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Environmental Monitoring for Historical Heritage Based on ZigBee Wireless Sensor Networks and Z-Stack

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Abstract: Aiming at special requirements for wild historical heritage conservation, this paper utilizes a ZigBee-based wireless sensor network for this protection and establishes a Z-Stack-based historical environmental Monitoring System to achieve telecommunications on ZigBee network. In addition, the design for software and hardware and system management software of sensor node and gateway node will be introduced in detail. Compared with traditional protective system, this system has convenient extension, flexible networking, low cost and dynamic network monitoring. *Copyright © 2013 IFSA.*

Keywords: ZigBee, Z-Stack, Sensor Mode, Wild Historical Heritage Conservation.

1. Introduction

China has a long history with its vast territory, complicated topography and numerous historical interests, however, there are some problems are very serious such as cultural relic damaged, stolen. Hence, how to effectively protect and manage heritage is an enormous challenge facing Heritage management. Wireless sensor network is a combination of computer, communications, and sensor, widely used in industrial automation control, public safety, defense, and environmental protection, health care, industrial environment monitoring and home automation [1].

The ZigBee-based Wireless sensor network node with its small size, lower power, low cost and high extensibility can be properly applied to storeroom environment monitoring and security as well as structural health monitoring in ancient buildings. As for wild environmental monitoring, deploying the terminal nodes around the heritage in a suitable way can obtain the data of surrounding temperature, humidity, lighting and rainfall. It should alert monitoring centre that do not conform to the requirements in order to be processed in a timely manner; but for relics stolen, it can use acceleration sensor to measure vibration, if vibration anomalies, and then it alarms the monitoring centre to check if there any through-wall and burrowing acts happened [2]. Thus, this kind of heritage conservation can not only save the human sources, but also can solve the problems of centralized data processing.

This paper designs the environmental monitoring system of wild heritage conservation based on Z-Stack. Z-Stack is an embedded operating system (OS) with ZigBee stack developed by TI, which can monitor the wild heritage environment of vibration and abnormal sound, transferring data to ZigBee gateway by public channels such as 3G to realize the effective control and management of telecommunications and heritage sites.

2. Overall System Program

The system mainly consists of sensor nodes module, ZigBee gateway, 3G communication module and management software. According to the special

environment requirements, various sensor nodes and ZigBee gateway are chose to arrange in the site for ZigBee network construction. In this case, sensor nodes select the sensor based on the amount and requirements of protective area, forming a star or cluster-tree network based on node quantities and geographical distribution intensity, and also extending the sensor nodes in line with actual needs in system. Connected with 3G communication modules, ZigBee gateway can be acted as a ZigBee network coordinator and a function for ZigBee stack and 3G stack transformations to get the combination of ZigBee network and external network. External network sends the real-time environmental information through public channel such as 3G to monitoring centre. The management software in monitoring centre uses access and distribution models for client/server (C/S) data through networking management, database management and alarm information management in protected areas to achieve real-time monitoring. The structures of system are shown in Fig. 1.

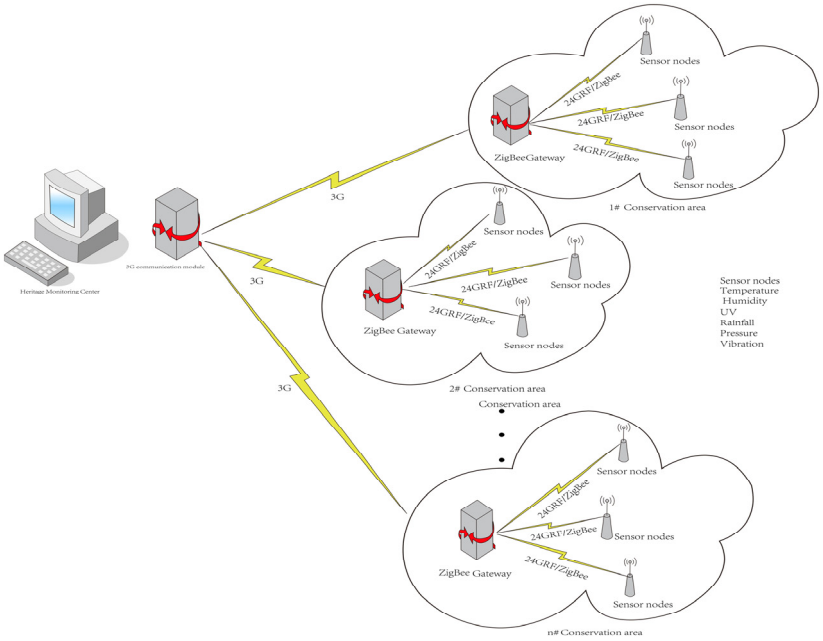

Fig. 1. Total structure of system.

3. Hardware Design

3.1. Sensor Node Design

Sensor nodes are placed on conservation site to collect environment parameters, whose hardware mainly contains a processor module, wireless communication modules, sensor modules, and power modules [1], as Fig. 2 shows.

3.1.1. Processors and Wireless Communication Module Design

In this paper, Processor modules and wireless communication modules use CC2530 produced by TI as core ships. CC2530 has integrated a controller core in an optimal low-power 8051 and a high-powered RF transceiver in favor of Z-Stack, which has two USART supporting a variety serial communications, two CSMA-CA State sensors as well as 21 general GPIO and 14-bit a/d converter to arrive the connection between CPU and various sensors. It is a RF transceiver for ZigBee and IEEE 805.15.4 applications and only needs to take the external capacitor inductor off board in RF-N and RF-P with a proper antenna forming wireless communication module, which simplifies the wireless module design. At the meantime, exclusive or standard compatible network for CC2530 can simplify the development. All these features can be available in monitoring wild environment. Fig. 3 shows its external circuit.

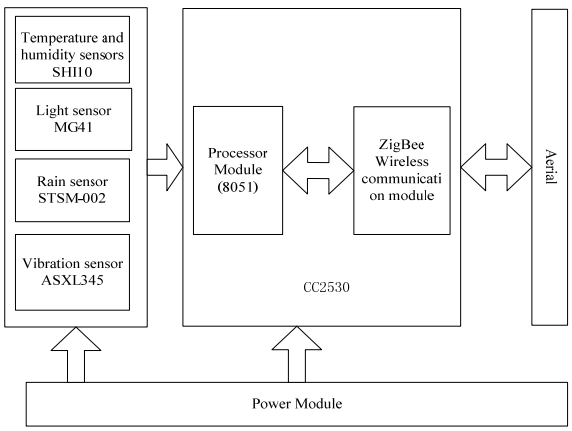

Fig. 2. The composition of sensor nodes.

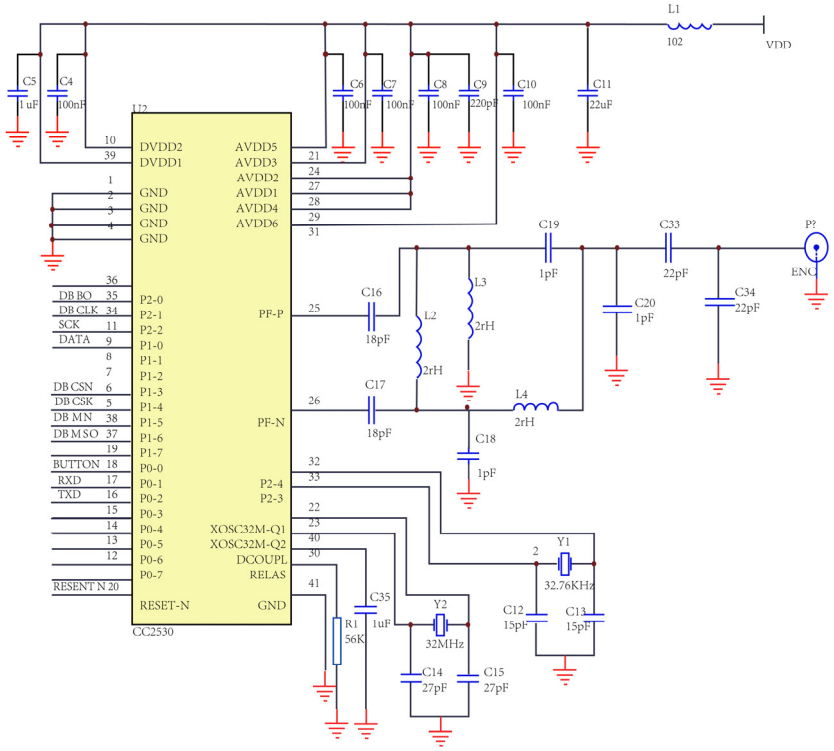

Fig. 3. External circuit.

3.1.2. Sensor Module Design

Based on the demands for heritage conservation, sensor modules collect its environment parameters including temperature and humidity, sunlight, rainfall and vibration. Temperature and humidity, sunlight, as well as rainfall are used to detect the reasonable range of air conditions, avoiding erosion and aging; in addition, vibration is for examining burrows and stealing, avoiding losses.

The internal part of SHT10 integrated temperature sensor ,humility sensor, a 14-bit A/D transciever and serial circuit through wireless network to collect data for temperature and humility in each protected area, which has a relatively high security, reliability and long-term stability. Besides, its voltage is 2.4-5.5 V, humid accuracy ±4.5 %RH, then the temperature accuracy is ±0.5 °C at 25 °C, which meets the needs for the measured accuracy in wild environment. When connected with CC2530, it just needs to combine the P1.0 and P1.1 in processor respectively with the data line DATA and clock line SCK of SHT10 with accessing a 10 kΩ pull-up resistor into DATA port, in order to transfer the signal into a high level and complete the data collection and transmission by relative software design. The application circuit is shown at Fig. 4.

The extent of damage at cultural relics is judged by UV through photoresistor MG41 on the basis of light intensities. This photoresistor has a long lifespan and long-term stability, and its dark resistance is equal or greater than 0.1 MΩ, brightresistance equal or less than 1 kΩ, which attains measurement accuracy. Added 100 100 kΩ divider resistance in the circuit can acquire the voltage across the MG41 under different lighting conditions that is different light intensities in different voltage values. Furthermore, inserted a LM358 operational amplifiers into the circuit can easily complete the acquisition of light intensity as shown in Fig. 5.

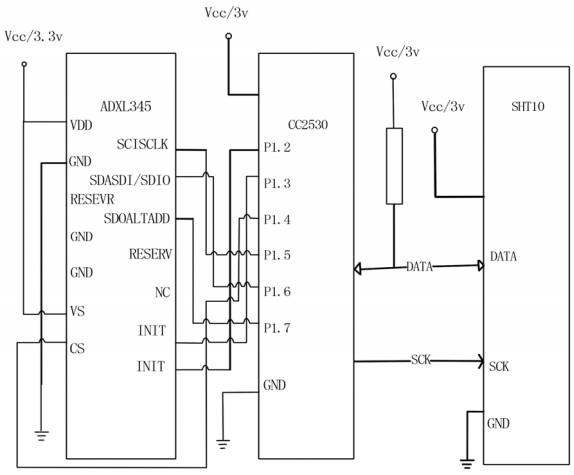

Fig. 4. Application circuit of SHT10 and ADXL345.

STSM-002-rain sensor using piezoelectric effect turns mechanical displacement into electrical signals. Once piezoelectric oscillators are be moistened by rain, the sensors vibrate in accordance with the strength and amount, transforming the impact energy into electrical signals, the P0.7 port of processor

CC2530 examining the electrical signals of rain sensor. When exceeding the constraints, it alerts the related staffs to take some protective measures. Its response time is less than or equal to 10 s, recovery time less than or equal to 30 s, which meet real-time requirements of the monitoring system.

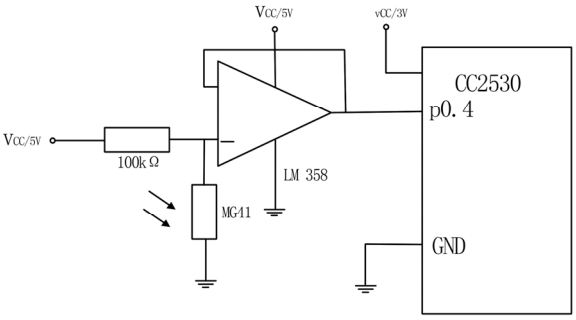

Fig. 5. Junction circuits across MG41.

ADXL345 is a kind of acceleration sensor with ultra-low power. When through- wall or burrows happened, it can generate dynamic acceleration in motion or vibration, and then converted into a recognizable signal which can be read by SPI port to give an alarm, as the Fig. 4 shows [5]. Its high-resolution (3.9 mg/LSB) is able to measure the changes of Tilt Angle less than 1.0°, measurement range±16 g and supply voltage 2.0-3.6 V, in addition, it can also offer a variety of special detection to achieve measurement accuracy and low-power for protection system.

3.1.3. Power Module Design

The working voltage of core control chip in sensor nodes is 2V-3.6V, and recommended working voltage is 3.3V. There are two modes of power supply, namely regulated DC power supply which is powered by USB bus, battery powered supply (two No.5 dry batteries) [6]. The devices in sensor node modules are low-power, most of which are in a sleep mode, and with sensor node random distributed in sites, it's inconvenient to supply with USB bus. Therefore, only battery power-up can do to supply nodes for about 6 months or two years [7].

3.2. ZigBee Gateway Design

ZigBee gateway is mainly used to transfer measurement data by ZigBee through 3G network to monitoring centre. Hence, gateway nodes must contain these two network stacks and can complete the transformation between the stacks [8] with data disposition and storage. Its hardware includes processor module, storage module, wireless communication module, 3G communication module, power module and I/0 ports, as Fig. 6 shows.

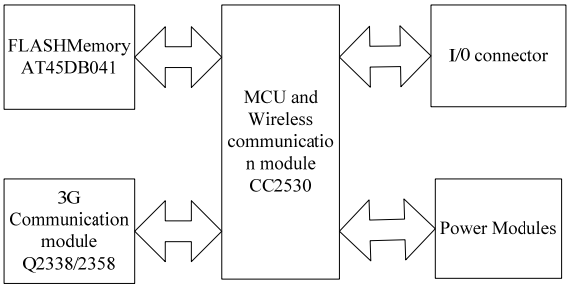

Fig. 6. Hardware structure of gateway nodes.

As an export of whole ZigBee network, the energy consumption and dataflow of gateway nodes are higher than sensor node, which requires a sustained power supply mode and a large sustained data throughput together with high data storage capacity, as well as strong data processing and control capability. In this case, it should select in an electric or solar powered way and use CC2530 as ZigBee gateway control chip in the integration of microprocessor and wireless communication module. Among them, CC2530 with 256KB of flash memory and 8KB RAM cannot satisfy the needs of rapid data processing for ZigBee gateway, thus, needs to circumscribe an AT45DB041 (528 K) Flash memory chip through the SPI port. Its embedded 3G module with Q2338/Q2358 in Wavecom can realize wireless remote data communication. Connected with CC2530, it transmitted the package processed by TCP/IP protocol stack to the outer network over air interface [9].

4. Software Design

According to the nodes in the sites are widely distributed and inconvenient to replace batteries, the system uses a way of hibernation- awake-hibernation to reduce energy consumption. Nodes in ZigBee network are not all in operative mode, only in receiving control commands, in order to gather and transmit data. Its software design transplants Z-Stack which provided an integrated routing protocol and completely transparency to application layer. Only conveying the data into the stack can it find the route automatically, and send the data to the destination.

4.1. Software Design on Sensor Nodes

After joined into network, sensor nodes are mainly in charge of the collection and transmission of information including humiture, light intensity, rainfall and vibration, as well as reception and execution of control command. Most sensor nodes are in a low-powered sleep mode, waiting for the timer. When sensor node invoked and received gateway node orders, it began to collect environmental data and send to ZigBee gateway through wireless network. Fig. 7 shows the workflow of this sensor node.

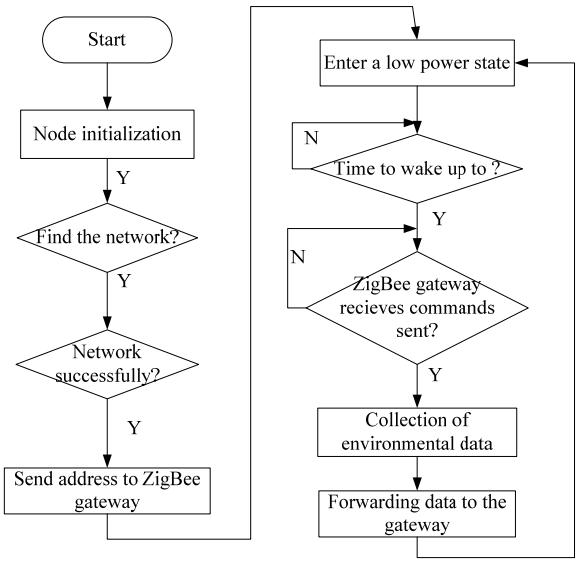

Fig. 7. Software workflow of sensor node.

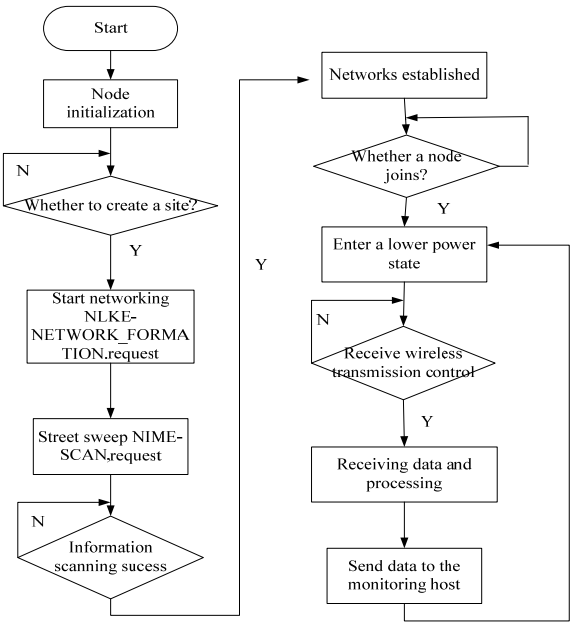

Fig. 8. Software processes in gateway node.

4.2. Software Design on ZigBee Gateway

ZigBee gateway mainly serves as a coordinator in wireless sensor network and a function of telecommunication. After system start, the hardware and protocol stacks should be initialized firstly, after then, starting networking primitives NLME-NETWORK-FORMATION. Gateway node selects an appropriate channel to set up ZigBee network together with P ANID and short address. While a new node applied to network, the gateway has one 16-bit address assigned to it and allows it being added to the network, and then went into hibernation. When received control command, gateway node started to collect and process data and transferred into a remote monitoring centre by 3G. This software process is shown in Fig. 8.

4.3. The Implementation of Information Collected in Z-Stack

ZigBee networks use OSAL operating system [11] of abstraction layer for mission design and task handling, the information process is shown in Fig. 9. Added some collected information including humiture, light intensity, rainfall and vibration to UserAppProcess() on the stack application layer, system has to judge whether the events will happen and is based on the manipulation function OSAL-START-SYSTEM() invocated by Task-ID and Event-ID, and then to have these related events handled.

4.4. System Management Software Design

Management system in heritage monitoring centre is a composition of database, GIS [12] and wireless communication such as Visual Studio 2005.

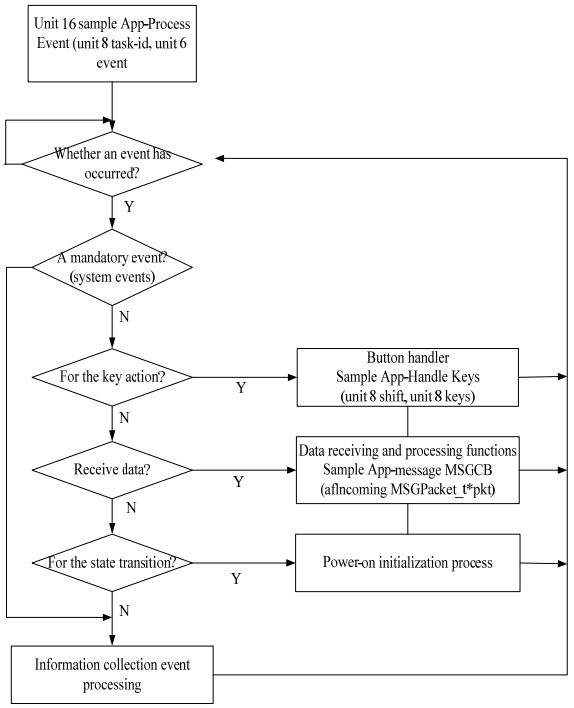

Fig. 9. Management software designs for information acquisition and task processing of system.

Net platform uses C# as development language and Microsoft SQL Server 2007 as backend databases to realize data management including the reception, analysis and processing for gateway reported data, as well as historical data inquiry and map storage for protected area; network management, including network control, monitoring for node energy consumption, ID and network topology; data management based on GIS which covers map

browsing, map scale switching and target searching; alarm information management, including alerts exceeding the data standard that is, clicking the alarm point on the map to show the geographical location information. The reliability and timeliness for data communication should be assured by network communications protocols on the application layer.

5. Experiment Results and Analysis

For connectivity and veracity of monitoring systems under poor environment and complex terrain, it simulates a protected area outside laboratory for testing, distributing the nodes in this area and placing ZigBee gateway and the monitored computer in the lab. Besides, the distance between the node and ZigBee gateway is about 50 m. After starting the monitoring system, the network transmits the collected data to the platform successfully, this data acquisition interface shown in the Fig. 10. From the monitoring data, we can know that system for data transformation is reliable and accurate.

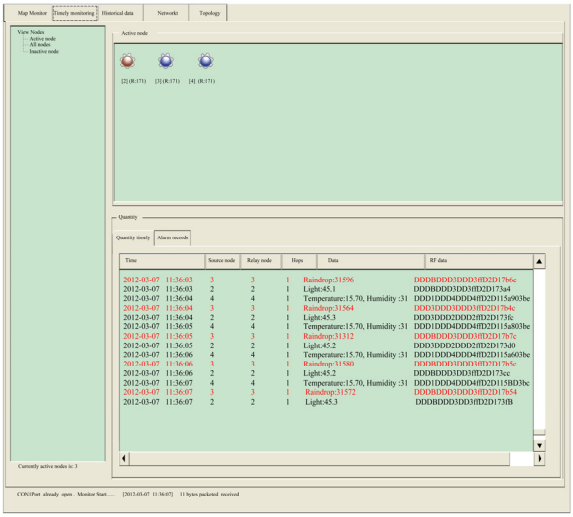

Fig. 10. Information collection interface.

6. Conclusions

In this paper, the design for environmental monitoring system based on ZigBee wireless sensor networks and Z-Stack can support multiple areas monitoring. Monitoring division depends on heritage location, and the nodes for long-term monitoring will be carried our only once with low-power and high real-time. As it is being used, it also can extend sensor module to monitor the other environment parameters (such as the concentration of carbon dioxide, etc.), or can make use of external energy (e.g. solar, wind and others) to increase network lifespan, in order to the realization of intelligent monitoring system for wireless energy sufficiency, low power consumption and ad-hoc networks.

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