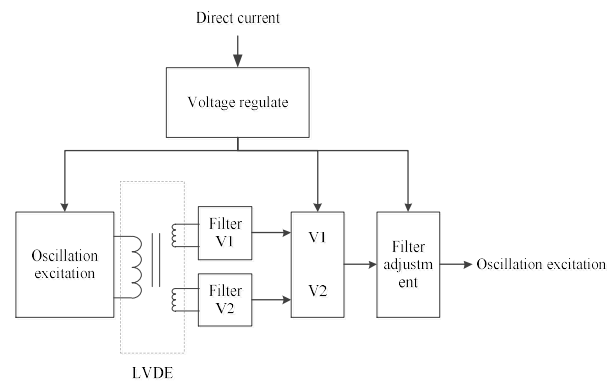
The wireless communication module is like a hub of the wireless sensor network in the center node(gateway) (Phares et al., 2004). It is applied for sending open or close instructions to each node at the front end, and collecting data received from each node. The master processing unit is mainly used to facilitate the normal operation of the center node, and maintain normal communication between the wireless communication module and the 3G module (Sommer et al., 1993). The 3G module is primarily used to establish connections with remote data servers for data transmission.

3.3. Wireless Sensor Node Hardware Circuit

Sensor nodes are deployed in different parts of the bridge to monitor relevant parameter changes. To be specific, wireless displacement sensor node is deployed in the pier and bridge board connection for bearing measurement (Rolander et al., 2001); wireless triaxial acceleration sensor node is deployed in each vault section for measuring the bridge vibration frequency; wireless tilt sensor node is deployed at L/4 point of each column for column slant measurement; and wireless temperature and humidity sensor node is deployed under the bridge surface for detecting the surrounding temperature and humidity changes.



(a) the sensor



(b) circuit connection diagram

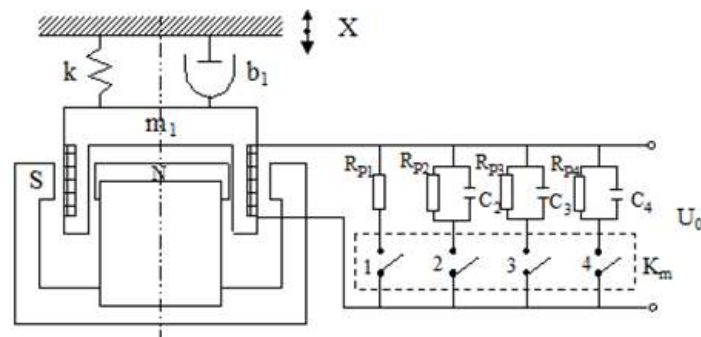
Figure 4. Diagram of MAS-LF500-Z hardware connection sensor

In the wireless sensor node, CC2530 chip is the core processing chip; and MAS-LF500-Z crack gauge/sensor is adopted in the joint expansion monitoring module for crack displacement measurement. Please refer to Figure4 for the sensor photo and its circuit connection diagram.

FS-ZD-SLP (Z) acceleration sensor whose typical hardware connections shown in Figure5 is applied in the vibration monitoring module.

A non-contact FS-HGC01 digital triaxial tilt sensors used as the tilt angle monitoring module for easier target tilt angle collection.

Finally, FS-WSD-01 digital sensor able to get calibration coefficient for OTP is adopted for temperature and humidity monitoring.

**Figure 5.** Hardware connection diagram of FS-ZD-SLP(Z)sensor

4. System Programming

The system programming is mainly used for automatic linkage of wireless sensors, seamlessly connecting the wireless sensor network with the Internet, and constructing a master server for user's remote access. Generally speaking, system programming is composed of center node programming, wireless sensor node programming, and master server programming.

4.1. Center Node Programming

Since the master chip S3C2440A of the center node (gateway) is embedded in the linux operating system, its chip programming is compiled and debugged by a GCC compiler to get a VMware Workstation (virtual machine) shell script. The center node programming comprises three main parts: the main control unit programming, the adaptation layer design, and the 3G module data transmission design. Its main program flow chart is shown in Figure6.

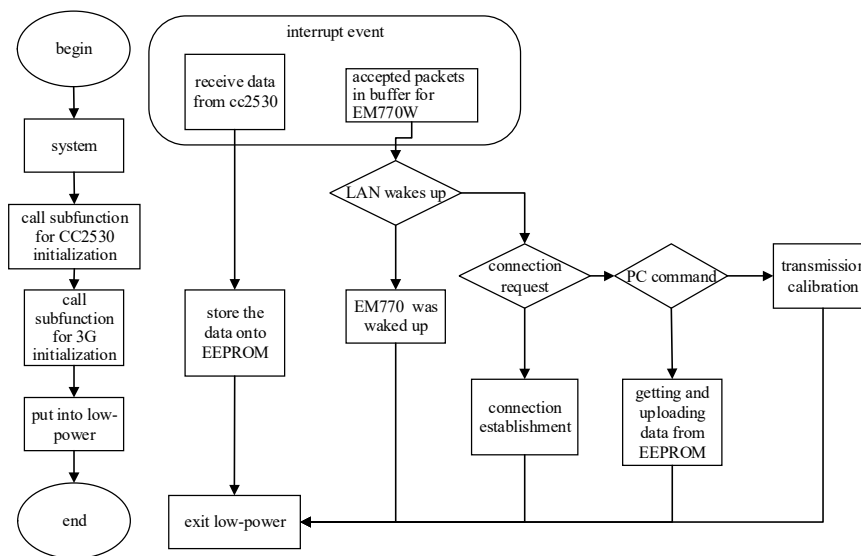


Figure 6. Main program flow chart

4.2. Sensor Node Programming

The sensor node programming is mainly used for communicating with the sensor module (Wu et al., 2016), automatic networking, and communicating with the center node. Here, the Contiki operating system and the IAR Embedded Workbench are applied as the operating system and the development platform respectively.

4.3. Master Server Programming

In this paper, B/S is chosen to build the software system. with Web server as a relay point, the client browser and database server are linked. In the design, whenever the user sends a request on the client browser to the Web server, the Web server will use the script engine to resolve the request and send a query instruction to the database. After receiving the query, the database will send back a result to the web server. The Web server then will transmit the results back to the client browser in HTML format. Thus, remote access to dynamic sites is realized.

This paper focuses on reaching the following two goals: (1) designing a reasonable database structure;(2) accessing the database through the Web server. The used three main functions are: “mysql_connect () function” for database connection, “mysql_select_db () function” for required database selection, and “mysql_query () function” for database operation. In order to verify the user’s identity and prevent unauthorized user’s access, user’s login information is sent to the database first for verification, and only those with registration information are permitted to access the database.

5. An Application Example

In this example, the entire system is constructed, and a variety of sensor modules indifferent communication methods are connected to the wireless nodes through ARM UART, while the main node and 3G module are linked to the system. First, we switched on all node modules of the system to automatically set up a network. After that, data was transmitted from each wireless sensor node to the CC2530 module in the center node(gateway) and then sent to the server via the 3G module. Finally, we logged in the client server on a PC to find out whether the corresponding data was transmitted back. Cloud platform interface is shown in Figure 7.



Figure 7. System debugging results

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