A dust sensor monitoring system using Wi-Fi mesh network

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Abstract. This paper proposes a dust sensor monitoring system using Wi-Fi mesh network, including wireless dust sensor node and Wi-Fi mesh networking procedure. The wireless sensor node is made by integrating a dust sensor based on GP2Y1010AU0F chip, a STM32F103ZET6 chip as its MCU, a Wi-Fi module as its wireless transceiver, and a LCD screen as its user-interface. The dust sensor takes the light scattering method, measuring the flash frequency and the duration reflected by particles in the air flow. Dust sensor nodes are networking by Wi-Fi mesh network. Practical experiments validate the effectiveness of the proposed system. The measuring error of dust concentration is less than 5%. As the network is made up of 8-10 nodes, if the root node is disconnected, the network recovery time is less than 9 seconds while the other nodes' is less than 5 seconds.

1. Introduction

With the rapid development of modern industry, productive dust is almost everywhere in the factory, which has become a major hidden danger of industrial production safety. For example, the amount of dust produced by mine increases rapidly, which damages the health of workers and brings insecurity [1]. Dust will reduce the quality of products and machine precision, and workers working in the environment full of dust for a long time will bring great harm to the body. If the concentration is too high, it will even cause explosion and cause great economic loss. Also, the risk of explosion in the textile industry has been underestimated and is probably still unknown to a great extent [2]. If we can monitor the dust concentration, of course, we can prevent it in the bud. The emergence of dust concentration sensor solves the problem that dust sampler and direct reading dust detector can't monitor the dust concentration in real time.

In recent years, the development of intelligent sensors, wireless communication technology and Internet of things [3] has promoted the integration of dust on-line monitoring and processing.[4] The distribution modes of wireless sensor networks include WLAN, Bluetooth, Zigbee [5]. Among them, the traditional Wi-Fi network has the disadvantage of limited coverage area because each station must be directly connected with AP within a certain range. In addition, traditional Wi-Fi networks are prone to overload because the maximum number of stations allowed in the network is limited by the AP capacity.[6] Bluetooth technology transmission distance is limited, and the speed is very slow. ZigBee of which communication frequency is 2.5GHz has a high network cost. The diffraction ability and the ability to pass through the wall is weak. Members of the group search for the information and learned that a high-performance distribution network mode, Wi-Fi mesh [7].

Wi-Fi mesh, wireless mesh network, which is a high-capacity, high-speed distributed network [6], is a multi-hop, self-organizing and self-healing broadband wireless network structure. Wi-Fi mesh can connect wireless routers far away from each other through some intermediate nodes, that is to say,

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each node in the network can send and receive signals. When one node can no longer operate, the rest of the nodes in the WMN can still communicate with each other, either directly or indirectly through one or more intermediate nodes. Many problems such as low scalability and poor robustness of traditional WLAN are solved. In addition, Wi-Fi mesh has bandwidth comparable to wired broadband [8].

Based on this background, the system combines dust concentration sensor, Wi-Fi mesh network and LCD data display to construct intelligent sensor network.[9] The system covers a large area and is suitable for large-scale deployment. Network transmission performance is excellent and not easy to overload. It is suitable for long-term use because of strong stability and high reliability and easy to realize network interconnection without purchasing expensive gateway. The system can automatically network which greatly reduces the cost of human resources, so that users only need to connect to the power supply while using.

2. Design of system

The dust monitoring and processing system based on Wi-Fi mesh is composed of personal devices, router (Gateway) and intelligent sensor network. The dust monitoring and processing system structure is shown in the figure 1.

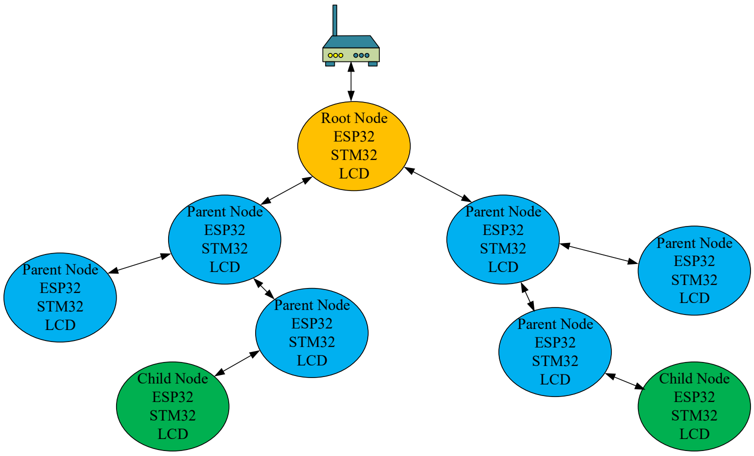

Figure 1. The dust monitoring and processing system structure.

In this system, the intelligent dust sensor node is controlled by STM32 to collect the dust concentration in the environment. When the concentration exceeds the set threshold, the buzzer will give an alarm. STM32 will transmit the collected dust concentration data to ESP32, and the ESP32 of each node will transmit the data through Wi-Fi mesh network. Each node is also equipped with LCD to display dust concentration data.

3. Design of Wireless Sensor Node

In this system, the main functions of intelligent dust sensor network node are data monitoring, data processing and transmission. The node is mainly composed of power supply, dust concentration sensor, microprocessor and communication module. The high precision GP2Y1010AU is selected as the dust concentration sensor. The microprocessor uses STM32F103ZET6 ARM chip as the main control chip. The chip is a 32-bit ultra-low-power MCU with clock frequency up to 72Mhz. It has large storage capacity, high integration of on-chip peripherals and fast processing speed. The communication module adopts ESP32 developed by Espressif company, which has the characteristics of stable performance, high integration and ultra-low power consumption. ESP32 not only integrates traditional Bluetooth, low-power Bluetooth and Wi-Fi, but also supports data transmission rate of 150 Mbps and antenna output power of 20 dBm, which can achieve the maximum range of wireless communication. The structure of wireless sensor node is shown in the figure 2.

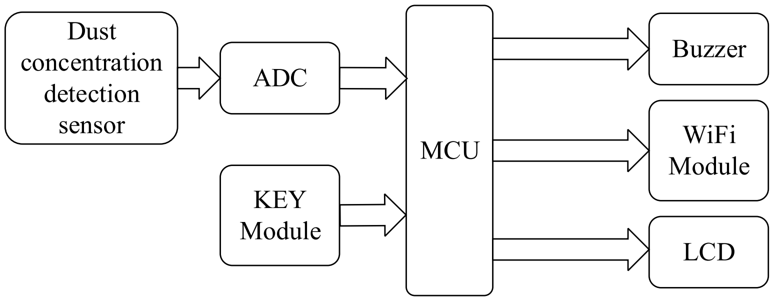

Figure 2. Structure of wireless sensor node.

4. Wi-Fi mesh networking process

The project uses ESP-mesh to build the Wi-Fi mesh network of the project. ESP-mesh is a network protocol based on Wi-Fi protocol. ESP-mesh allows a large number of devices (hereinafter referred to as nodes) distributed over large physical areas to interconnect under a single WLAN.

The topology diagram contains ten dust wireless sensor nodes, and the RSSI value of each node is marked in red font near the nodes. When the nodes are connected successfully, the solid line is used to connect, and the dotted line is used when the connection between nodes is broken. Photo 1 describes the process of each dust wireless sensor node forming the WSN in a space. Photo 2 describes the process of WSN recovery when the root node fails. Photo 3 describes the process of switching the root node when the RSSI value of the root node is reduced to a lower level. Photo 4 describes the process of the WSN recovery when a parent node fails.

1. Networking Building Process

The construction process of Wi-Fi mesh network includes[6]: ①Selecting the root node E. ② Forming the second layer. ③Forming the remaining layers. ④Limiting the depth of the tree. The node E with the strongest RSSI which is selected as the root node connects to the router and allows the formation of downstream connections. The free nodes in the RSSI range of the node E begin to connect with the node E to form the second layer including nodes C\F\G. The remaining idle nodes B\D\H\J are connected with the RSSI range of the second layer node to form a new layer. When the network level reaches the maximum allowable level, the nodes A\D\I\J on the maximum allowable level will become leaf nodes. It is also stipulated that other free nodes are not allowed to connect with leaf nodes.

2. Root Node Failure

After the root node fails, the process of WSN recovery includes: ①Root node E is disconnected from the router. ②Second layer node tries to reconnect with the root node. ③Starting a new root node election and electing node G to connect with the router. ④Connecting the second layer node with the root node. For the new root node election, the node which has the strongest RSSI among the original second layer nodes will be selected as the new root node.

3. Root Node Switching

When the RSSI value of the root node decreases to a certain degree, but it has not reached the level of disconnection, the current root node will instruct the nodes in the network to initiate a vote. At this time, the current root node remains connected. If the current number of votes of the root node is still the largest, the root node remains unchanged. Otherwise, the root node will be replaced with another node with the largest number of votes. The working process is as follows: ①Root node E initiates voting and disconnects from router. ②Root node E disconnects from new root node G and keeps the remaining connection unchanged. ③New root node G connects with router. ④New root node G establishes connection with layer 2 node E.

4. Intermediate Parent Node Failure

When the intermediate parent node fails, the recovery process of WSN is as follows: ①After the failure of reconnecting with the parent node, the child node will disconnect from the parent node. ②

Child node begins to look for a new parent node and forms a connection. Since there is no parent node in the range of node D, node D and node B form a connection after node B selects node F as the parent node. The child node remains idle indefinitely if it has no other potential parent node.

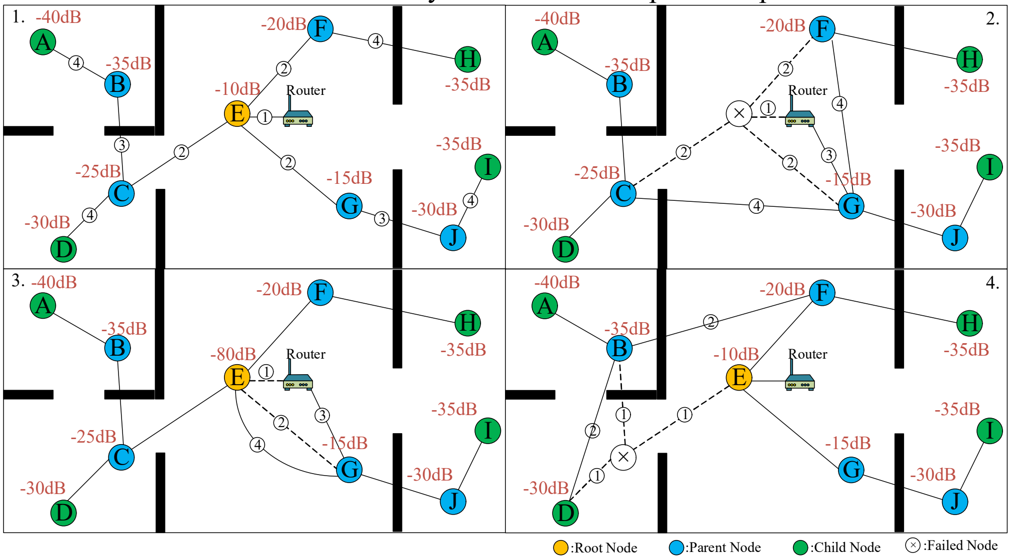

Figure 3. Wi-Fi mesh networking process.

5. System Hardware Design

5.1 Microcontroller Unit circuit design

The MCU of this system is STM32F103ZET6 designed by ST company, and the core is Cortex-M3 with excellent performance. The maximum clock can reach 72MHz. The built-in ADC can convert the data from the dust sensor. The power consumption is low. The program memory capacity of STM32F103ZET6 is 256KB and the RAM capacity is 48K. The microcontroller unit circuit design is shown in the figure 4.

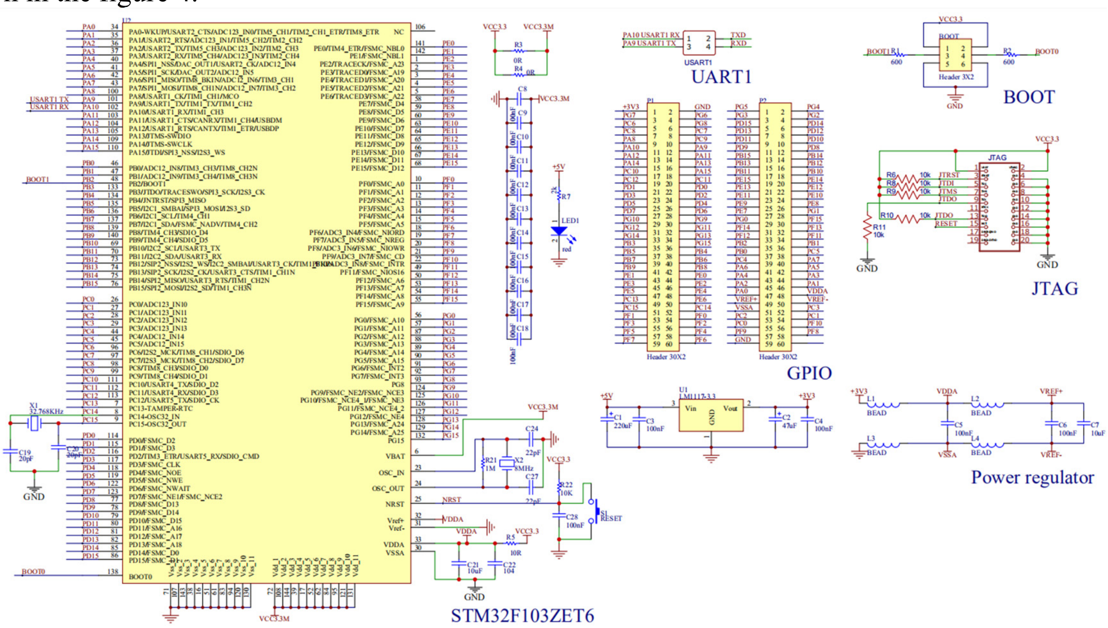

Figure 4. Microcontroller Unit circuit design.

STM32 MCU circuit is made up of five parts: STM32 minimum system design, JTAG debugging design, voltage regulating circuit design, UART communication design, GPIO output. Reset circuit and crystal oscillation circuit are the components of STM32 minimum system. The system works under the basic clock signal generated by crystal oscillator circuit. When the program is out of control, the reset circuit will make the program return to its original state. The JTAG debugging circuit can help programmers download and debug programs so that they can reduce the probability of program errors. The voltage regulating circuit changes the 5V by the power supply to 3.3V of the chip. UART communication ensures data transmission between ESP32 and STM32. The introduction of GPIO pin facilitates the design of more functions in the future.

5.2 Dust Sensor Interface Design

GP2Y1010AUOF takes the light scattering method, measuring the flash frequency and the duration reflected by particles in the air flow. An infrared emitting diode and an phototransistor are diagonally arranged into this device.[10] In particular, it is very effective to detect very fine particles such as cigarette smoke. Besides, it can distinguish the smoke and dust by the pulse waveform of the output voltage. [10] Based on the manufacturer's recommendation, a 150Ω resistor and 220uF capacitor were added to the pin 1.[11] The sensor has 6 pins, 1 is the separate power supply terminal (infrared circuit), 2&4 is the grounding terminal, 3 is the infrared terminal, 5 is the signal output terminal, and 6 is the separate power supply terminal. The dust sensor circuit design is shown in the figure 5.

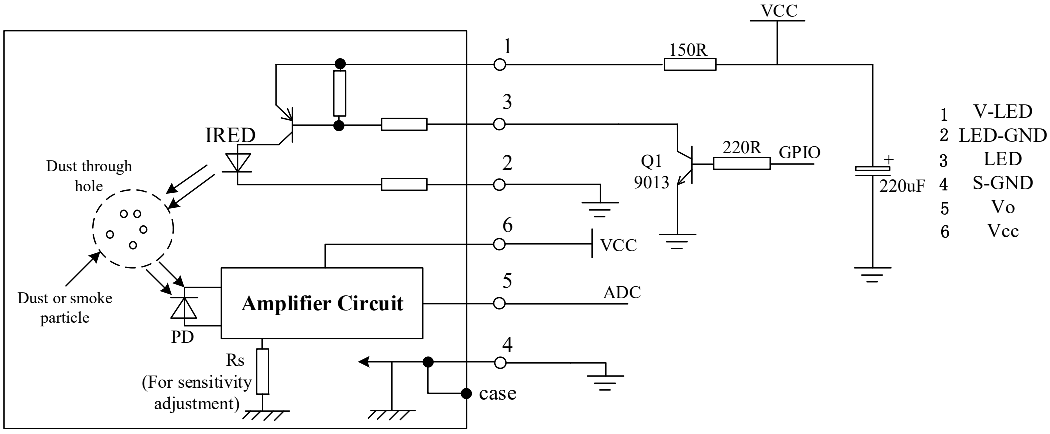

Figure 5. Dust sensor circuit design.

6. System Software Design

The system software design is made up of two parts: the MCU processing program and the mesh networking program. Figure 6 is the flowchart of system software design.

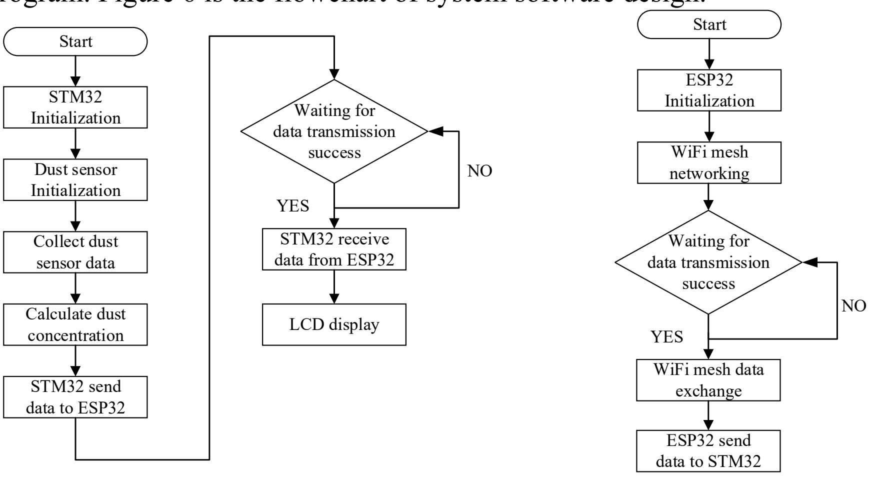

Figure 6. System software design.

Firstly, STM32 and dust concentration sensor module are initialized. After initialization, the dust sensor collects the dust concentration in the environment and sends the data to STM32. STM32 calculates the data through the algorithm, and then sends the calculation results to ESP32 through the serial port. After waiting for the data transmission, STM32 waits to receive the data sent by ESP32. STM32 displays the dust concentration and received dust concentration on LCD. The flow chart of program design is shown on the left side of figure 6. ESP32 will be initialized first. Then enter Wi-Fi mesh distribution network mode, and wait to receive the data sent by STM32 after the distribution network is successful. After receiving, the data is exchanged between nodes through Wi-Fi mesh network, and then the data is sent to STM32.

7. Test result analysis

Test scheme: environmental dust concentration was tested and calibrated by standard instrument TSI-8532. TSI-8532 can measure dust concentration in the range of 0.001 to 150 mg/m3, which is a high-precision dust concentration measurement instrument. The robustness of Wi-Fi mesh network is tested by measuring the recovery time of the network after a node in the wireless sensor network is cut off. The real product photo of the wireless sensor network in the lab is shown in figure 7. And the LCD display is shown in figure 8.

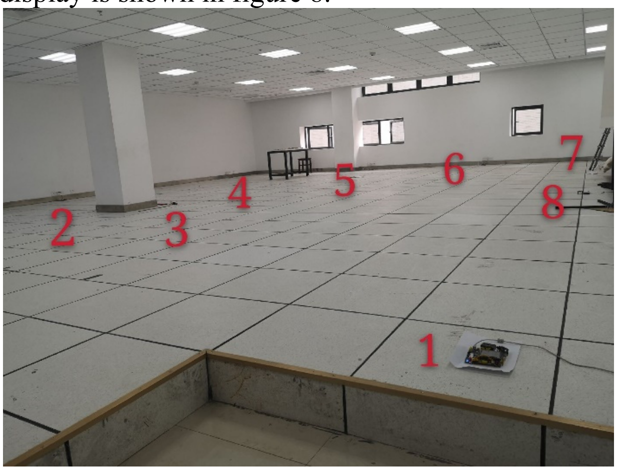

Figure 7. The real product of the WSN.

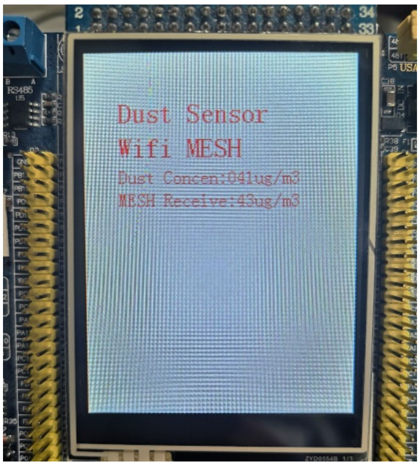

Figure 8. The LCD display.

In the environmental dust concentration test, the dust concentration in the laboratory environment, external environment, smoke environment and flour environment are tested respectively. After many tests and calibration with the standard instrument test results. The experimental results are shown in table 1.

Table 1. Dust concentration experimental results.

Environment Type	Measurement Results(ug/m^3)	Calibration Results(ug/m^3)	Measurement Error
Laboratory	37	38.79	4.84%
External	63	65.77	4.40%
Smoke	214	224.26	4.58%
Flour	483	502.37	3.86%

After testing, the measurement error of dust sensor is less than 5%, which has high precision.

There are 8-10 nodes in the network. After the Wi-Fi mesh distribution network is successful, disconnect the power supply of a node arbitrarily, and measure the time spent on the restoration of mesh network. After many tests, several typical values are taken out. The experimental results are shown in table 2.

Table 2. Network robustness experimental results.

Node Type	Time Spent(s)
Root Node	8.65
Parent Node	4.89
Chile Node	4.27

8. Conclusions

The paper proposes a dust wireless sensor network system based on Wi-Fi mesh networking. The results show that the system has high accuracy in dust concentration measurement. In the aspect of Wi-Fi mesh networking, the fast networking time and short repair time can prove the good robustness of the network. In addition, the system can organize the network in an ad-hoc manner without human involvement, which is beneficial to human health in dust room.

Acknowledgments

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