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Design & implementation of an Air Quality Monitoring System for Indoor Environment based on Microcontroller

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Abstract

Indoor air quality is a very important parameter for living environments, which is closely related to people's daily work and health. However, nowadays, the environmental pollution, haze weather and other issues have become increasingly prominent. In this context, it is necessary to design an automatic detection device for monitoring the air quality in buildings. In this paper, an indoor air quality monitoring system was designed and implemented based on LPC2148 micro-processor by means of the sensor technology, embedded technology and communication technology. The system could simultaneously monitor a variety of harmful gases and monitoring gas and setting alarm values according to the requirements of the indoor environment, such as indoor temperature, humidity, formaldehyde and methane, as well as PM2.5. All of the measured data is transmitted to the remote server to process through Ethernet. The experimental results show that, the system works stably and has high accuracy, which has broad market prospect.

Keywords: *Indoor air quality, gas concentration detection, embedded system, sensor, PM2.5*

1. Introduction

The indoor environment within buildings is the main arena for people to live and work. The statistical data shows that people spend up to 80% - 90% of their time indoors. Hence, quality of the air in the indoor environment is essential for people's health [1-2]. However, urbanization, coupled with rapid industrial advances in recent years, results in more and more serious environmental pollution [3-5]. To make things even worse, many families are seriously harmed by environmental and air-quality problems caused by harmful substances, like formaldehyde in finishing materials. This gives cause for concern. According to WHO statistics, indoor environment within over 30% of buildings in China is substandard and houses poisonous or harmful gases, thereby posing grave threats to people's health. On the other hand, it is proven that the high-quality air indoors is helpful in improving activeness of staff and can increase working efficiency by 2%-16% [6-7]. If we can get gas concentration data timely and accurately and when the concentration of harmful gases in the environment exceeds the standard of indoor gas, an acousto-optic will start automatically, all of these will provide a comfortable living environment in real-time.

To sum up, indoor air quality at home or the office has great effects on people's quality of life, health and efficiency. The development of the indoor air quality monitor has undergone two stages since the 1980s. The first stage concerns laboratory analysis, yielding such methods as colorimetry, chromatography and spectroscopic luminosity. These methods provides high resolution, are accurate, reliable and thus suitable for

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scaling and arbitration. Their weaknesses are that they entail long measuring periods, financial costs and complicated operations. The second stage concerns portable on-site instrumentation. In [8], the authors proposed a most simple module that measures air quality using the CAN protocol. The measuring node consists of the CAN controller and the CAN transceiver. In the case of the sensor's value exceeding the pre-set value, an alarm will be triggered and the ventilator will be opened. In [9], ZigBee WSN-based system for monitoring indoor air quality is implemented via the CC2430 chip. Each sensor node is integrated with the module for sensing temperature, relative humidity and CO2. In [10], the low-cost tin oxide semiconductor sensor is used to design a smart distributed system for measuring indoor air quality in the health center. Because the semiconductor sensor is featured with low selectivity and stability, the system is not very effective. These methods are mostly focused on the measuring of indoor temperature, humidity, concentrations of CO2 and CO, paying little attention to the monitoring of suspended particles indoors.

Therefore, by using the embedded and network communication techniques, we propose a tool for monitoring indoor air quality in this paper. In addition to the real-time monitoring of concentrations of poisonous and harmful substances (e.g. HCHO, methane, PM2.5 dust), the proposed tool can also measure environmental parameters like the temperature and humidity. These measurements will then be sent to users' mobile phones through GPRS remote communication, informing users of air quality indoors.

2. Requirements Analysis

The objective of this designed system is able to monitor indoor daily invisible pollution source, such as formaldehyde, methane, ammonia, carbon monoxide, inhalable particles, temperature and humidity *et al*, and overcomes the disadvantages of traditional measuring instrument can only monitor single gas. At the same time, the proposed system can carry out the alarm to the harmful gas, and display values of these harmful gases according to the corresponding measurement and analysis results. Specific functional requirements are as follows:

(1) Monitor temperature and humidity: collect and store thermal environment parameters such as temperature and humidity in real-time; trigger the alarm when the temperature and humidity goes beyond the comfort range.

(2) Monitor harmful gases: collect concentrations of harmful gases like formaldehyde and methane in real-time, and trigger the alarm when the measurements exceed the normal range.

(3) Monitor PM2.5 concentrations: collect PM2.5 concentrations indoors in real-time, and trigger the alarm when the measurements exceed the upper limit.

(4) Communicate and control remotely: the measurements can be uploaded in real-time or at specified time and the concentration upper limit can be changed by users remotely.

3. System Design

The high-performance chip ARM7 of LPC2148 is used as the core, which integrates the 512kB high-speed flash memory. It also provides many peripherals and communication ports, including two high-speed 10-digit ADC input channels and one 10-digit DAC output channel. It supports various serial bus protocols (e.g. UART, SPI, I2C) and 45 high-speed GPIO universal pins. In addition, the 64-pin LQFP package is very suited for the power-sensitive small-scale embedded system and thus finds widespread uses in industrial control, medical treatment, health, and data collection. Fig.1 shows the hardware system structure of the proposed tool, including the sensor collection module, alarm module and the network communication module.

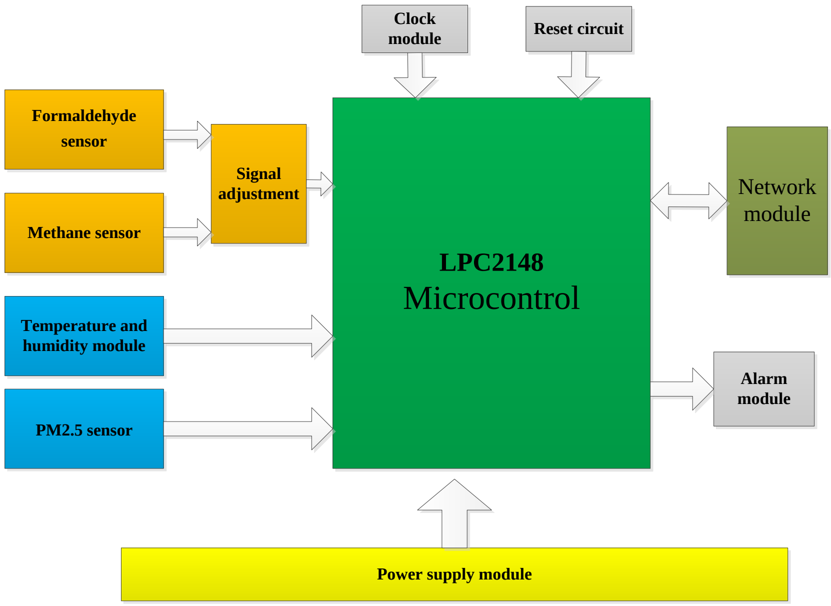


Figure 1. Structure of the Monitoring System Hardware Design

3.1. Second-order Headings

The temperature and humidity sensor employs a digital DHT11 module, which incorporates a resistance-type humidity sensing component and a NTC temperature measuring component. It can communicate with LPC2148 through one single I/O data line and supports 3~5V power supply. It is desirably featured with low power consumption, small size and simple circuits. Installing a pull-up resistor between the data line and the power line is recommended to achieve stable data communication. The sensor sends to the processor 40 bytes of data which puts high addresses before low addresses, including 16 bytes of temperature data, 16 bytes of humidity data and 8 bytes of checking data. Parameters of the sensor are given in Tab.1.

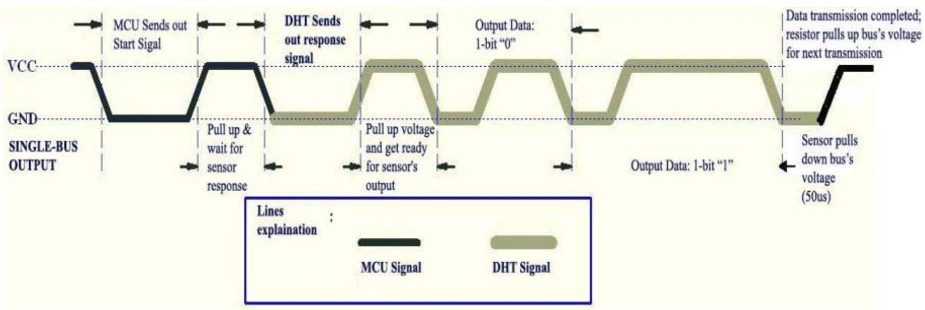
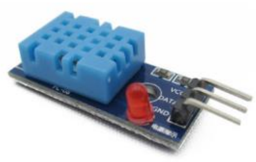
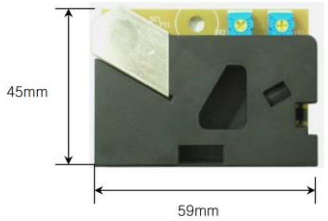


Figure 2. DHT11 Overall Communication Process

Fig.2 shows the sequential chart of communications between DHT11 and LPC2148 modules. The bus is at a high level by default; LPC2148 puts the bus to a low level by itself to initiate a read process, restores the bus to the high level, and then waits 20us-40us before reading the back signal of DHT11. DHT responds by putting the bus to a low level, and then restores the bus to the high level to prepare for data transmission. As shown in the figure, each bite of data begins with a low level. The data "0" stays at the high level for about 26~28us, and the data “1” stays at the high level for 116~118us. Generally, a round of communication takes 3ms at most and a continuous sampling interval no less than 100ms is recommended for the host.

Table 1. Parameter of Sensors

Types	Picture of sensor	Supply Voltage	Sensitivity	Response time
Temperature and humidity sensor		3-5.5V	Temperature ：1℃ Humidity：1%RH	1s
Formaldehyde sensor		5V	2000nA/ppm	10s
Methane sensor		3V	20~40mV	10s
PM2.5 sensor		5v	1um	30s

3.2. Second-order Headings

Formaldehyde is detected using the electrochemical sensor ME3M-CH2O. This module has the ability to determine the gas concentration by measuring the current intensity, because the current generated by the gas during the electrochemical oxidation process at the electrode is in proportion to its concentration. It is featured with small size, low power consumption and high intensity, and thus has been widely used for formaldehyde detection at home or in public places. Fig.3 shows the hardware detection circuit of the ME3M-CH2O sensor. Current signal variations detected by sensors are converted to voltage signals and amplified using the operation amplifier, and then collected by feeding them to the AD module of the LPC2148 processor.

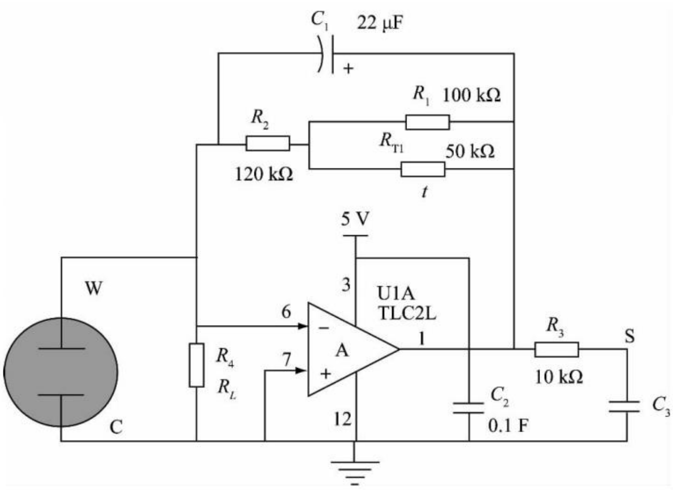


Figure 3. Hardware Circuit of Formaldehyde Detection

3.3. Second-order Headings

The methane sensor uses the MC112 gas sensitive component; the compensation element and the detection element of the sensor comprise the electric bridge's two arms. In the case of detecting the methane, the detection element's resistance value will increase due to chimerical reactions, resulting in variation of bridge voltages. And the intensity of the generated voltage signals is in proportion to the concentration of the combustible gas. In application circuits, the bridge that enables the sensor to work needs 3V direct working voltage in order to provide the sensor with sufficient combustion heat during its contact with methane. In this case, variations occur to the resistivity, temperature and bridge output voltage of the detection element. These variations indicate the methane concentrations in the air. The detection circuit of MC112 is illustrated in the following figure. Considering the fact that the sensor's signal output is very weak, the AD623 amplifier is used here to amplify it before feeding it to LPC2148 for signal collection.

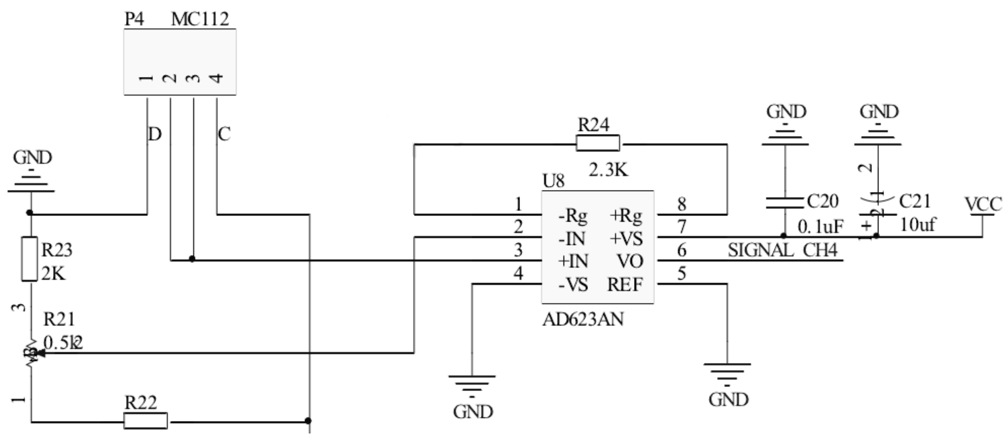


Figure 4 Hardware Circuit of Methane

3.4. Second-order Headings

The PM2.5 sensor adopts the DSM501 module imported from Korea. The working principle of this module is as follows. First, the indoor air goes into the module through self-heating. After being exposed to the detection light from LED, the particles will be excited to scatter. Next, the optical pulses are converted by the convertor to electrical pulses, thus achieving recognition of particles.

This module is capable of detecting suspended particles over 1um in diameter. The signal is output through PWM. A DSM501 sensor alone can measure the particle concentration in the space of 30m2 at most. As shown in Tab.1, the DSM501 module has 5 pins, where the pins 3 and 5 are responsible for power supply, the pins 2 and 4 are output pins. The pin 2 can be used to detect suspended particles as small as 1um in diameter, and the pin 4 is designed for the detection of suspended particles as small as 2.5um diameter. The detection sensitivity of the pin 4 can be controlled via the pin 1, because it changes with the resistance.

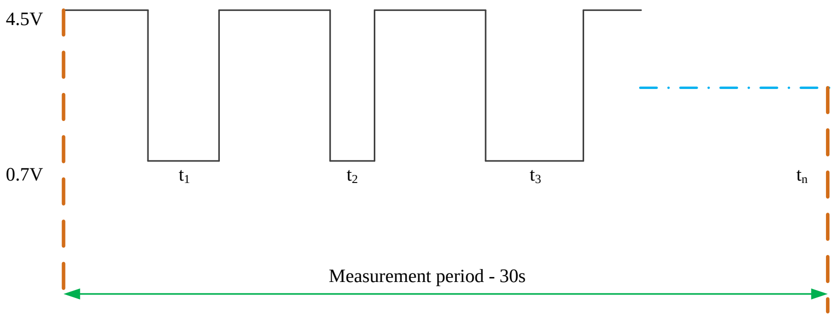


Figure 5. Output Waveform of DSM501

The PWM output waveform and detection steps of DSM501 are shown in the figure. The width of the output low-level pulses ranges from 10ms to 90ms. According to Eq.(1), after knowing the proportion of the low level in a measuring period, the number of PM2.5 particles can be computed via linear lookup. Before the detection process, the module should be warmed up first for about 1 minute. Then, the low-level pulses from DSM501 can be counted through LPC2148 based on Eq. (1). The relation between the low-level pulse rate and the number of particles is shown in the following figure.

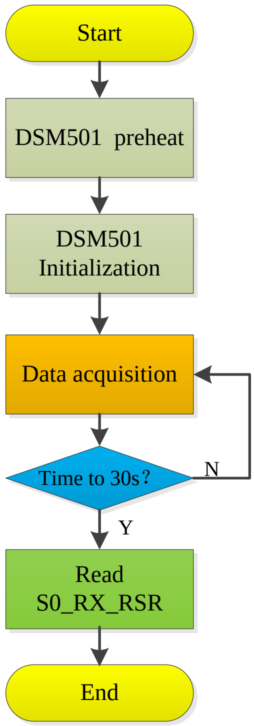


Figure 6. Flowchart of PM2.5 Detection

3.5. Second-order Headings

The traditional Ethernet driving chip needs to write a driver in the microprocessor, which incurs a long period of challenging development. Therefore, the Ethernet driving chip W5300 which integrates the TCP/IP stack is used in this paper. This chip is a multi-purpose one-piece network interface chip from WIZnet in Korea, providing high-performance low-cost Ethernet solutions. The internal structure of this chip is shown in the following figure, where the power supply is 3.3V and the chip has a built-in 1.8V voltage adjustment circuit, simplifying the system's power design. The external input clock signal is usually 25MHz, and can be doubled to 150MHz through the phase-locked loop module. It also supports 8- or 16-bit parallel bus connection, and the maximum communication rate can be up to 50Mbps.

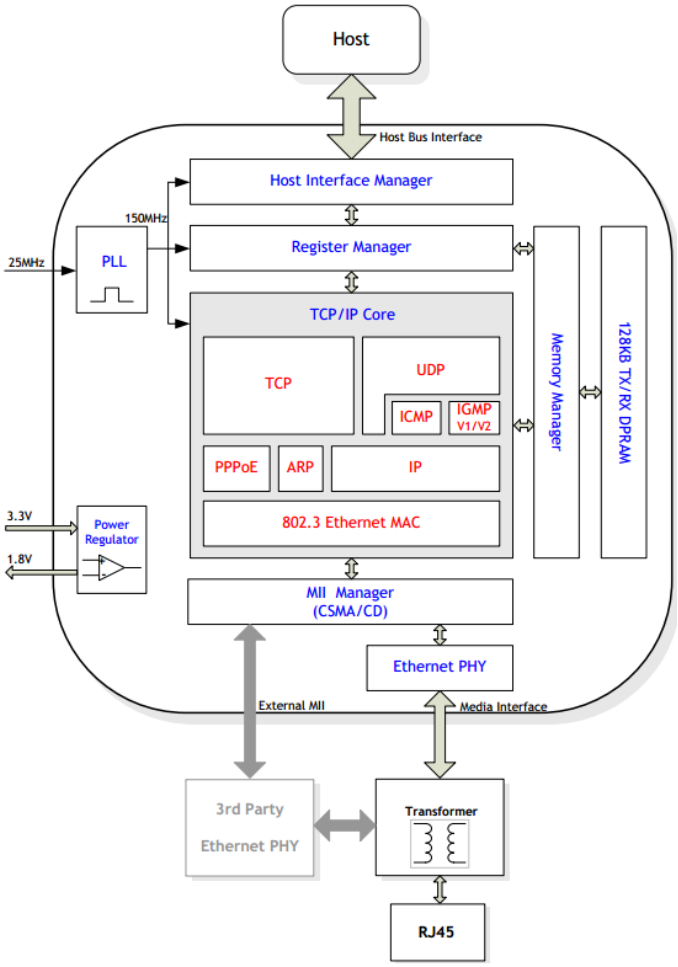


Figure 7. Block Diagram within the W5300 Chip

Steps of the software driver are as follows:

(1) Initialization

Set up the MAC address, default IP address and the default gateway address for W5300, initialize SOCKET, and configure the operational mode of the TCP server.

(2) Data reception

W5300 receives data in an interruption manner. When the reception buffer of W5100 receives data, an interruption signal will be created and then analyzed through the interrupt processing program in the processor of LPC2148. First, the value of the length register S0_RX_RSR stored in the buffer is first read; then, the data length is read and returned.

(3) Data transmission

After receiving data requests from the client, the processor collects data from sensors by first duplicating the data to be sent into the TX transmission buffer of SOCKET. Next, the length of the data to be sent is computed and written into the register S0_TX_WRSR. All this being done, data transmission begins.

Steps of the W5300 software driver are illustrated in the following figure. First, the chip is reset and initialized, setting up MAC and IP addresses and other parameters. During restoration, the low-level signal must be maintained for at least 2 us. Then, it should wait for about 10ms until the phase-locked loop stabilizes, before establishing Socket connections. Later on, it waits for the program to send the read or transmission commands and then perform relevant operations accordingly.

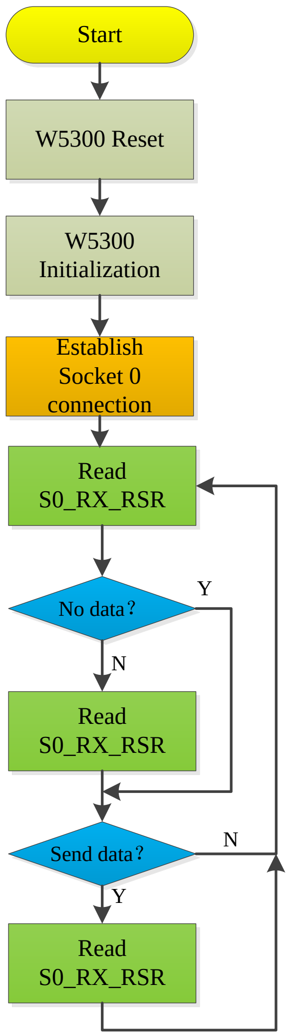


Figure 8. Flowchart of W5300 Communication

4. System Design

4.1. Second-order Headings

To evaluate the measuring accuracy of the proposed system, the measured values are tested using the standard instruments. The testing environment is described below:

(1) Formaldehyde: room temperature (15~25℃), relative humidity≤85%RH

(2) PM2.5: temperature (20℃±5℃), relative humidity≤75%RH

(3) Temperature and humidity: the room-temperature environment

Table 1. Formaldehyde Gas Detection Results

No.	1	2	3	4	5	6	7	8	9	10
Actual value (ppm)	0.5	0.6	0.7	0.8	0.9	1	1.2	2	4	6
Measured value (ppm)	0.48	0.61	0.69	0.82	0.93	1.02	1.23	2.05	4.02	5.93

Table 2. Methane Gas Detection Results

No.	1	2	3	4	5	6	7	8	9	10
Actual value (ppm)	100	300	500	700	900	1200	1500	1800	2100	2400
Measured value (ppm)	109	291	518	720	889	1232	1520	1789	2123	2431

Table 3. PM2.5 Detection Results

No.	1	2	3	4	5	6	7	8	9	10
Actual value (μg/m^3)	30	60	90	120	150	200	300	400	500	600
Measured value (μg/m^3)	32	57	93	125	144	208	293	411	488	613

Table 4. Temperature and Humidity Detection Results

Type	Temperature					Humidity				
No.	1	2	3	4	5	1	2	3	4	5
Actual value (μg/m^3)	5	10	15	20	30	30	40	50	60	70
Measured value (μg/m^3)	5	10.2	14.8	20.5	30.2	33	37	51.3	64	72.8

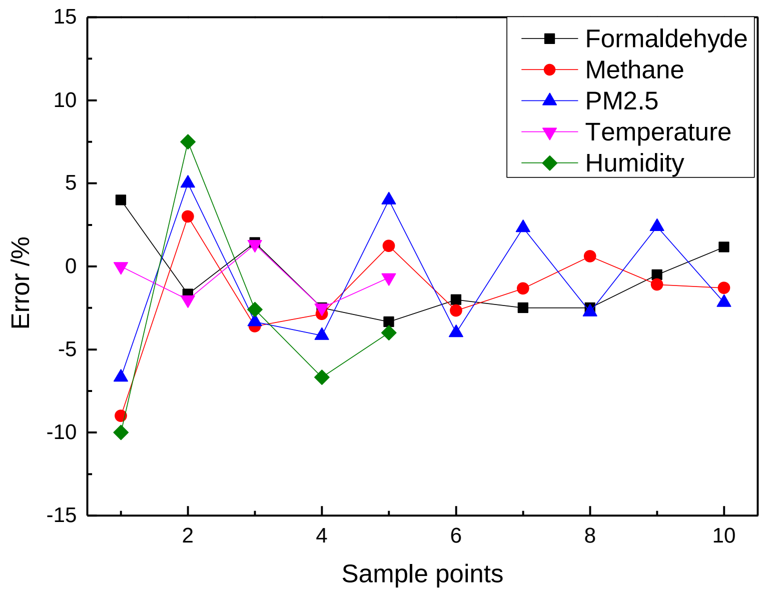


Figure 9. Measurement Errors

Table 1 ~ Table 4 show the measurement results of formaldehyde, methane, PM2.5, temperature and humidity. From these tables, it can be seen that, the measurement accuracy of the system is relatively high, which could meet the needs of the indoor air quality monitoring in daily life. Furthermore, Figure 9 shows the corresponding errors of different monitoring parameter. It can be seen that the measuring errors are large at the beginning of measurement. Generally, the measuring errors can be attributed to many factors, such as the structure of instruments, design of circuits, and the environment. In the case of low gas concentrations, the measuring errors are mostly due to circuits. When the gas concentration is high, the measuring errors are caused by non-circuit factors.

Hence, if the gas concentration is low, the measuring accuracy can be improved by averaging over many measurements; if the gas concentration is high, the system will trigger the alarm promptly and advise to ventilate or evacuate the room.

5. Conclusion

By using the chip LPC2148 as the core and employing various sensors, the hardware circuit and software program of the system for monitoring indoor air quality is designed and implemented. The proposed system has the ability to automatically measure concentrations of harmful substances (e.g. formaldehyde, methane and PM2.5), as well as thermal environment parameters (e.g. temperature and humidity). The proposed system can be managed and maintained easily by transmitting data across a long distance through Ethernet. Test results show that the proposed system is very accurate, stable and thus suitable for home, hospital and office. Due to its modularization design, the proposed system is greatly portable. This means that slight modifications enable the system to be used for similar monitoring applications. Hence, the proposed system is of great research and application value. Further work can be done to improve the proposed system. For example, we can reduce the measuring errors when the gas concentration is low by improving the hardware circuit, or increase the measuring accuracy by introducing the software correction algorithm.

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