Intelligent IoT Based Dust Concentration Measuring and Monitoring System

BUI Dang Thanh

Abstract— *This paper presents an approach for research, design, and implementation of a dust concentration measuring and monitoring system with the Internet of Things (IoT) application. Dust concentration measuring devices, in the system, are designed with Corter-M3 Microcontrollers (MCUs) STM32 and dust sensing elements based on the principle of laser scattering. Besides, a software program is developed on Webserver that allows collecting data from remote measuring devices, storing and processing gathered data using calculating algorithms, displaying information chronologically and geographically, and alerting multiple air quality levels. Experimental results show that the system worked stably at three different locations and can measure PM10, PM2.5 dust concentration up to* 999µg/m3.

***Keywords*— PM10, PM2.5, laser scattering, air quality, IoT.**

1. INTRODUCTION

Air pollution is one of the serious problems of urban areas. Air quality assessment is closely related to measuring and monitoring dust concentration. The two most common fine dust types that have a major impact on human health are PM10 and PM2.5. Thus, the research and development of dust measuring and monitoring systems with IoT-based applications is an urgent need to warn and support the improvement of the health of the community.

There have been several methods of measuring dust concentration in scientific reports including the method of measuring dust concentration according to the Gama principle [1]. Despite being a highly accurate measurement method, the large size and high cost characteristics make the Gama principle-based devices not suitable for online measuring and monitoring devices. On the other hand, the traditional method for determining dust concentration needs to calculate the volume [2], which also gives accurate results at low cost. However, to obtain results, operators need to wait for a long enough time, which limits the application of traditional method. In fact, dust concentration measuring methods using laser scattering has become the most popular method [3]-[4]. They allow determining the concentration of dust with the convolution accuracy.

Currently, research on wireless sensor-based surveillance systems [5]-[6] has been developed, including multiple wireless sensor nodes and gateway. This system provides a unique, wireless and easy solution with better spatial and time resolution. Therefore, the application of smart IoT for measuring and monitoring systems are highly on demand [7]-[8]. These systems allow Server to collect data, process and give different levels of alert to users.

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In this study, we focus on researching and developing of a dust concentration measuring and monitoring system based on smart IoT technology. Three dust concentration measuring devices using laser scattering method have been developed for different requirements. These devices can operate continuously for a long time with a wide measuring range. In addition, the software can be changed flexibly to improve function, accuracy or reliability. The developed devices could be placed anywhere by using telecommunications networks to transmit data with Webserver. Built-in webserver can connect to multiple devices at the same time, store and display measurement results accurately, continuously and intuitively.

2. MEASURING PRINCIPLE

The measuring method employed in this study is laser scattering. When a laser beam passes through dust-free air, light from the beam is not scattered. If dust exists in air, the light will be scattered around. Scattered light is then collected by a detector and converted into an electrical signal to be amplified and processed. Number and diameter of particles can be obtained by analyzing the signal because its waveform has a certain relationship with the particle diameter.

Based on the photometric method, optical dust measurement principles in this paper are based on the attenuation of the intensity of a beam of light by absorbing and dispersing into spatial environment with the solid particles.

Beer–Lambert law [9] describes the relationship between the transmitted light and dust concentration *c* according to the following equation:

$$I = I_0 . e^{-\varepsilon . l . c} \tag{1}$$

where:

- I_0 is the initial intensity
- I is the resulting intensity of the light beam
- l is the measuring distance
- ε is the coefficient of extinction

- c is the dust concentration. The optical dust concentration principle schematic is presented in Fig. 1.

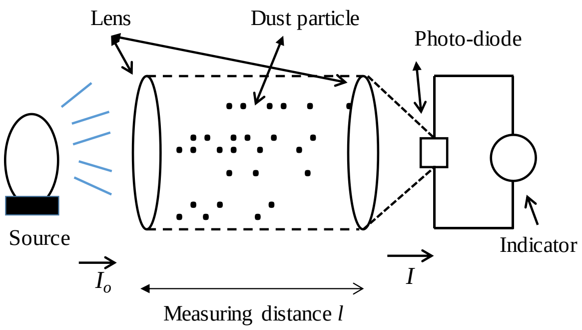


Fig. 1. Schematic Diagram of the Dust Concentration Measuring Principle.

3. SYSTEM DESIGN

Block diagram of the smart IoT based measuring and monitoring system for dust concentration is shown in Fig. 2.

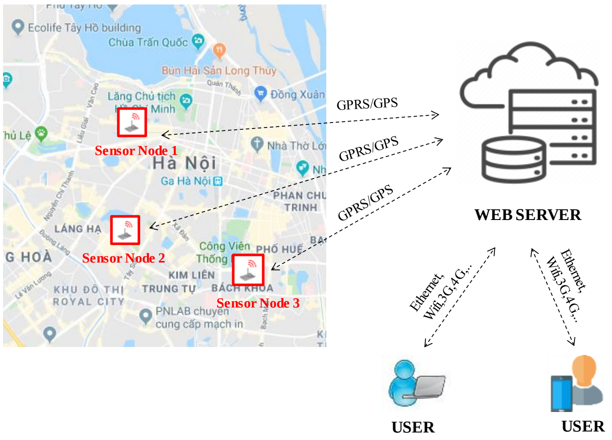


Fig. 2. System Block Diagram.

We developed three dust concentration measuring devices (Sensor nodes) that utilize wireless communication to send measured values to Webserver. A software program has been developed on Webserver with purpose of collecting measured data from sensor nodes, storing, performing information display and warning functions. In our system, users can easily access statistics and alerts on the web interface.

3.1 Sensor Node Block Diagram

Sensor node was built based on STM32F103 microcontroller. The measured data from sensing element is transmitted to microcontroller unit (MCU) via Universal Asynchronous Receiver Transmitter (UART). Using data processing algorithms, MCU processes the received data, removes noises and displays results on LCD screen before packaging and sending them via wireless connection protocols. In order to send packets from sensor nodes to the Webserver, we have defined a data frame according to the user protocol. The frame includes the start delimiter field, end delimiter field, and address field to identify the address of the sensor nodes as well as the frame check sequence field. Fig. 3 describes block diagram of a sensor node.

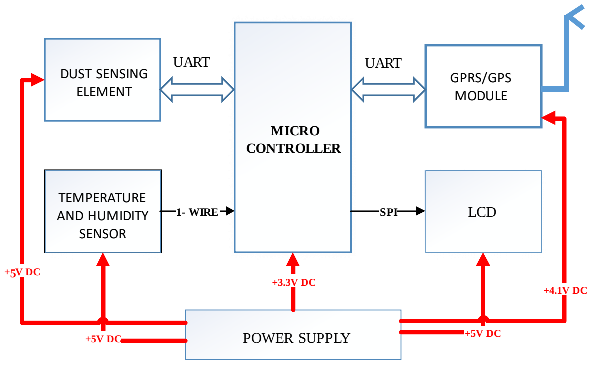


Fig. 3. Block Diagram of Sensor Node.

Besides the use of a dust measuring element, a temperature and humidity sensor was also integrated in this device. Measured data from temperature and humidity sensors will support algorithms for calibrating dust measurement data. Sensor nodes send data to Webserver by GPRS module. Measured results were stored and displayed on Webserver.

3.2 Microcontroller Unit

To enhance the ability of process information as well as open functions for the device, it is necessary to have a strong MCU to perform this task. However, the price of the MCU should be taken into account. In this study, STM32F103C8T6 of ST Microelectronics has been chosen for this study. These are enhanced performance chips of ARM Cortex-M3 core, 32-bit RISC operating at 72MHz frequency, which are capable of handling all communicative tasks as well as fast transmitting to sensor elements. STM32F103C8T6 chips have common communication interfaces including: 02 I2C-ports, 03 SPI-ports, 05 UART-port, and 01 USB&CAN-port.

3.3 Dust Sensing Element

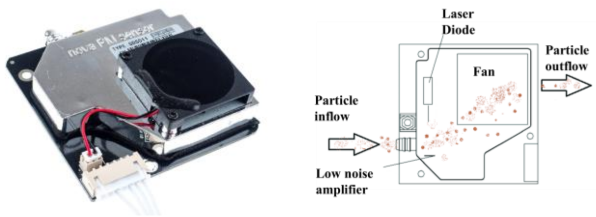
Dust sensing element used in this study was SDS011 from Nova Company, operating based on the principle of laser scattering. This element can measure floating dust particles of 0.3-10µm diameter within range of 0 ÷ 999 $\mu g/m^3$ with high accuracy, hence making it specifically suitable for measuring PM10 and PM2.5 in different environments. Description of SDS011 function is presented in Fig. 4.

3.4 Temperature, humidity sensor

The temperature and humidity sensor used in this study was DHT22 module. This is an intelligent sensor that allows measurement of ambient temperature and humidity. Built-in sensor includes:

- Humidity signal converter based on the principle of impedance (resistive-type).

- Temperature signal converter based on the principle semiconductor thermistor, NTC type (resistance decreases with increasing temperature and vice versa).
- 8-bit digital processor to digitize measurement results and communicate with the MCU.



a) Real image of the sensor

b) Dust measuring principle of the sensor

Fig. 4. SDS011 Sensor.

3.5 Other Components

- ***LCD Screen***

Measured results were displayed directly on LCD screen of the Sensor Node. The screen used was Nokia's N5110. LCD communicates with microcontroller via SPI interface. Screen resolution is 84x48 monochrome pixel and its interface use SPI Interface.

- ***Power Source***

The power supply was designed with various voltage outputs: 3.3V, 4.1V and 5V to provide the components in the device.

- ***Communication part***

In this study, we used Sim808 module to communicate with Webserver. Sim808 is an upgrade of Sim908 with full features of GSM/GPRS/GPS but with higher accuracy. The module supports the bandwidth of 850/900/1800/1900MHz and can be programmed by using AT instructions.

4. SOFTWARE IMPLEMENTATION

After being sent out through serial communication in the form of 10-byte packages from the sensing element SDS011, the measured values bytes (PM2.5 and PM10, temperature and humidity) were gathered and calculated to find out accurate results with MCU algorithm. Processed data was then transmitted through UART to GPRS modules before uploading to Webserver facilities with the support of AT instruction set. The final task was recording measured parameters along with ID of each sensor node and displaying in chronological order for users to supervise air quality across covered areas. The data flow diagram is shown in Fig. 5. This diagram shows the progress of the data flow from the sensor nodes to the data collection, web application software and finally to the user.

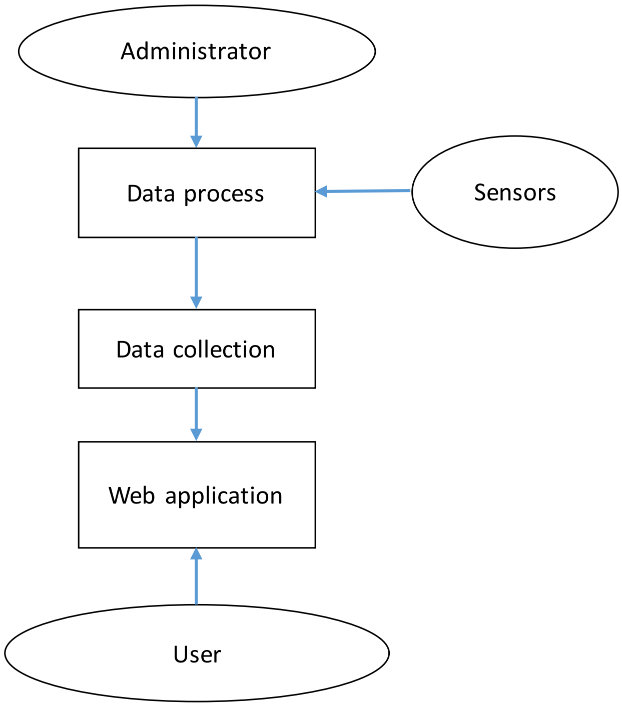


Fig. 5. Data Flow Diagram.

The context diagram is presented in Fig. 6. This diagram describes an overview of the environment in which the system will operate and describes the interaction between system, administration and users. The diagram also represents operations such as:

- Administration collect data from sensors, store data and create display interfaces.
- Users can follow the results on the interface that has been created.

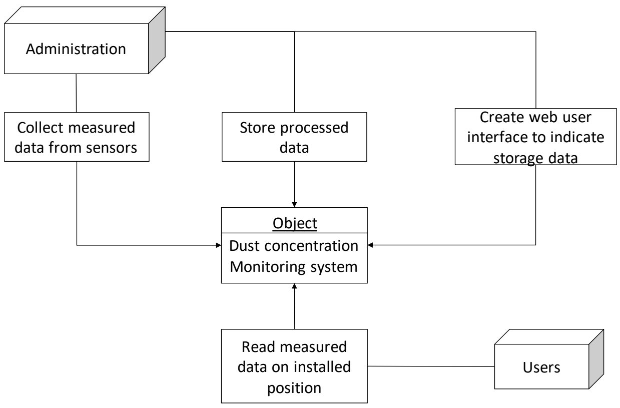


Fig. 6. Context Diagram.

The sequence diagram shown in Fig. 7 describes interaction between components of the system. The administrator first gets the data from the sensor, processes and then sends calculated data to server. User will access server through the graphic interface to reach processed environmental data. This operation sequence can be done with different sensor nodes within the system. The identification of these nodes as well as their data are distinguished by the individual addresses attached to the data transmission frame.

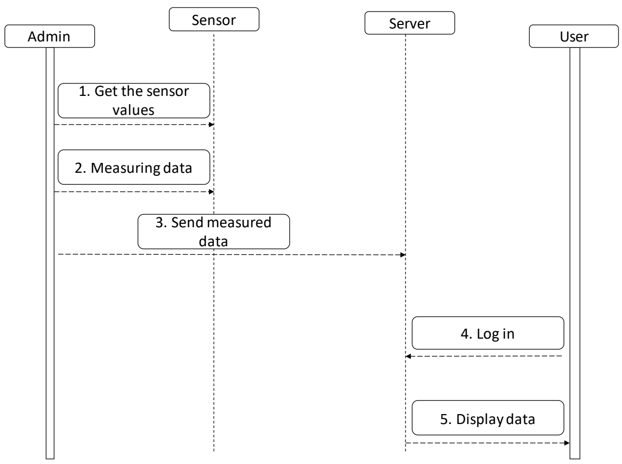


Fig. 7. Sequence Diagram.

4.1 MCU Algorithm

MCU software program has been developed using IDE KeilC V5. The algorithm is presented in Fig. 8. The first step is to initialize the system parameters, initialize UART1, UART2, and SIM808 module. Next, MCU will read data from sensors (temperature, humidity and dust sensor) in the sensor node, and check for any errors after transmission. Finally, the parameters of PM10 and PM2.5 dust concentration will be calculated according to the algorithms developed in the MCU and send this post-processing data to the Webserver and LCD.

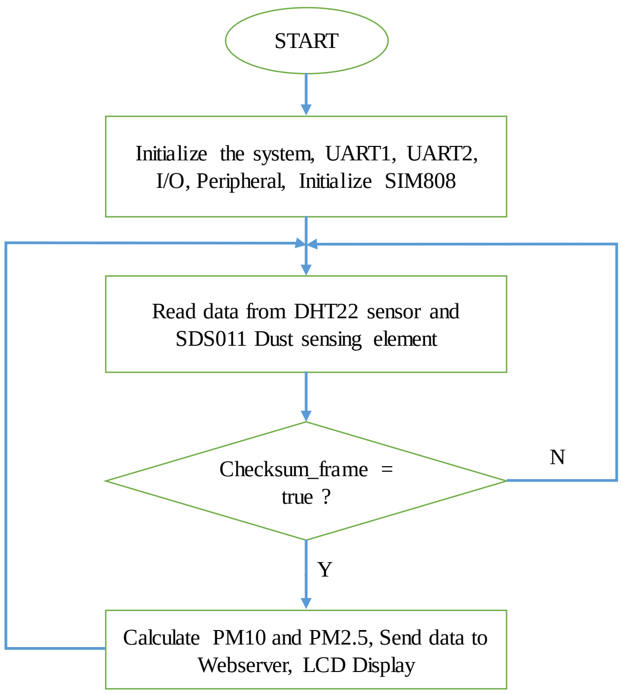


Fig. 8. Operation Algorithm of MCU.

4.2 Data Receiving Interrupt Flowchart

Communication protocol from sensor node to Webserver was programmed on the SIM 808 module. To assure reliability of serial transmission between MCU and sensor element, a receiving interrupt was used to check if the quantity and value of bytes from UART buffering registers were correct or not. Data will be received from the in-buffer until the number of data bytes reaches 9. The received data was then added with information about error correction, packed into frames and transmitted to the webserver. The flowchart for checking received data integrity from sensor is illustrated in Fig. 9.

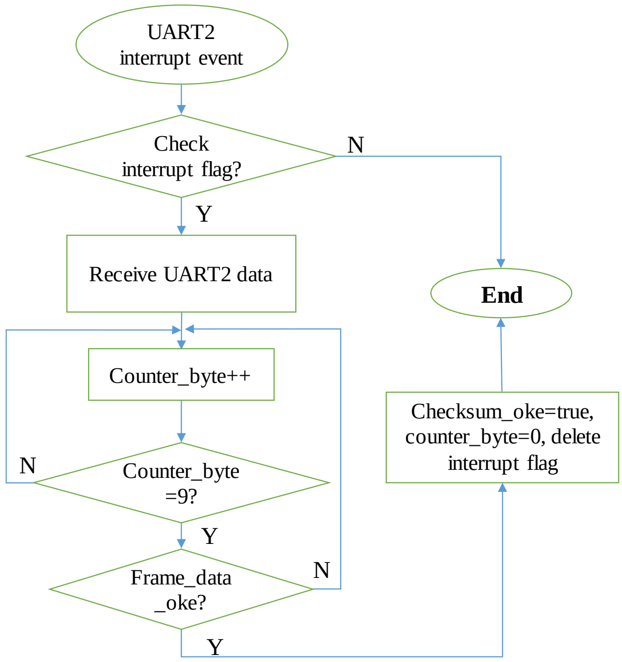


Fig. 9. Sensor Output Data Checking Interrupt Flowchart.

5. EXPERIMENTAL RESULTS

5.1 Sensor node

We have conducted laboratory tests, calibrated accuracy and conducted dust concentration measurements in different areas of Hanoi. Initial results show that the long-term operation of the device was stable. Data from these devices was transmitted completely to the Webserver. Experimental hardware of the device measures the dust concentration is shown in Fig. 10.

5.2 Software interface in Webserver

The software developed on Webserver allows displaying PM2.5 and PM10 dust concentrations in both numerically and in wave diagram. If there is any exceeded warning threshold, a notification will appear on the screen. The interface of the software program is shown in Fig. 11. This measurement data was carried out at Tran Dai Nghia Street, Hanoi, Vietnam. The red and blue graphs show the corresponding evolution of PM10 and PM2.5 dust concentrations. The present value of PM10 was 49$\mu g/m^3$ and PM2.5 was 22$\mu g/m^3$. Temperature and humidity were 33^{o}C and 51%, respectively.

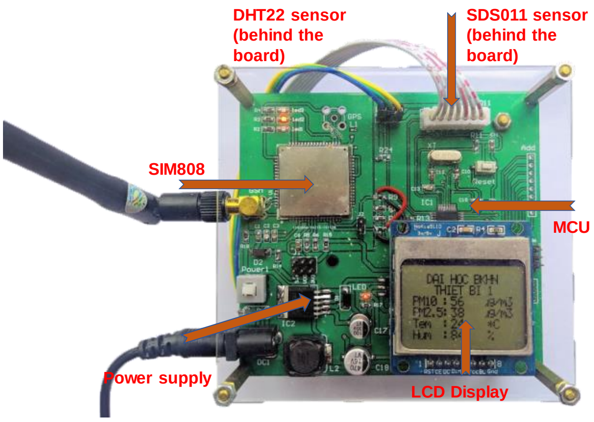


Fig. 10. Sensor Node Hardware.

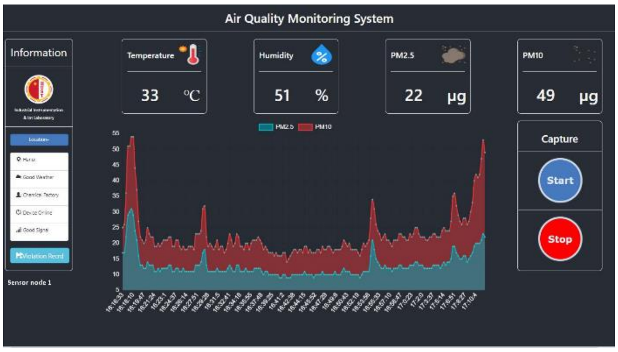


Fig. 11. Dust Concentration Evolution at Tran Dai Nghia street, Hanoi, Viet Nam.

At the same time, we also read the data on sensor node 2 at Hanoi University of Science and Technology (HUST). It can be seen that the concentration of PM10 and PM2.5 dust in schools was quite low compared to that of streets. Evolution of measured values is shown in Fig. 12.

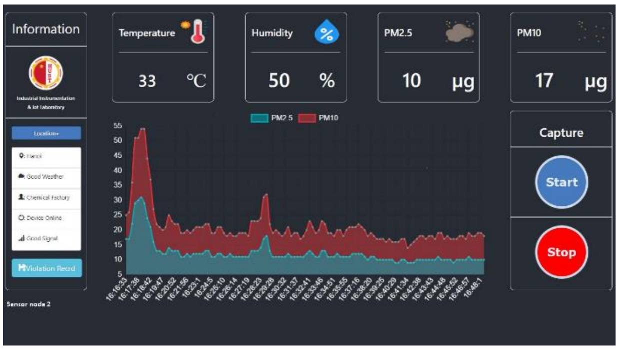


Fig. 12. Dust Concentration Evolution at HUST, Hanoi, Viet Nam.

We also collected data on PM10 and PM2.5 dust concentrations with sensor node 3 located at the side of Dai Co Viet street, Hanoi, Vietnam. There was a slight difference in temperature from the above 2 measurement points. Evolution of measured values at this location is shown in Fig. 13.

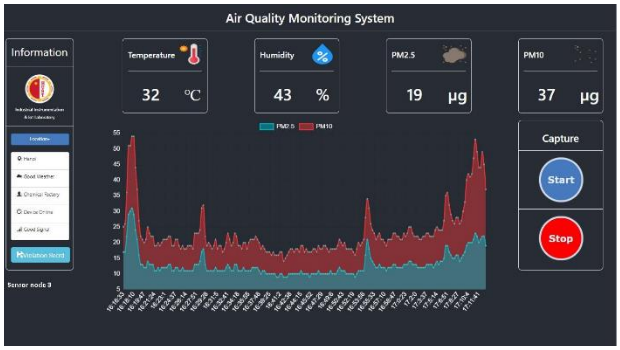


Fig. 13. Dust Concentration Evolution at Dai Co Viet street, Hanoi, Viet Nam.

6. CONCLUSION

We have successfully designed and implemented three dust concentration measuring devices. These devices can measure dust concentrations within the range of 0 ÷ 999 µg/m^3 (for PM10 and PM2.5). The data will then be transmitted to Webserver, afterward, they will be processed according to algorithms before being displayed and stored. Data exchange algorithms and errors compensate algorithms (due to changes in temperature, humidity) have operated properly designed. Initial tests at three measurement points have shown that the system designed for intelligent dust concentration measurement on the IoT platform has run stably. The sensor nodes created in this system are inexpensive, allowing them to expand the network with a larger number of points. The expansion of multiple points along with further weather parameters measurement will allow a large amount of data to be processed, helping us develop new system features such as forecasting the air quality level and the spread of pollution in urban areas.

ACKNOWLEDGMENT

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