ISSN: 2664-9640

Industrial air supply equipment based on PID controller

Li Lu, Qiangzhong Zhao, Jie Hu*, Zhongyi Liu, Shaofa Zhou

School of Yangtze University, Hubei 434000, China;

* Corresponding Author

Abstract

This paper introduces a kind of industrial intelligent air supply equipment based on PID controller and GD32F130C8T6 microcontroller. The microcontroller generates PWM signal to control the rotation of brushless motor and drive the fan impeller to supply air. Use flow sensors to detect wind flow. The devices constitute a closed-loop control system, and a PID control algorithm is used to maintain a constant gas flow. The MCU captures the feedback signal of the motor to detect the actual speed of the motor, and calculates the pollution degree of the filter element of the inlet according to the relationship between the PWM duty ratio and the actual speed. Real-time data of system operation are uploaded to the software management platform through 4G module. Buzzer is used to generate alarm sound, and OLED screen is used to display local data. After a lot of experiments and repeated debugging, the air supply equipment can finally meet the design requirements.

Keywords

PID controller, Microcontroller,Sensor,Air supply system.

1. Introduction

With the rapid development of IoT technology and the popularization of 4G networks, more and more intelligent industrial equipment has been applied to social production practices. As a common industrial equipment, air supply equipment can provide workers with a safe and healthy breathing environment and provide basic support conditions for production activities. In recent years, industrial development has faced many challenges. The rapid development of the manufacturing industry has placed higher requirements for the creation of a safe working environment for workers. Industrial production processes are usually accompanied by large amounts of heat release and pollution emission[1].The industrial production environment has become complex and changeable, and workers may have to work in various harsh air environments. This requires reliable and intelligent air supply equipment to escort the safety of workers. Therefore, the research, improvement and innovation of industrial air supply equipment is particularly important. Aiming at this problem, this paper studies and proposes an industrial air supply equipment based on PID controller, and maintains a constant flow rate and calculates the resistance of the filter element as the core function and research object.

2. Overall System Design

2.1. System Composition

As shown in Figure 1, the air supply equipment can be simplified as a device that is driven by a motor to rotate a fan to generate directional airflow. Under the action of the motor and fan, the outside air enters the device after being filtered by the filter element, then passes through the air flow sensor, and finally flows out of the air outlet pipe to the hood for the user to breathe. In order to ensure the user's normal breathing and use comfort, the air supply device should maintain the air flow at a set value. Therefore, the system uses an air flow sensor to detect the flow rate of the air outlet. When the flow rate is lower than the set value, the system increases the motor speed; when the flow rate is higher than the set value, the system reduces the motor speed.

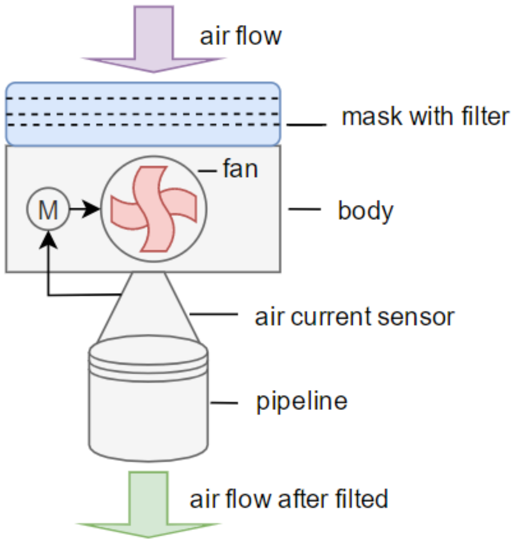

Figure 1: Air supply system

2.2. System Block Diagram

This system is mainly composed of GD32F130C8T6 MCU and 4G module. The MCU is used as the main controller of the system, and the 4G network module is used to communicate with the background server. Peripheral devices are: battery, buzzer, OLED display module, BLDC and air current sensor. The battery is used to power the device, the buzzer is used to generate prompt and alarm sounds, the OLED display module is used to display the system operating status, the brushless motor drives the fan blades to generate air flow, and the air current sensor is used to detect the air flow at the air outlet. The overall composition of the system is shown in Figure 2.

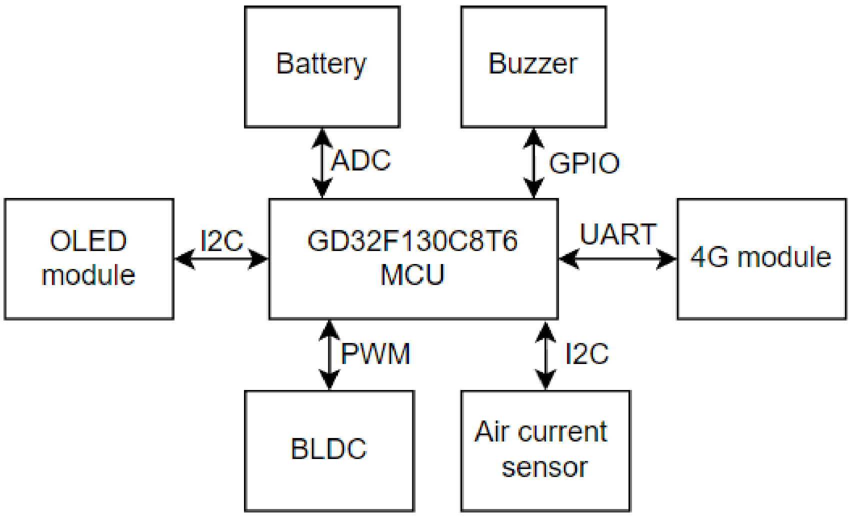

Figure 2: System block diagram

3. Hardware Circuit Design

3.1. Motor Power Circuit

In order to improve and maintain the working performance of the motor, this design stabilizes the working voltage of the motor instead of directly using the battery voltage for power supply. In the circuit design, a booster chip model XL6019 is used to boost and stabilize the battery voltage to 18.7V to supply power to the motor. The XL6019 chip supports a maximum output current of 5A, and the output voltage VOUT is configured through the feedback voltage on the FB pin. The schematic diagram of the XL6019 boost circuit used in the system is shown in Figure 3.

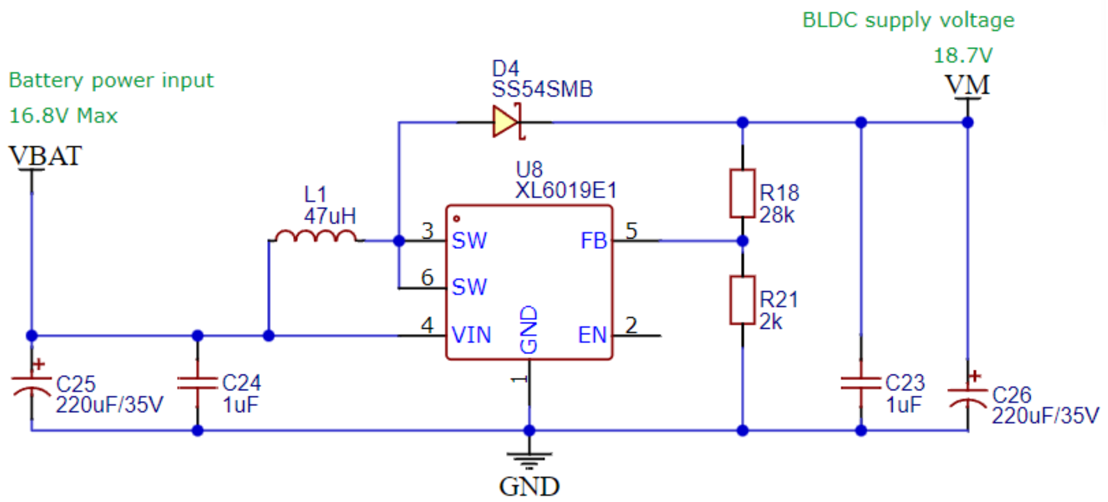

Figure 3: XL6019 boost circuit

3.2. 4G Module Power Circuit

The working voltage range of the 4G module used in this design is 3.6V~4.3V, and the module needs a current supply of at least 1A to ensure stable operation. Because the battery voltage is high and the step-down pressure difference is large, this design selects the DC-DC step-down solution instead of the LDO step-down solution. Comprehensive consideration, the circuit design uses a DC-DC chip model JW5033S to step down and stabilize the battery voltage to 4.0V to supply power to the 4G module. The JW5033S chip has a maximum current output capability of 2A, and configures a stable output voltage through the feedback voltage input on the FB pin. The JW5033S step-down circuit used in the system is shown in Figure 4.

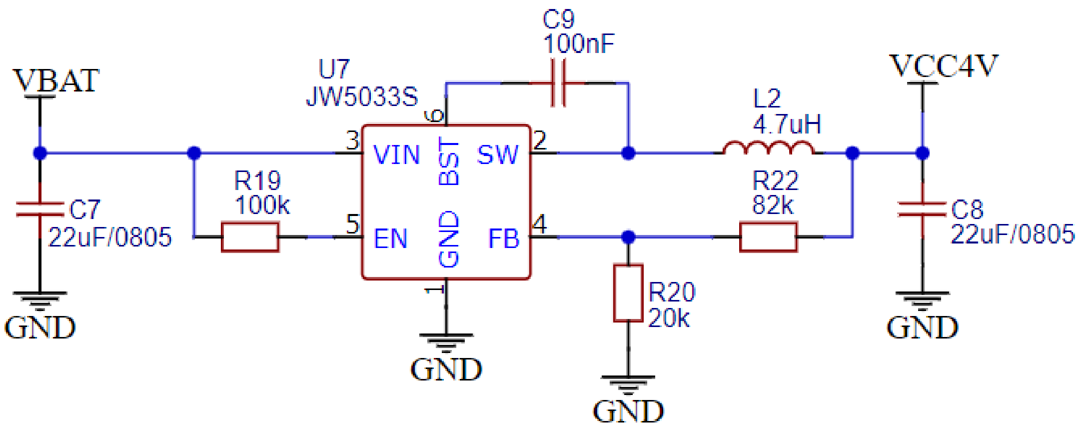

Figure 4: JW5033S buck circuit

3.3. MCU Power Circuit

The MCU and some discrete components are powered by 3.3V power supply. Since there is already a 4.0V power supply network in the 4G module power supply circuit, a low-dropout LDO chip with model AP2112K-3.3TRG1 is selected to convert from 4.0V to obtain 3.3V power supply . The AP2112K-3.3TRG1 chip has a simple peripheral circuit, a small package and a maximum current output of 600mA. The AP2112K-3.3TRG1 step-down circuit used in the system is shown in Figure 5.

ISSN: 2664-9640

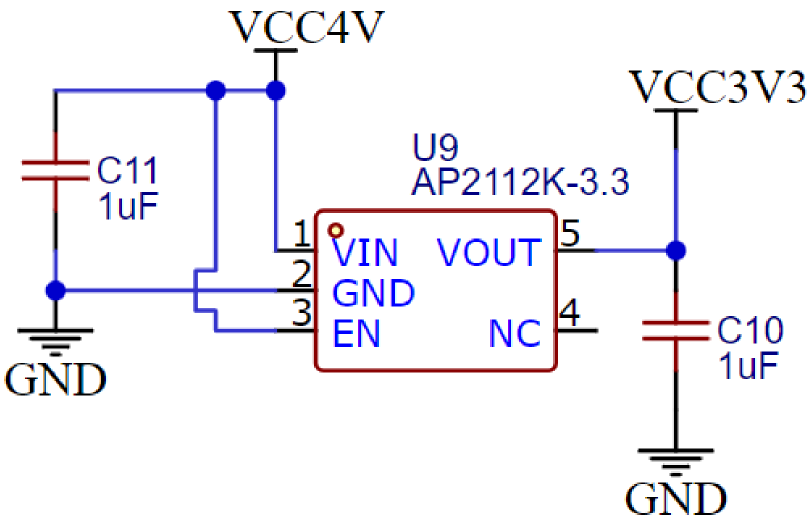

Figure 5: AP2112K LDO circuit

3.4. BLDC Interface Circuit

The system uses a Nidec smart 20S brushless motor to drive the fan impeller to rotate to generate airflow. The working voltage range of this motor is 5~24V, and the normal working current is 1.2A. The speed of the motor can be controlled by a PWM signal with a frequency of 15~25KHz. The higher the duty cycle of the PWM signal, the faster the motor speed. The motor has a speed feedback signal line FG, which generates 6 pulses per revolution. The FG signal line is an open-drain output, and an external pull-up resistor is required to generate pulses normally. The brushless motor interface circuit used by the system is shown in Figure 6.

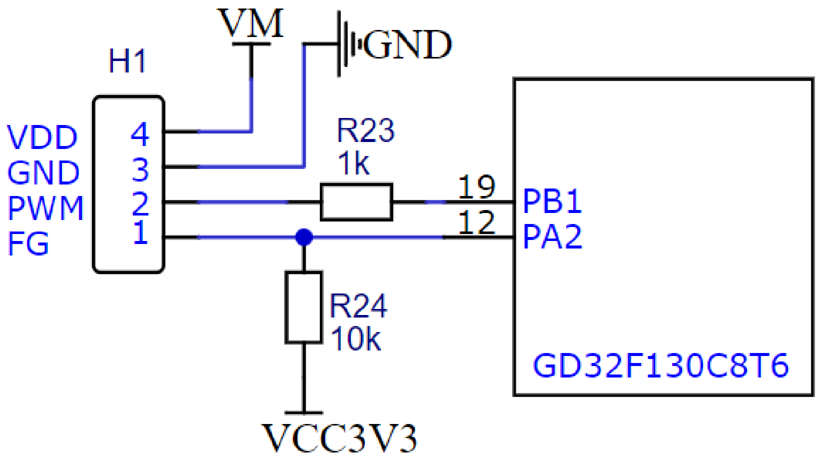

Figure 6: BLDC interface circuit

3.5. Battery Voltage Detection Circuit

When the lithium battery is working normally, its voltage will decrease as the power decreases. Using this feature, the power of the lithium battery can be monitored by measuring the voltage of the lithium battery. The input voltage of the ADC channel of the microcontroller used in this system cannot exceed 3.3V, so the lithium battery voltage needs to be divided by two resistors and then input to the ADC channel of the microcontroller. The microcontroller collects the input voltage signal and uses Ohm's law and proportional relationship to calculate The battery voltage is calculated to calculate the battery percentage data. The lithium battery voltage detection circuit used in this system is shown in Figure 7.

ISSN: 2664-9640

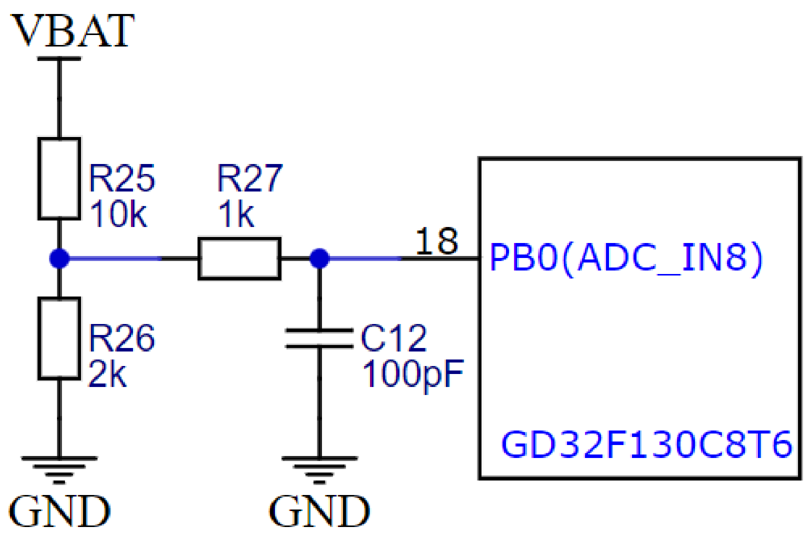

Figure 7: Battery voltage detection circuit

The ADC resolution of the MCU is 12 bits, the reference voltage is its working voltage of 3.3V, which is represented by VREF, the voltage input by the battery voltage acquisition channel is represented by VCH, and the digitized value collected by the channel is represented by value_ch. The relationship between them is as follows (1) shown.

$$\frac{VREF}{2^{12}-1}=\frac{VCH}{value\_ch} \tag{1}$$

In this circuit, 10K and 2K resistors are used to divide the battery voltage and input it to the ADC channel of the microcontroller. Therefore, the relationship between the battery voltage VBAT and VCH is shown in formula (2).

$$\frac{VBAT}{R25+R26}\times R26=VCH \tag{2}$$

Combined with formula (1) and formula (2), the battery voltage VBAT can be calculated by value_ch from the digitized value collected by the channel.

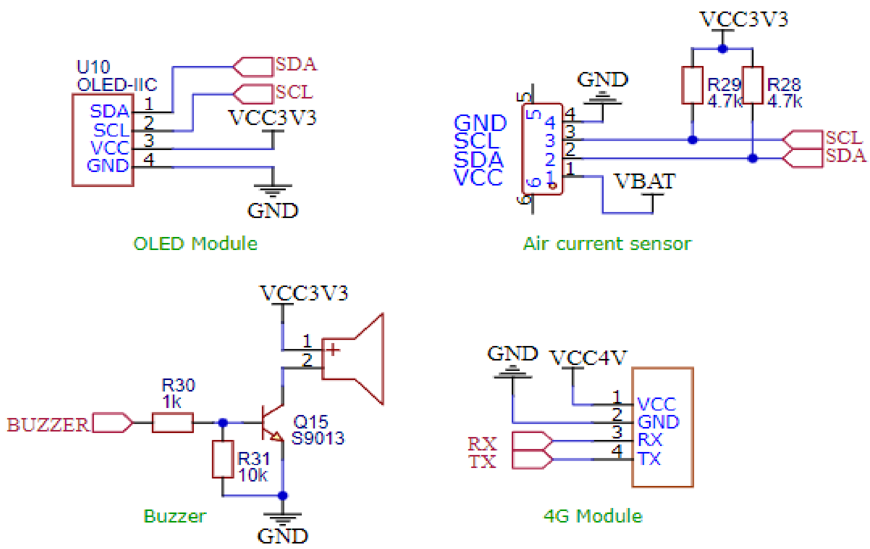

Figure 8: Peripheral interface circuit

3.6. Peripheral Interface Circuit

The peripheral interface circuit part includes :

OLED module interface circuit

Flow sensor interface circuit

Buzzer circuit

4G module interface circuit

The circuit of this part is shown in Figure 8.

4. Software System Design

4.1. PID Controller

PID control is the most widely used control system among feedback control systems with its simplicity, clear functionality, applicability and ease of use. PID control is a control method that provides the system to fit to the desired reference value by processing the error obtained by subtracting the feedback signal from the reference value in parallel with proportional, integral and derivative effect [2]. The mathematical model of the PID control structure is given in equation(3).

$$u(t) = K_p e(t) + K_i \int_0^t e(t)dt + K_d \frac{de(t)}{dt} \tag{3}$$

where,u(t) indicates the control signal,t stands for time,Kp, Ki and Kd coefficients in the equation are proportional, integral and derivative constants, respectively.The function of the proportional link Kp is to proportionally control the deviation signal when the error occurs, quickly adjust the system to restore a stable state, improve the adjustment accuracy of the system, and reduce the residual error of the system. The main function of the integral link Ki is to eliminate the residual error of the system, but it may also make the instantaneous response of the system poor, and the integral time constant determines the strength of the integral action. A derivative controller Kd is processed to the control mechanism which is directly proportional to the derivative of error signal (SP-PV). It will increase the stability of any control system and reduce the overshoot and improve the transient response[3].

Almost all feedback control systems are realized using discretized (discrete-time and discrete-value) signals[4]. Especially in the field of industrial automation control, the discretized PID algorithm is usually used because the microcontroller is better at solving discrete problems. The discreted mathematical model of the PID control structure is given in equation(4).

$$u(k) = K_p e(k) + K_i \sum_{j=0}^{k} e_j + K_d [e(k) - e(k-1)] \tag{4}$$

The system is simulated using a closed-loop control model, as shown in Figure 9.

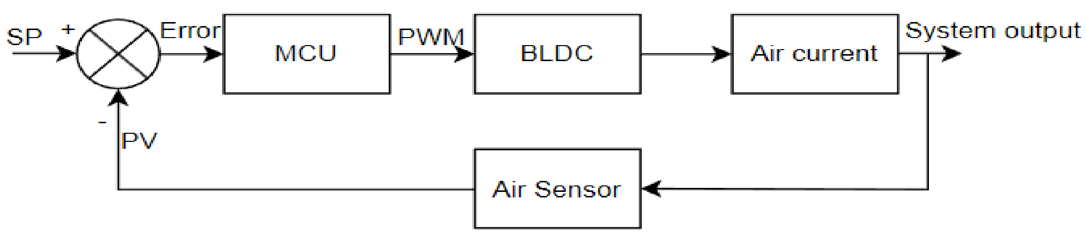

Figure 9: System closed-loop control principle

The parameters of the PID controller used by the system are shown in Table 1. The PID controller was applied to the system software, and the test found that the flow rate could quickly stabilize to around the set value of 125L/min.

Table 1: PID model parameter settings

	P	PI	PID
Kp	2.6	2.6	2.6

Ki	0.0	0.2	0.2
Kd	0.0	0.0	0.1

4.2. Filter resistance estimation

As the equipment runs over time, the filter element at the air inlet will be polluted by the ash layer in the air, causing its resistance to increase. When the resistance of the filter element increases to a certain level, in order to continue to maintain a constant air flow, the motor speed becomes very high, which makes the equipment noise louder and the power consumption rises sharply, which affects the equipment life and user experience. Therefore, the device needs to alarm and prompt the user to replace when the filter element resistance exceeds a certain threshold, which requires the system to have the ability to estimate the filter element resistance.Analysis of the system shows that under a constant airflow, the resistance of the filter element is approximately proportional to the motor speed, that is, the higher the filter element resistance, the faster the motor speed needs to be, so as to maintain a constant airflow. Therefore, a mathematical relationship model can be established between the actual speed of the motor and the resistance of the filter element.

4.2.1. Resistance Experiment

Experimental method: Use standard filter elements with resistances of 0Pa, 108Pa, 153Pa, 259Pa, 366Pa, 418Pa, 504Pa, 635Pa, 686Pa, set the air flow rate of 125L/min when the equipment is running, and record the frequency of the feedback signal FG of the motor. In order to reduce accidental errors, each resistance filter element was tested 20 times, and the average value was taken as the final result. The experimental results are shown in the table 1.

Table 1: Resistance experiment data

FG(KHz)	Filter resistance(Pa)
1.087	0
1.172	108
1.212	153
1.299	259
1.377	366
1.414	418
1.474	504
1.559	635
1.595	686

4.2.2. Resistance Data Fitting

Import the actual motor speed and filter element resistance data obtained from the experiment into Excel, build a scatter plot with a smooth line, and display the fitted formula. The obtained function expression is shown in Figure 10.

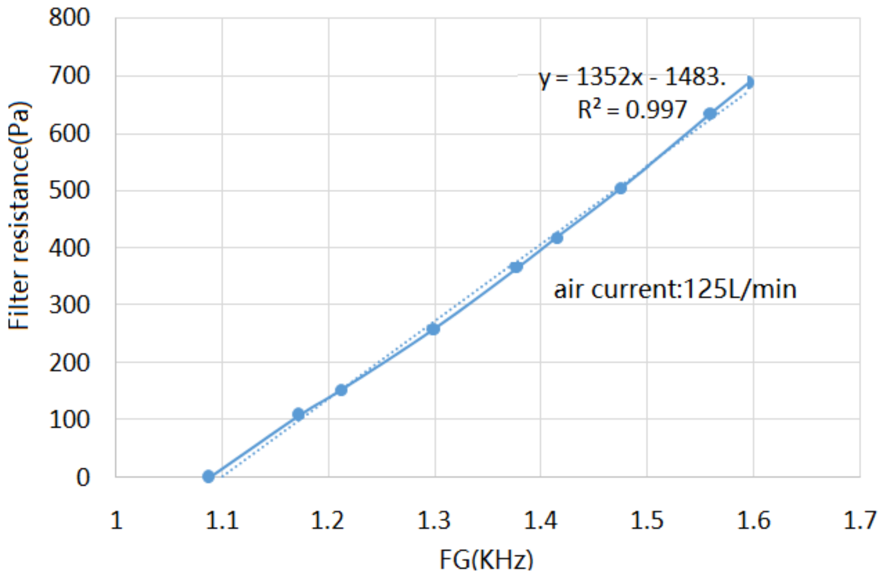

Figure 10: resistance curve

4.2.3. Resistance Model Validation

The function of the filter element resistance obtained by the data fitting experiment on the actual speed of the motor is applied to the microcontroller program, and then the standard resistance filter elements of 112Pa, 153Pa, 268Pa, 382Pa, 427Pa, 516Pa, 650Pa and 721Pa are used to test on the machine, until the system is stable. Then, record the resistance data calculated and displayed by the system, and then calculate the deviation to get Table 2.

Table 2: Resistance validation

Standard resistance(Pa)	Calculated resistance (Pa)	Error(Pa)
112	113.5	1.5
153	161	8
268	270.6	2.6
382	392.3	10.3
427	419.7	-7.3
516	501	-15
650	630.2	-19.8
721	695.4	-25.6

It can be found from Table 2 that the function of the filter element resistance on the actual speed of the motor fitted by the resistance experiment can roughly reflect the mathematical relationship between the two. Although there is a certain error, the error is within the acceptable range. The system uses this mathematical model to calculate the resistance of the filter element, making the device more intelligent.

5. Conclusion

This paper describes the design of an industrial intelligent air supply system based on a PID controller. The system uses the PID control algorithm to stabilize the supply air flow, applies the discrete PID control algorithm to the MCU, and achieves a stable flow control effect by repeatedly tuning the PID parameters. Through the resistance experiment, the mathematical model between the resistance and the motor feedback is established. Based on the reference

ISSN: 2664-9640

structure of the model, the resistance of the filter element during operation can be estimated. Numerical example results show that the method and model have good performance.

References

[1] Xu Yukun et al. Direction air supply design and optimization in industrial settings to reduce gaseous contaminant exposure[J]. Building and Environment, 2022, 216.

[2] Yasin ÇAKAR and Yıldıray ORMAN and Selçuk KİZİR. DESIGN OF A MODEL REFERENCE ADAPTIVE PID CONTROLLER FOR DC MOTOR POSITION CONTROL: COMPARED WITH PID AND FUZZY CONTROLLERS[J]. Mugla Journal of Science and Technology, 2020, 6 : 25-35.

[3] Niharika Mishra and Sameer Bajpai and Esh Narayan. Speed Control of DC Motor using PID Controller FED H-Bridge[J]. International Journal of Innovative Technology and Exploring Engineering (IJITEE), 2020, 9(10) : 274-282.

[4] Okuyama Yoshifumi. Model-Reference Discretized PID Control and Robust Stabilization for Continuous Plants[J]. IFAC Proceedings Volumes, 2011, 44(1) : 5813-5818.

[5] Hong yu Liu and Liu Hong yu and Ni Yan shu. Numerical Simulation and Test of filter Resistance of vehicle Wood Fiber Air filter[J]. IOP Conference Series: Earth and Environmental Science, 2020, 587(1) : 012021-.

[6] Kim Jung-Hyun et al. Pressure drop of filtering facepiece respirators: How low should we go?[J]. International journal of occupational medicine and environmental health, 2015, 28(1) : 71-80.

[7] [1]Ali Murad,Haitao Yu,Yao Wang,Yilin Yang. Control of linear generator based on hysteresis-SVPWM current rectification and bidirectional buck/boost converter used for energy storage[J]. IET Renewable Power Generation,2021,15(14).

[8] [1]Sivamani D,Shyam D,Nazar Ali A,Premkumar K,Narendiran S,Albert Alexander S. Solar Powered Battery Charging System Using Optimized PI Controller for Buck Boost converter[J]. IOP Conference Series: Materials Science and Engineering,2021,1055(1).