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Design of indoor dust concentration monitor based on light scattering detection method

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Inhalable particles and fine particulates in dust will pollute the indoor environment and endanger people's health. It is an important task to take effective measures to control indoor dust pollution. The key is to keep abreast of the dust concentration, and to monitor, control and evaluate the sources of indoor dust pollution. This paper analyzes the main sources and characteristics of indoor dust and uses dust sensor to collect dust and transform photoelectric signals. It applies micro control unit (MCU) to control the system and process data, and designs the dust concentration monitor. The monitor can be used as an independent equipment and also a combination of a variety of sensors through the serial port to monitor indoor environmental parameters and control environmental control facilities, thereby purifying indoor air.

Key words: Light scattering, dust, dust sensors, micro control unit (MCU).

INTRODUCTION

Dust, known as "airborne particles", refers to the solid particles that can be suspended in the air (diameter ≤ 100 um). Among them, dust with diameter <100 um is called "total suspended particles", named as TSP for short, while dust with diameter between 2.5 and 10 um is called “particulate matter", shortened as PM10. Dust with diameter <2.5 um, known as "fine particulate matter", is referred to as PM2.5. The harm of dust to human beings is related to their size and composition. Dust with diameter > 10 um will be blocked out from the human nasal cavity, while PM10 can enter the upper respiratory tract of the body. Particularly, after being inhaled by the human body, PM2.5 can directly enter the blood through the bronchi and alveoli, which will be phagocytized by macrophage. Their long-term stay in the alveoli will exert negative impact on the human cardiovascular, nervous system and other organs, posing threat to people’s health (Si et al., 2012). According to a survey, modern people spend up to 60 to 80% of time indoors, especially for infants, young children and the elderly as well as sick and disabled people, who stay even longer indoors. Dust in indoor air can be suspended in the air for a long time, PM10 and PM2.5 particles of small diameter permanently stay floating in the air. It is difficult for them to settle on the ground, but easy to be inhaled (Liu et al., 2009). Consequently, air quality of the indoor environment has caused great concern. Indoor dust mainly comes from outdoor air containing dust, body dust, air-conditioning

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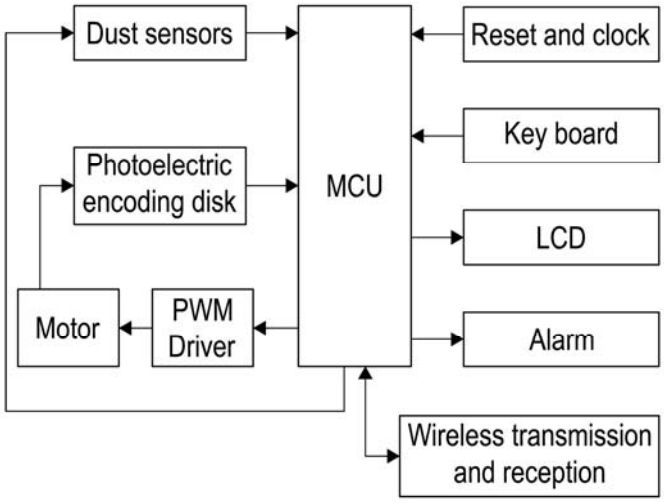

Figure 1. Structural diagram of the dust-concentration monitor.

equipment, smoking, cooking and other human activities as well as furniture, decoration materials, printers, etc., which aggravates indoor environmental pollution and even causes PM2.5 concentration higher than outdoor (Liu and Lian, 2007).

Therefore, it is an important job to take effective measures to control indoor dust pollution. The detection of indoor air dust concentration and dust diameter distribution directly reflect air quality. Therefore, the key is to keep abreast of the dust concentration, and to monitor, control and evaluate the sources of indoor dust pollution, which will encourage people to take effective measures to improve indoor air quality. The primary means to control indoor dust pollution is to develop a portable, low-cost and rapid and effective monitoring instrument with real-time online detection. This paper analyzes the main sources and characteristics of indoor dust and uses dust sensor to collect dust and transform photoelectric signals. It applies micro control unit (MCU) to control the system, process data and designs the dust concentration monitor.

DESIGN PRINCIPLE AND STRUCTURE

Design principle

Light scattering occurs to dust particles in the air when the light catches them. It is because the light will scatter to the surrounding due to the dust particle when certain wavelengths of light enter the dust area. Light scattering parameters are directly related to the dust concentration and the diameter of the dust particles, and the intensity of scattered light is directly proportional to the dust concentration. Through the measurement of the strength of scatter light perpendicular to the direction of the incident light, the concentration of dust particles in the dust region can be inferred (Zhao, 2012). Depending on the angle of scattered light of the dust particles, they are divided into two categories, forward scattered light and backward scattering light. For particles with large diameter, the energy distribution of the scattered light is more concentrated, mainly focusing on the forward direction. However, for particles with small diameter, the energy distribution of the scattered light is relatively wide. The smaller the particle diameter, the more uniform the distribution of forward scattered light and the backward scattered light. If the particle diameter is increased, the components of the forward scattered light will grow, while those of the backward scattered light will decrease.

Overall design

Dust concentration monitor mainly consists of a dust sensor, A / D conversion circuit, a wireless transmitting and receiving circuit, an alarm circuit, MCU (Micro Control Unit), reset and clock circuit, a liquid crystal display, a keyboard, a motor, a PWM (pulse Width Modulation) driver circuit and power supply circuit, etc., as shown in Figure 1. First, the dust particle information is converted into an electrical signal by the dust sensor, and after passing the pre-amplifier circuit of the sensor, it is converted to digital electrical signals by A / D conversion circuit, which is fed to MCU for processing and analysis. MCU will display processed and analyzed data through the LCD display, and when MCU determines dust concentration exceeds preset indicators, sound and light alarm will be given out through the sound and light alarm circuit. Dust concentration monitor can save the data, adjust and view the parameters, and adjust alarm intensity through the keyboard. The wireless transmitting and receiving circuit is used to achieve the sharing and real-time transmission of data and information. Leaves installed to the motor make it become a fan for the intake of air and traffic control.

DESIGN OF KEY COMPONENTS

Photoelectric detection

This paper uses a dust sensor (Model GP2Y1010AU0F, smallest particle detection capability > 0.8 um and sensitivity 0.5 V/0.1 mg/m^3) to design dust concentration monitor to get the dust concentration. The sensor is able to detect pollen, tobacco smoke and other house dust, mainly composed of LED (Light Emitting Diode), lens 1, PD (Photoelectric Diode), lens 2, the flow channel, the measuring chamber and electrical fan, as shown in Figure 2. When the electrical fans maintain a stable

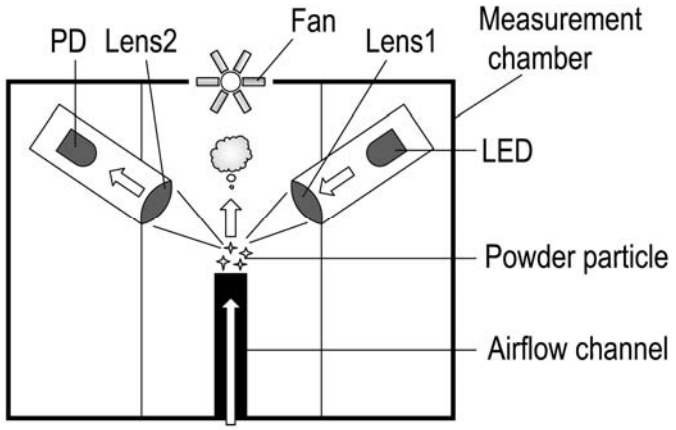

Figure 2. Structural diagram of dust sensor.

rotating speed after being powered by 30 s, external air is inhaled through the airflow channel to measurement points. LED emits strong light into the lens; when lens 1 will change the light emitted from LED into parallel light launched into the flow of measurement points to form a beam. When every dust particle in the air stream passes through the measurement point, it would be scattered by the incident ray, producing the reflected light pulse signal. The reflected light pulse signal is sent through the lens 2 to converge into stronger light pulse signal to PD, and PD will transform the light pulse signal into to an electric signal. As the photocurrent generated by PD is very weak, the dust sensor will pre-amplify it, outputting a 0 V ~ 5 V voltage signal. The voltage is inputted into MCU (Model ATmega2560) after being filtered, and MCU will do the calculation to transform the received data into the dust concentration information of corresponding units.

Air traffic control

With the volume of air divided by the number of dust particles, the monitor could be used to obtain the dust concentration. When the diameter of the air flow path (9 mm) is fixed, the change of the flow rate of air per unit determines the systematic error of the monitor. In the process of air collection, set the acquisition flow and time and calculate the deviation between the actual air flow and theoretical air flow as well as its rate of change according to the reference input and feedback signal. Then it is regarded as a reference after the fuzzy treatment to control the fan motor by calculating the controlling quantity, and regulate the gas flow of fan by adjusting the PWM width. The DC-Micro motor with photoelectric encoder is selected as the fan motor (voltage of 5 V, no load current of 35 mA, locked-rotor current of 320 mA, speed of 2600 rev / min, 334 coded discs and output rectangular pulses). Output 334 pulse voltage with motor running around. This pulse inputs the A / D conversion circuit which will then be used to convert the pressure signal to the digital signal and input it to MCU. Then MCU will generate a PWM control signal according to the number of feedback pulse, aiming to accurately control the motor speed by the motor driver chip (model ULN2003, input voltage 5 V, output voltage <50 V, output current <500 mA) as well as the air flow entering the dust sensor module, and achieve a constant flow of air collection.

Other circuits

Arduino open-source electronic platform, including hardware and software, originates from the open source code simple I / O interface version. The sensor can be easily connected with a variety of electronic components to sense the environment and feedback and affect the environment by controlling various devices. Arduino Mega control panel is adopted to control dust concentration monitor, and MUC on the control board could program by Arduino programming language, which is then compiled into a binary file and burned into the MCU.

HCI is the basic function of the intelligent instrument, which is composed by the keyboard (4 × 4 matrix) and a liquid crystal display. LCD display module (Model MK-D12864E, 2.9 inches with a resolution of 128 × 64) is connected to the system through the serial port and it could receive commands issued by it. The measurement data and system commands menu are displayed, which could achieve the real-time dust concentration and realize HCI.

In order to realize the sharing and real-time transmission of data and information, there are a variety of communication-methods used by dust concentration monitor, mainly including wired serial communications and wireless data communications. The former one adopts the USB interface for charging and computer-connection in order to ensure reliable data transmission. While the latter one adopts the wireless LAN technology and Bluetooth wireless technology to install WIFI wireless communication transceiver module (Model the CC1101, data transmission chip of 433 MHz, 868 MHz, 918 MHz, communication distance <500 m) and achieve wireless data transmission. In addition, to be connected to a smart phone, the reference node could also be set and the location information of each reference node is stored on the computer of the monitoring center to achieve the node positioning functions.

CALIBRATION TESTS

When measuring the dust concentration using dust

concentration monitor, it is necessary to take into consideration the monitor system error, so the parallel calibration method is required to improve accuracy. According to the height of people's breathing, the height of the sample point is 1.3 ~ 1.6 m without using any air-conditioning system, so the calibration test is carried out under the condition of natural ventilation. Install a Laser Dust Monitor next to the monitor (Model LD-5L, configuring the 40 mm filter sampler, cutter TSP with replaceable particles, PM10, PM5, PM2.5, detection sensitivity of 0.01 mg/m^3, measuring range of 0.01 ~ 100 mg/m^3, repetitive error ± 2%, measurement accuracy ±10%, directly-readable dust mass concentration mg/m^3) when measuring the dust concentration. Record 10 sets of data measured by the detection system and take their average value as the measured value of the detection system. Record 10 sets of data measured by the laser dust monitor and take their average value as its measured value. Compare them to verify the accuracy and error of the monitor system, and extract its functional data. Input the data in the software as a relevant basis, and adjust the motor speed of the fan of dust concentration monitor via software until it is close to the measured value of the laser dust monitor.

Conclusion

The application shows that this dust concentration monitor are superior in many ways, including simple circuit structure, high integration level, easy-to-use, simplified detection process and operation, and low cost, etc. Therefore, it could be used to grasp the indoor dust concentration distribution and reduce the harm to us caused by the dust. This monitor not only can be used as stand-alone equipment, but also can be combined with a variety of sensors by the serial port integration, thus detecting indoor environmental parameters and controlling the environmental facilities to purify indoor air.

Conflict of Interests

The author(s) have not declared any conflict of interests.

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