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The Design and Reliability Analysis of Elevator Monitoring System Based on the Internet of Things

Xiaohong Pan

Yangtze University College of Arts and Science, HuBei, JingZhou, 43400 China
1064617031@qq.com

Abstract

In order to solve the problems of high cost, complicated wiring and inconvenient operation of the elevator monitoring system, this paper designs an elevator safety monitoring system based on Internet of things technologies. In this system, the CC2530 acts as a processor and communication module, the DHT11 as a temperature and humidity sensor module, and the ADXL345 as an accelerometer sensor module. The power supply module uses the chip LM2576S to provide 3V and 3.3V voltage. The fault tree analysis method is employed to analyze the reliability of the system designed in this paper. The data acquisition module, power supply module and MCU I/O port are given relatively large weight, which demonstrates that they are more likely to cause system failure. In this paper, the environmental parameters of elevator in a certain residential area are tested. According to the test results, the average relative errors of temperature, air humidity and velocity are 0.47%, 1.40% and 1.36%, respectively. The experimental results show that this easy-to-operate system can monitor the environmental parameters of the elevator with high precision, and can achieve the real-time monitoring on the running state of the elevator.

***Keywords**: Internet of Things; temperature and humidity; velocity; elevator; monitoring; reliability*

1. Introduction

Along with the rapid development of urban economic construction, more and more high-rise buildings have emerged. The safety of elevators as a manned vertical transit tool is directly linked with occupant safety. In recent years, the occurrence rate and severity of frequent elevator-related tragedies in China are far above those in developed countries and regions [1]. Therefore, the Chinese government and the society have increasingly focused on safe lift operation [2]. Today, there are three methods which are mainly used for elevator safety monitoring at home and abroad [3]. The first method is GPRS/GSM technology by which the monitoring system can transfer data to the remote data center. The second method is embedded chip technology by which the monitoring system has some disadvantages such as high power consumption, wiring troubles, and difficult to realize some signal to access. The third method is Zigbee technology by which the monitoring system has some advantages of low power consumption, low cost, and easy to move [4-6].

As the traditional approach to lift management and maintenance fails to satisfy present-day requirements, it is imperative that Internet of Things technologies are applied to elevator monitoring, helping achieve automatic control and management of elevator safety.

Elevator operation is influenced by physical or environmental conditions, especially by temperature, air humidity and velocity. According to the Safety Rules for the Construction and Installation of Electric Lifts(GB7588), the operating temperature shall be within a range of 5~40^{0}C. The summer temperature and humidity of the main

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controller shall be within the range of 20~26^{0}C and below 60%, respectively. The winter temperature and humidity of the main controller shall be within the range of 18~23^{0}C and above 45%, respectively. In terms of speed, there are three types of elevators: low-speed elevator, express elevator, and high-speed elevator. The speed of elevators of less than 12 floors, 12-22 floors, and 22-32 floors is respective 1m/s, 1.75m/s and 2m/s.

Wireless sensor network (WSN, for short), a multi-hop self-organizing network system, is built of numerous micro sensor nodes [7-8]. These nodes connect to each other through radio communication in the monitoring areas, where the objective data is perceived, collected, processed, and forwarded. For the WSN system applied to elevator safety monitoring, online monitoring of parameters including temperature, humidity and velocity is of practical significance [9]. Most of elevator remote monitoring systems transmit data in special line, facing the problem of high cost, sophisticate wiring, and inconvenience of network management [10]. In this connection, the paper proposes an elevator monitoring system that targets at temperature, air humidity and velocity. In this cost-efficient and reliable system, the environmental parameters of elevator are collected and processed at the same time when the upper computer achieves real-time data monitoring.

2. Design of the Overall Structure and Hardware of the System

This system basically consists of wireless sensor node module, GPRS module, and upper computer monitoring module. The system structure is shown in Figure 1. The wireless sensor node module is responsible to gather the environmental parameters in elevator cabs, including temperature, humidity and acceleration. GPRS module sends the data to the upper computer for data display.

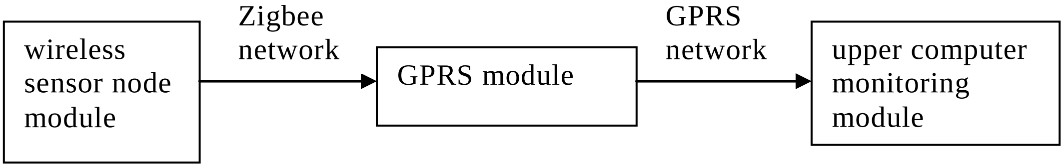

Figure 1. System Structure

2.1. Design of the WSN Node Hardware

Sensor nodes are composed of sensor module, processor module, wireless communication module, and power supply module. Sensor mudule is in charge of data collection and data conversion within the monitoring area. Processor module dominates all operations of sensor nodes, as well as store and process data that are either collected by itself or received from other nodes. Wireless communication module communicate with other sensor nodes wirelessly in exchange of control data. It also collects, sends and receive data. Power supply module provides energy for sensor node mudule. The DHT11, a temperature and humidity sensor, and the ADXL345, an accelerometer sensor, are adopted in the sensor module. Figure 2 shows the node hardware structure.

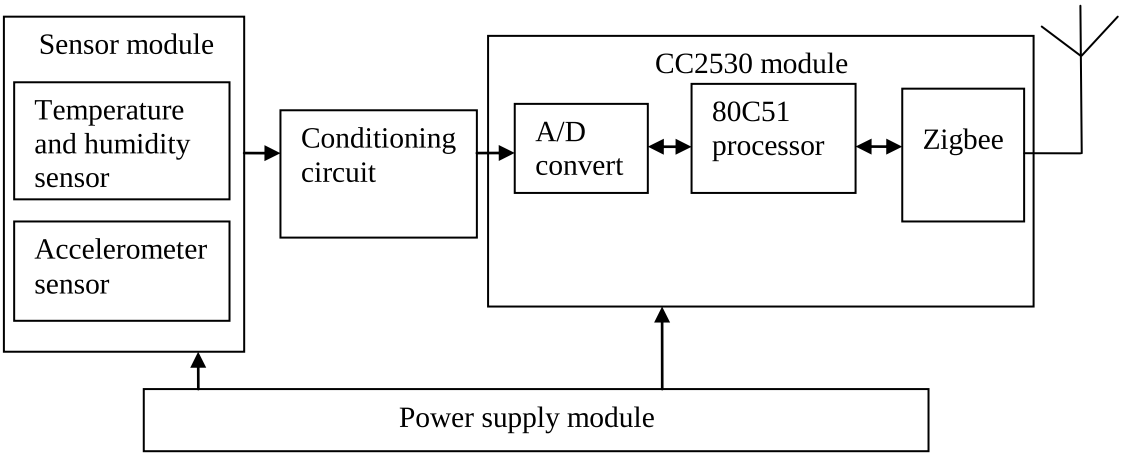

Figure 2. System Structure

2.2. Microprocessor and Radio Frequency Module

CC2530 chip is used in the system to integrate enhanced 8051 MCU kernel. It is characterized by high price/performance ratio, low power consumption, and state-of-the-art RF transceiver merits. It serves for 2.4GHZ IEEE 802.15.4 and RF4CE standards, with programmable Flash storage and 8KB RAM. The module is equipped with 2.4G omnidirectional antenna that has the reliable transfer distance of 250m and the auto-reconnect distance of as long as 110m. Given the complicated elevator system environment, it is necessary that the through-the-wall steady communication distance for wireless sensor nodes is at least 100m [11]. Therefore, CC2591 power amplifier chip is used in order that the transfer distance can be prolonged to 1,600m.

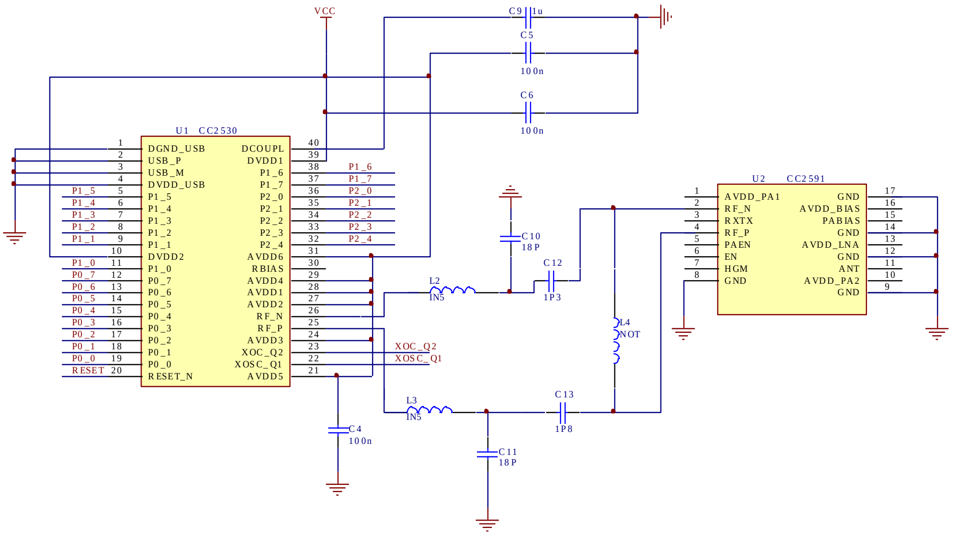

Figure 3. The CC2530 Module Circuit

2.3. Temperature & Humidity Sensor Module

DHT11 digital temperature & humidity sensor module is connected to MCU in the test. It contains a resistance humidity component and a NTC temperature component 3.3V power supply(VDD), ground(GND) and P0 port of MCU are connected to the respective 1Pin, 4Pin and 2Pin of DHT11. Figure 4 is the corresponding circuit diagram.

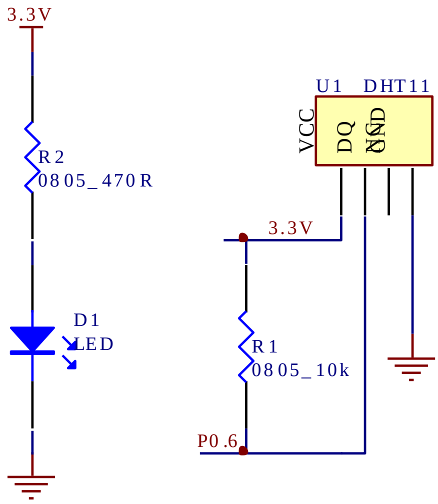

Figure 4. Circuit Diagram for Temperature & Humidity Sensor Module

2.4. Acceleration Sensor Module

3V power supply ADXL345 is used to test elevator acceleration.I2C mode is available when the CS Pin of ADXL345 connects to VS. SDA and SCL are the respective data pin and time pin of I2C BUS. VDD is connected to the 3V power source outputted by the power supply module. Pin 2, 4 and 5 are grounded. ADXL345 SDO is connected to CC2530 P1.0. ADXL345 INT1 and INT2 are connected to CC2530 IEN0 and IEN1, respectively, in order to produce interrupt signals. Figure 5 is the corresponding circuit diagram.

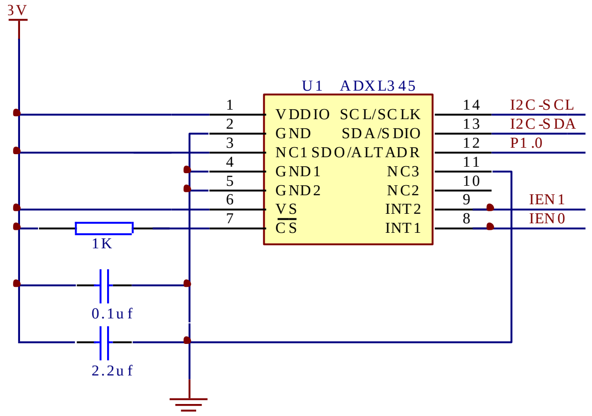

Figure 5. Circuit Diagram for Acceleration Sensor Module

2.5. Power Supply Module

3.3V power source is required for CC2530 and DHT11, and 3V power source for ADXL345. LM2576S chip is used for voltage reduction. Figure 6 is the circuit diagram.

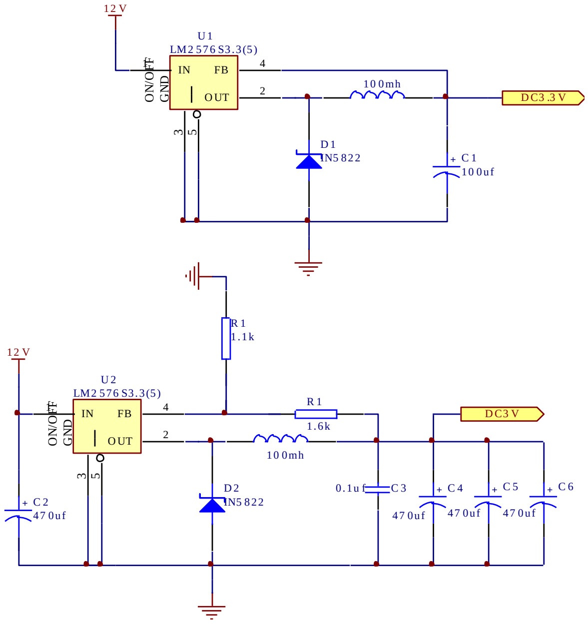

Figure 6. Circuit Diagram for Power Supply Module

3. System Software Design

The “top-to-down” modularized method is used for the system software, in order to enhance program readability and to facilitate system debugging. The system software include sensor data acquisition module, data processing module, data communication module, and failure alarm module. Figure 7 is the flow chart of main system programs.

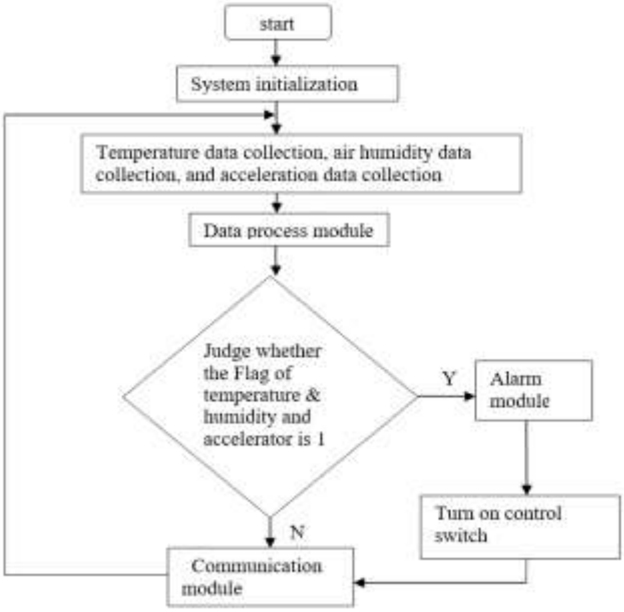

Figure 7. The Flow Chart of Main System Programs

4. System Reliability Analysis

It is necessary to take system reliability into account for fear of system-failure-induced elevator accidents. Therefore, fault tree analysis is used in the paper to test the reliability of the designed system.

Fault tree analysis is a top down, deductive failure analysis in which an undesired state of a system is analyzed to combine a series of lower-level events. It can effectively analyze the reliability of the design, test and failure of a complicated dynamic system [12-13]. A system failure tree is established in the paper, according to the working principle of elevator environmental parameter monitoring system. System failure acts as the top event, represented by T. Sensor module failure M1, sensor and data acquisition module failure M2, MCU control module failure M3 and data transfer module failure M4 are intermediate events. Temperature sensor module failure X1, humidity sensor module failure X2, acceleration sensor module failure X3, data acquisition sensor module failure X4, 3V power supply module failure X5, communication module failure X6, MCU I/O port module failure X7, and 3.3V power supply module failure X8 are bottom events. Figure 8 is the established failure tree.

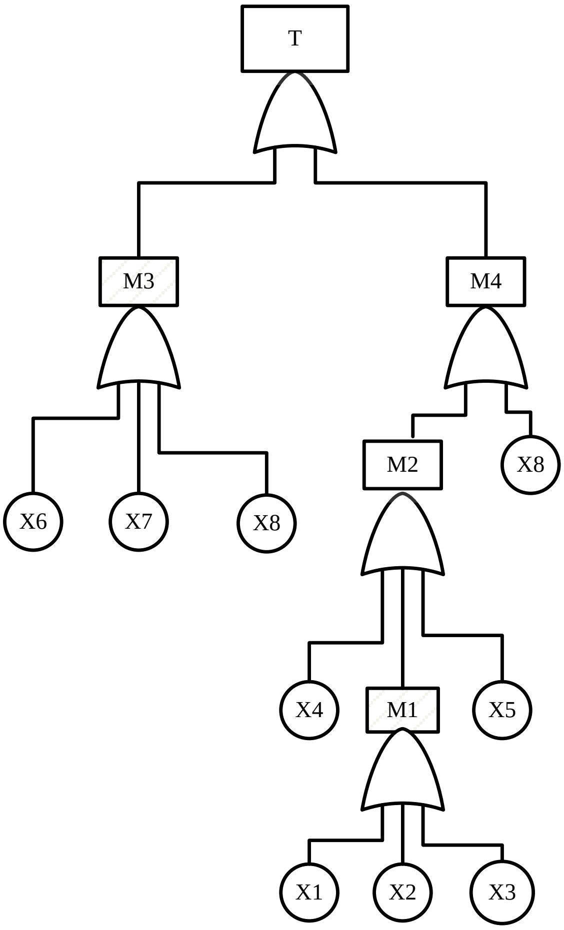

Figure 8 System Failure Tree

According to reference [14-15] as well as typical empirical data, the general failure rate is subject to exponential distribution. Table 1 contains the failure rate. Formula (1) and Formula (2) are used to calculate the importance degree of basic components $W(X_i)$ and the importance degree of basic component modes $W_N(X_i)$. Formula (3) and formula (4) are used to compute system reliability degree and mean system lifespan. Where N denotes the total number of simulation times, m_r represents the total times of system failure when t is less than or equal to t_r, and $R_S(t)$ is system reliability degree. MTBF displays mean system lifespan, and $P_S(t_r)$ is the probability distribution of system malfunction.

$$W(X_i) = \frac{The\ number\ of\ system\ failure\ induced\ by\ basic\ component\ X_i\ failure}{The\ total\ number\ of\ basic\ component\ X_i\ failure} \tag{1}$$

$$W_N(X_i) = \frac{The\ number\ of\ system\ failure\ induced\ by\ basic\ component\ X_i\ failure}{The\ total\ number\ of\ system\ failure} \tag{2}$$

$$R_S(t) = 1 - \frac{m_r}{N} \tag{3}$$

$$MTBF = \sum_{t_r=0}^{T_{\max}} [t_r \cdot P_S(t_r)] \tag{4}$$

Table 1. Characteristic Parameters of Bottom Events

Bottom event	Failure rate ($10^{-6}.h^{-1}$)	importance degree of basic components	importance degree of basic component modes
X1	1.365	1	0.0466
X2	1.392	1	0.0475
X3	1.378	1	0.0470
X4	12.057	1	0.4115
X5	5.163	1	0.1762
X6	0.926	1	0.0316
X7	4.381	1	0.1495
X8	2.637	1	0.0900

According to Table 1, the basic importance degree of bottom events is 1, which means that any failure of a component will cause system malfunction. The data acquisition module, power supply module and MCU I/O port are given relatively large weight, revealing a higher probability to cause system failure. This phenomenon complies well with actual conditions.

5. Practical Test and Result Analysis

With the designed system, both the network package loss rate and the environmental parameters in the elevators are tested in a certain residential area. In the test, sensor nodes collect data every 20 minutes, and the test continues for consecutive 28 days. The statistical data are obtained and shown in Table 2, where send package denotes the sent data package, and receive package represents the received data package, and dropped is the package drop rate. The package drop rates at node No.3 and node No.9 are relatively high, because there are obstacles in the actual environment. The average package loss rate of the overall network is 12.39%, which means that the system is highly accurate.

Table 2. Package Loss Rate

Node ID	Send package	Receive package	Dropped%
1	2016	1825	9.47
3	2016	1573	21.9
6	2016	1953	3.12
7	2016	1847	8.38
9	2016	1629	19.1

With the use of standard measuring instrument, the environmental temperature, air humidity and velocity in elevator No.6 building, elevator No.11 building, elevator No.12 building, elevator No.16 building, elevator No.18 building are separately tested. The test data for consecutive 12 hours are obtained. By comparing the test data with the data acquired by the designed system, the mean relative error of temperature, air humidity and velocity is 0.47%, 1.40% and 1.36%, respectively. Therefore, the system is of high precision. Table 3 is a comparison of air humidity data and velocity data. Figure 9 is a comparison of temperature data.

Table 3. System Test Result

	Air humidity/%RH			Velocity /m/s	
Elevator No.	Measured value	Theoretical value	Test location	Measured value	Theoretical value
No. 6	55	56	No. 6	1.0	0.98
No. 11	57	57	No. 11	1.5	1.49
No. 12	56	57	No. 12	1.5	1.47
No. 16	59	58	No. 16	1.75	1.73
No. 18	58	59	No. 18	2.0	1.98

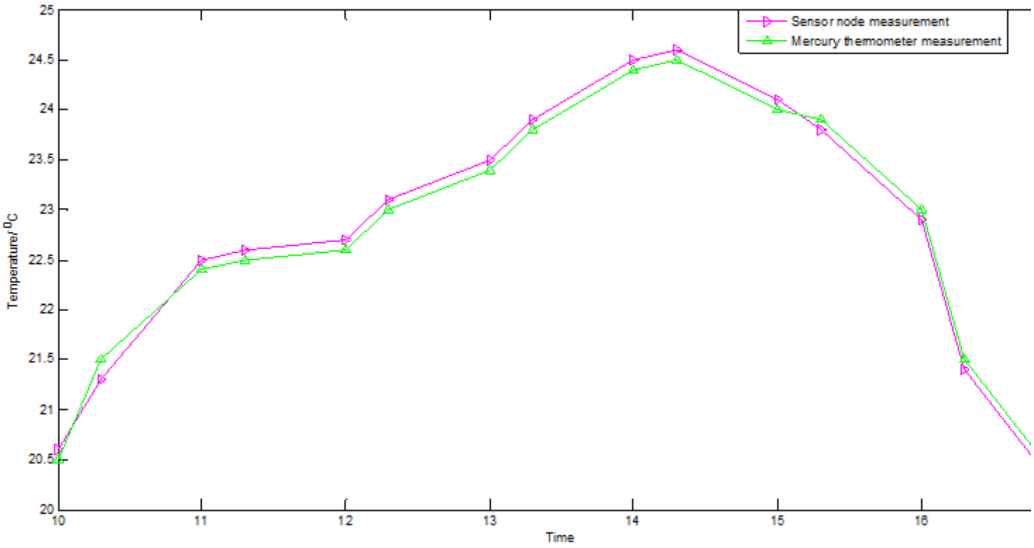

Figure 9. System Test Result

6. Conclusion

Based on the Internet of Things technologies, the paper designs an elevator safety monitoring system to realize real-time data transfer. In this system, the temperature data, humidity data and acceleration data are collected by wireless sensor nodes and sent to upper computer via GPRS network. The fault tree analysis method is used to analyze system reliability. For the practical system test, the result shows that the designed system produces reliable and precise measurement data, because the mean relative error of temperature, air humidity and velocity is 0.47%, 1.40% and 1.36%, respectively. In terms of the follow-up study focus, the author attempts to expand system functions on the basis of existing research achievements, and further optimize the system.

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Author

Xiaohong Pan. She received her B.S. in Electronic and Information Engineering (2004) and M.Sc. in Technology of Computer Application (2009) from South China Agricultural University. Now she is full lecturer of electronic information at Mechanical and Electrical Department, Yangtze University College of Arts and Science. Her current research interests include different aspects of Electronic Technique and Signal Processing and Internet of Things Technique.