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Development of an Airflow Monitoring System for Air Handling Unit using IoT

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Abstract

This paper presents the development of an airflow monitoring system for air handling units using NodeMCU ESP32. The main purpose of this project is to improvise the use of microcontroller with on-par performance for industrial applications. This proposed system consists of two sensors that measure airflow from the air handling unit. The first sensor is an airflow speed, which measures the airflow speed from the air handling unit. The second sensor detects and indicates the temperature and humidity of the airflow. The testing parameters show very good correlations among variables, indicating the efficiency of the system to monitor the airflow.
Keywords: Airflow, IoT, Temperature, Humidity, Air Handling Unit

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1.0 Introduction

Air Handling Unit (AHU) is a vital part of the Heating, Ventilation and Air Conditioning (HVAC) system inside a building. The main function of AHU is to purify or renew the building's indoor air quality with fresh air intake. AHUs are usually installed on the rooftop or at any suitable building area and circulate the air into each room and space inside the building through the ducts. Any failure of the AHUs unit can cause the HVAC system to operate inefficiently. It will lead to energy waste and poor indoor air quality and might increase the building operating costs (Leong, 2019).

HVAC systems include a variety of devices such as dampers, sensors, and controlled actuators. To ensure the efficient operation of an HVAC system, AHU should always be kept in optimal operating condition. Thus, a mechanism to regularly monitor the airflow from the air handling unit is necessary to maintain its good performance. Specifically, it is crucial to monitor the airflow, temperature, and humidity measurements in all the ducts close to the air handling unit. The next section presents the literature review of airflow monitoring systems.

2.0 Literature Review of Airflow Monitoring Systems

There are many attemps to develop HVAC systems in existing literature on this area. Research articles that are related to the development of HVAC systems include Bentley (2005), Hoffman (2014), Hunt (2012), Leong (2019), Roulet *et al.* (1999), which proposed the estimation

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of airflow in air handling units by electrical measurement. This method uses the current and voltage measurements at the fan motor's electrical terminals to generate estimates of average flow through the fan. In addition, this method generates numerical estimates of the flow through the duct, which can be used to detect any fault in the air handling unit. However, the proposed method has an issue where it is hard to implement and is not a portable device.

Roulet *et al.* (1999) proposed measuring airflow rates and ventilation efficiency in air handling units using the tracer gas technique. This method can be applied to any unit and allows the detection and quantification of unexpected airflows, such as leaks or shortcuts. However, the poor mixing of the tracer gas with the airflow in the air handling unit causes wrong airflow rates, which are frequent in the actual system. Furthermore, this method requires proper preparation and specific knowledge to interpret the tracer concentration.

2.1 Issues Identified with HVAC Systems

Over the following years, there has been a progressive improvement in the design of HVAC units along with the improvement in science and technology. For example, a more recent method that has been used is the pressure differential method. Ronneseth *et al.* (2019) used the pressure differential method to determine the airflow. This pressure differential method is relatively accurate and thus used as the reference measurement. However, it is unsuitable for duct flow measurements due to its high-pressure penalty and long straight duct requirement. Another issue reported with these systems is that they are sensitive, expensive, and caused additional pressure drops (Bentley, 2005). The devices' sensitivity also decreases as the airflow velocity decreases.

As buildings evolve, they will require higher levels of insulation and air tightness, so ventilation systems will need to provide a minimum number of air changes and lower energy consumption by recovering heat from the air before it is expelled. This necessitates monitoring the operational performance of these systems so that the air quality or energy efficiency of the building is not compromised (Hirata *et al.*, 2009). Monitoring airflow rates can indicate problems in the design, installation, and operation of an AHU system (Hirata *et al.*, 2009; Han *et al.*, 2012).

2.2. Objective and Significance of the Study

Following the review literature and issues identified with HVAC systems, this paper presents an improved method for monitoring the airflow of the air handling unit at the duct by measuring the airflow speed, temperature, humidity, and air density values. This system consists of several important sensors and components, which are the DHT11 sensor, Infrared (IR) sensor, LCD to display the measurement value, and NodeMCU ESP32 microcontroller board. In addition, this system is integrated with Internet of Things (IoT) technology. The IoT technology enables the communication between the machine or system and humans and the communication between the machine itself through internet networking so that the monitoring or controlling function can be established (Abbas Helmi *et al.,* 2019; Aman *et al.*, 2022; Jamal *et al.,* 2019; Mohammed *et al.,* 2019; Yusof *et al.,* 2022). As the most recent technology, the Internet of Things (IoT) plays a crucial role in communicating and gathering all the data from the installed sensing units (Deekshath *et al*., 2018). Using the IoT system, the reading value of the measured airflow system can be displayed anywhere on a device remotely if the internet connection is available (Aggarwal *et al*., 2012; Mohamed *et al*., 2019; Widi *et al*., 2020). This feature will help the maintenance personnel or building owner to monitor AHU's performance or the HVAC system.

Although IoT application has been used in many industrial applications, its application in monitoring or controlling the airflow is still new and there are many opportunities or aspects that can be explored. The practical significance of this project includes the ability of the developed system to be installed permanently or temporarily in the ducting of the AHU system. This feature will help the building management or facility manager to decide the installation method based on the requirement and budget. The next practical significance of the system is the capability of displaying monitoring parameters both on the LCD of the system as well as remotely via personnel devices such as smartphones, using IoT technology. The next section explains the development of the proposed systems.

3.0 The Designs of the Proposed Airflow Monitoring Systems

In this paper, the development of two designs of airflow monitoring systems is presented. Section A describes the basic design of airflow monitoring systems, while the integration of IoT applications to control the fan speed is described in section B.

A) Basic design of Airflow Monitoring System

Figure 1 shows a schematic circuit of the airflow monitoring system using Atmega328P microcontroller-based temperature. This project aims to design a temperature control circuit to control the fan motor's speed on the Low, Medium, and High speeds automatically according to the change of environmental temperature using the sensor temperatures. To control the fan motor rotation, the Triac component is used on the output circuit and will be controlled by a microcontroller. The circuit starts from the circuit insert section on the Block J2 terminal for the 240VAC voltage entrance supply. The AC voltage amplitude to the motor can be controlled by a Zero Crossing Detector circuit on the position of the R3 and R4 components. Meanwhile, the components of D1,2,3,4, U4, and R5 are used to produce the pulse signal that will be processed into the microcontroller and will release Pulse Wave Signal Modulation (PWM) on PIN 5 to drive Gate on Triac. This way, Amplitude and Phase Angle at the motor output voltage will be able to control according to the desired motor rotation speed.

As shown in Figure 1, sensor temperature DS18b20 is used on the 11-microcontroller input to control the motor speed according to temperature. A Display LCD circuit is used on the output pins 13 to 18. Potentiometer RV1 is used to control the brightness and contrast of the LCD. The motor speed is changed according to the temperature of three LEDs used as Indicator Light on the U1 microcontroller output pin from PIN 23, 24 and 25, respectively. Interestingly the speaker is also used on the 6-microcontroller pin with the Q1 transistor amplifier circuit, where the circuit will sound like a melody signal every time there is a change of the fan motor speed by temperature, simultaneously with the flares of the Indicator's LED.

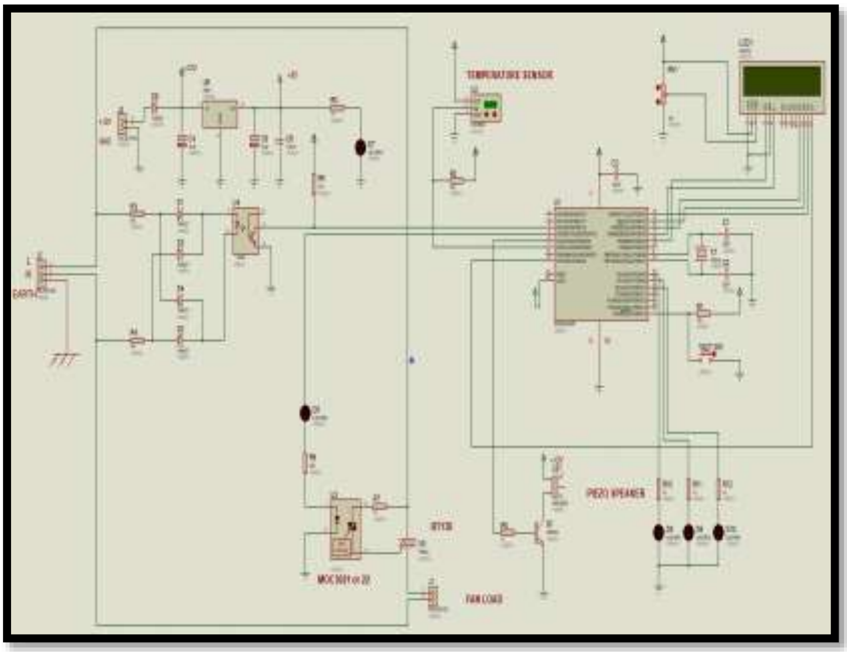


Fig. 1. Circuit Diagram of the Basic Airflow Monitoring System

Next, the Microcontroller U1 circuit with Crystal, 16MHz frequency speed as the CLOCK Oscillator circuit is used for the data processing part. On pins 9 and 10, there are Ceramic C1 and C2 Capacitors with 22PF value functioning as a filter, so the circuit is more stable. The push button on PIN 1 on IC U1 is used to reset the microcontroller when necessary. This circuit's DC power supply source can use the 12V adapter connected directly to enter the Block J3 terminal. This DC flow via the D6 Protection avoids reverse polarities that can damage the circuit. The power supply to this logic circuit uses the voltage regulator on the U6 IC 7805 to supply a very stable 5V voltage to the Microcontroller IC U1 circuit, where Power Indicator Light LED on the D7 will lighten when the circuit is switched on.

For this basic design of the airflow monitoring system, the Arduino IDE is used to perform the source code coding. The software enables the compilation of the commands and source code into the processor, the Atmega328P microcontroller. Specific source code libraries are used to program the Arduino Uno to calculate the fan rotation when the temperature sensor is detected.

B) Proposed design of Airflow Monitoring System for Air Handling Unit with the integration of IoT

The block diagram for the proposed design using IoT is shown in Figure 2. This system consists of a NodeMCU ESP32 microcontroller, an Infrared (IR) sensor module to measure the airflow speed, and a DHT11 sensor module to measure the temperature and humidity of the air inside the AHU ducting. The system is then configured to present the measured value through LCD mounted on the device and displayed on the BLYNK application on mobile devices such as smartphones using IoT capabilities.

Arduino IDE is utilized to perform the source code coding for the IoT capabilities. The software enables the execution of necessary commands and source code into the processor, which is the NodeMCU ESP32. Specific source code libraries are used to program the Arduino Uno to calculate the DC fan rotation per minute when the IR Sensor detects the white spot on the fan.

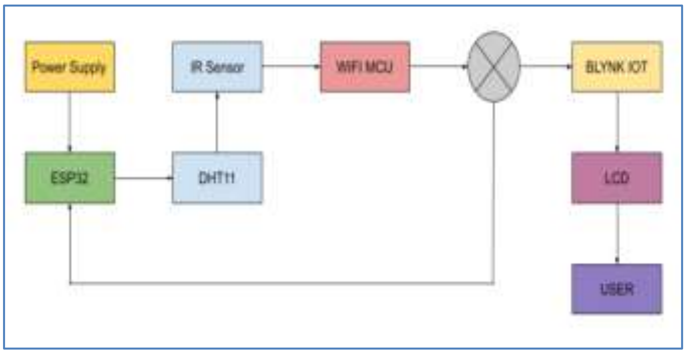


Fig. 2. Block Diagram of the Proposed System with IoT Integration

To power up this system, the NodeMCU microcontroller board is powered by a 2.2V to 3.6V operating voltage. The ESP32 in this module, as shown in Figure 3 below, will be responsible for the internet connection so that the module can be connected to the network and devices by using IoT configuration. Based on this configuration setup, the microcontroller module will process all measured data from the DHT11 sensor module: temperature and humidity. The data from the Infrared module is used to calculate the airflow speed.

The data obtained from the sensors will be processed and displayed on the LCD. At the same time, the data will be transmitted to the linked BLYNK application in the registered user's smartphone. With these remote monitoring capabilities via smartphones, it is much more convenient for the personnel to monitor the performance of AHU and airflow inside the ducting. This feature will save time, cost, and manpower so that maintenance can be arranged more effectively.

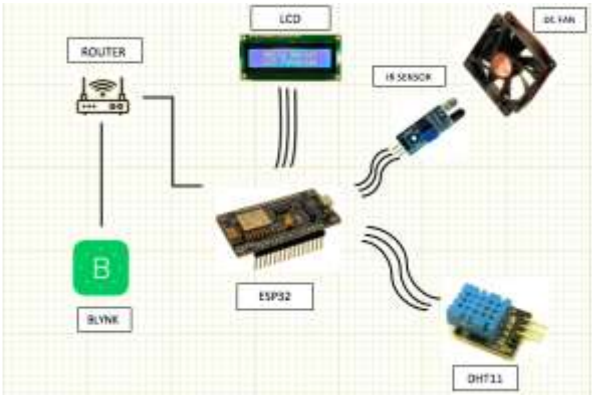


Fig. 3. Circuit Diagram of Airflow Monitoring System with IoT Integration

4.0 Results and Discussion of the Developed Airflow Monitoring Systems

This section presents the results of the developed airflow monitoring systems, followed by a discussion of the results.

(A) Results of the Basic Airflow Monitoring System

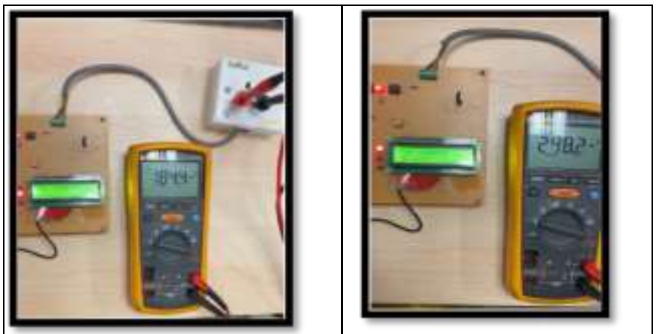
The results of operating the prototype model for the basic airflow monitoring system at various temperatures are shown in Table 1. The results specify the behaviour of the embedded system upon its reactions to temperature variations in real time.

Table 1: Basic Airflow Monitoring System Results

Fan Speed	Temperature °C	Output AC volt
0	Below-24.9	26.5 V
1	25-28.9	97.7 V
2	29-34.9	184.4 V
3	35-above	248.2 V

A temperature-controlled fan is constructed using an Arduino IDE. The fan speed is regulated using an Arduino board in response to the temperature measured by the temperature sensor, as shown in Figure 4. As indicated in Table 1, when the air temperature is below 24.9^{0}C, the fan speed is automatically set to equal 0. In this condition, the output AC voltage is 26.5V and the fan is in an OFF state. Meanwhile, when the temperature is between 25^{0}C and above, the fan speed increases from 1-3, and the output AC voltage is at around 97.7V, 184.4V, and 248.2V, respectively. This satisfies the project's goal to control the fan's speed automatically. Whenever the system is up and running, the temperature will control the fan speed, hence there is no need to adjust the speed according to the changes in temperature, manually.

	
(a)	(b)



(c)	(d)

Figure 4: The performance (a) Speed 0, (b) Speed 1, (c) Speed 2, and (d) Speed 3 of the Basic Airflow Monitoring System

The design and construction of a fan speed control system for managing room temperature and turning on/off temperature sensors are described in this part. To determine the room temperature, the temperature sensor was used. Next, the Arduino was successfully programmed using C Language to compare temperature with standard temperature and set the fan speed and show their values on the LCD. The result concludes that the fan speed will automatically increase when the room temperature rises. Finally, the system established in this study operates efficiently under any temperature variations and could be classified as an automated control system. However, this basic system lacks the integration of the IoT features to send the visual output to users remotely. Thus, the airflow monitoring system design with the integration of IoT is proposed and discussed in the next session.

B) Results of Airflow monitoring System for Air Handling Unit with IoT Integration

In this study, the prototype of an airflow monitoring system with IoT integration for an air handling unit is tested to validate its efficiency during operation. This part focuses on sending the final output from the NodeMCU microcontroller to the LCD as well as to the BLYNK apps installed in a smartphone.

In the BLYNK app, all parameters are measured from the sensor modules, which are airflow speed, temperature, humidity, and air density obtained from the air handling unit ducting. This prototype measures airflow speed by attaching the Infrared sensor module to the DC fan. The flow speed is detected based on the rotation of the DC fan in revolutions per minute (RPM). Then the airflow speed is calibrated using a UT363 Mini Anemometer to obtain the actual and accurate airflow speed. Table 2 shows the calibration data by using a hairdryer to produce the airflow:

Table 2: The Calibration data

Hairdryer Speed Mode	**Airflow Speed**	**UT363 Mini Anemometer**
1	6.33 m/s	6.4 m/s
2	8.85 m/s	9.0 m/s

When the prototype was successfully calibrated, an experiment was carried out using the calibrated prototype set with an air conditioning unit set at various fan speeds and temperatures to determine its performance. The parameters investigated were airflow speed (S), temperature (T), air density (P), and humidity (H). Figure 5 below illustrates the position of the LCD on the prototype. The airflow rate, air density, humidity, and temperature values are displayed on the LCD. The airflow that passes through the prototype will be used to calculate the reading.

Fig. 5. The Placement of LCD on the Prototype

Table 3 below shows the result of the experiment. As shown in the table, when the air conditioning unit temperature was raised, the temperature reading on the prototype increased. When the air conditioning unit temperature increased, it was observed that the humidity of that tested area decreased. It was also observed that when the air conditioning unit was set at the lowest blower speed, the airflow speed was measured at 2.8 m/s. When the air conditioning unit was set at the highest speed, the airflow speed was measured at 4.4 m/s. The measurement variation between the air conditioning unit and the prototype was found to be minimal, thus, it is safe to claim that the performance of the airflow monitoring system developed is good.

Table 3: Experiment Results

Air-conditioning Temperature	S		Temperature (T)	Air Density (P)	Humidity (H)
	Min	Max			
18°C	2.9m/s	4.4m/s	19°C	1.01 kg/m^3	81%
20°C	2.9m/s	4.3m/s	20°C	1.00 kg/m^3	75%
22°C	2.8m/s	4.3m/s	22°C	0.98 kg/m^3	73%
24°C	2.8m/s	4.4m/s	24°C	0.97 kg/m^3	65%

Figures 6 (a) and (b) show the final prototype design of the airflow monitoring system and the user interface for monitoring purposes by using the BLYNK app installed on a smartphone. In this prototype, the DHT11 and infrared (IR) sensor were attached to the DC fan to get the simulation measurement value when air flowed through. The measurement values from the sensors are displayed on the LCD, which is mounted on the prototype set, and are also sent simultaneously to the Blynk app. The Blynk app provides the feature of a live measured data view to the users using their smartphones for remote monitoring capabilities.

The testing parameters of the developed system show very good correlations among temperature, air density and humidity, indicating the efficiency of the system to monitor the airflow. The results obtained from the developed systems confirm the practical implications of the systems, which are the improvement in HVAC system preventive maintenance. In addition, the theoretical contribution of the study is established by enhancing the body of knowledge surrounding the IoT applications for mobile monitoring HVAC systems using portable devices such as smartphones.

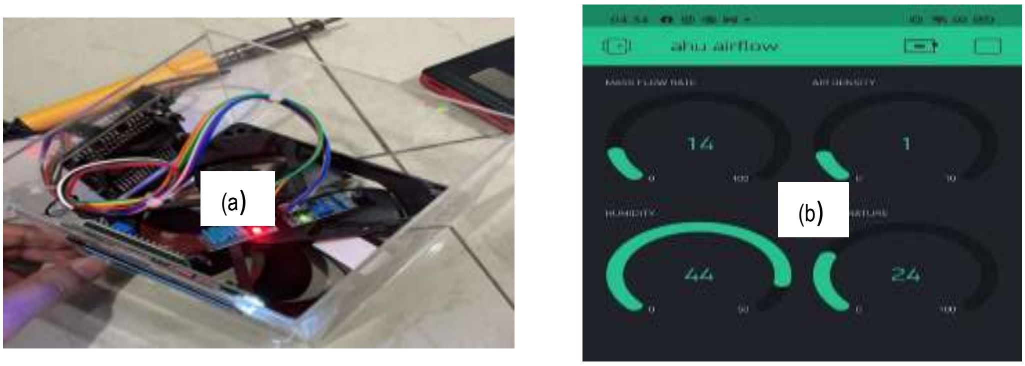


Fig. 6. (a) Overall Circuit Setup, and (b) Measurement Parameters in Blynk App on Smartphone.

5.0 Conclusion

In summary, this paper has presented an airflow monitoring system design for an air handling unit with IoT integration, managed by a NodeMCU ESP32 microcontroller. The NodeMCU ESP32, with both DHT11 and IR sensors, were proven to be reliable in measuring the monitoring parameters as well as in communicating with a smartphone via the BLYNK app to send data for remote monitoring purposes. The implementation of IoT technology in this project enables remote monitoring and viewing for airflow measurements by using smartphones or web-based systems. Thus, this enables the portability of the systems for convenient use by the maintenance personnel to monitor and control the system. Recommendations for future research include the integration of AI elements and the use of additional sensors to collect more data such as vibration or strain gauges.

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Paper Contribution to Related Field of Study

This research paper contributes to the field of Library and Information Management.

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