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Multifunctional Intelligent Water Curtain Air Cabinet

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Abstract

This project aims to develop an intelligent model-specific water curtain system, providing a compact, cost-effective, and high-performance comprehensive solution for model enthusiasts and small studios to address issues such as formaldehyde pollution, particulate diffusion, temperature and humidity, and noise during painting operations. The system integrates formaldehyde sensors, temperature and humidity sensors, and a display screen, and uses intelligent control algorithms to link formaldehyde concentration with fan speed, ensuring air quality remains within safe limits. Additionally, the system features real-time data display, alarm notifications, and remote control capabilities, enhancing user experience. Experimental results demonstrate that the system meets expected targets in purification efficiency, energy consumption control, and operational convenience. In the future, with further advancements in intelligent technology, this system is expected to play a greater role in model making and air purification, providing users with a healthier and more environmentally friendly working environment.

Keywords

Environmental Pollution; Miniaturization; Intelligent Control; Indoor Environment; Model-Specific

1. Introduction

Spray painting in model making (e.g., Gundam, military, car models) releases hazardous particles and gases, posing health risks and polluting the workspace. While water curtain systems can capture particles and purify air, existing industrial solutions are too large and expensive for hobbyists or small studios.

This project develops an intelligent, model-specific water curtain system that is compact, low-cost, and efficient. It integrates sensors (formaldehyde, particulate, noise) and smart algorithms to enable real-time air quality monitoring and automatic fan speed adjustment, ensuring a safe working environment. The system also includes real-time data display, alarm alerts, and remote control for enhanced usability.

Key innovations include real-time health protection through pollutant monitoring, intelligent fan control, energy-efficient operation, and a user-friendly design tailored to model enthusiasts. By addressing the limitations of traditional equipment, this system advances intelligent air purification technology for specialized small-scale applications.

2. Market Research and User Requirements

This project aims to develop a multifunctional intelligent water curtain system for modeling enthusiasts and small studios, providing a compact, cost-effective solution to address formaldehyde pollution, particulate dispersion, and noise during spraying operations.

Traditional purification equipment is typically bulky, expensive, and functionally limited, failing to meet the needs of small-scale users. Our system integrates multiple sensors to monitor air quality in real-time and automatically adjust purification intensity. [1] It supports real-time data display, alarm notifications, and remote control, balancing efficient purification with user-friendly operation.

With the growing number of modeling enthusiasts and increasing environmental awareness, demand for intelligent purification equipment continues to rise. By offering a comprehensive solution that prioritizes health protection, energy efficiency, and enhanced user experience, this project addresses a clear market gap while promoting sustainable industry development.

3. Hardware Construction

3.1. Sensor Connection

The MQ138 formaldehyde module will utilize an analog output interface and be connected to the control board's PB15 pin as an analog input. The DATA output of the DHT11 temperature and humidity sensor will be connected to the control board's PC7 pin as an input. The positive power supply for both sensors will be connected to 3V3, and the negative to GND.

3.2. Display Connection

This display is designed to be used with this specific control board and connects via dedicated pins on the board. The corresponding pins are specifically SCL (PB4), SDA (PB5), RES (PB6), DC (PB7), CS (PB8), and BLK (PB9).

3.3. Power Connection

The fan used in this exhaust system requires a 24V power supply. Therefore, a 24V switching power supply is utilized. The three-phase power lines are connected to the input of the 24V switching power supply, while the positive and negative terminals of the fan are connected to its output, thereby completing the power connection.

3.4. Water Curtain Chamber Assembly

The main framework is constructed using custom-cut PVC foam boards, which are assembled according to the pre-designed modeling drawings and bonded with PVC-specific adhesive. The water pipes and circuits are then connected, integrating the hydraulic and electronic control components. Finally, all parts are assembled to ensure normal system operation.

4. Software Control Description

The entire system operates through a closed-loop control mechanism: environmental parameter changes → sensor data acquisition → data processing → PWM regulation → environmental improvement, forming an automatic adjustment cycle. Simultaneously, the system provides real-time visual feedback on the LCD. The process is outlined as follows: First, the analog voltage value from the MQ138 sensor is read via ADC, and temperature and humidity data are acquired from the DHT11 sensor. The raw ADC value is then converted into formaldehyde concentration (mg/m^3). Based on the formaldehyde concentration, an inverse PWM duty cycle is calculated, achieving the effect that higher concentration results in a lower duty cycle and faster fan speed. Finally, the display outputs the real-time formaldehyde concentration, temperature (°C), humidity (%), and the current PWM duty cycle percentage. The system executes a complete acquisition and control cycle every 2 seconds, enabling continuous monitoring and adjustment[2]. The corresponding code is shown in the figure below.

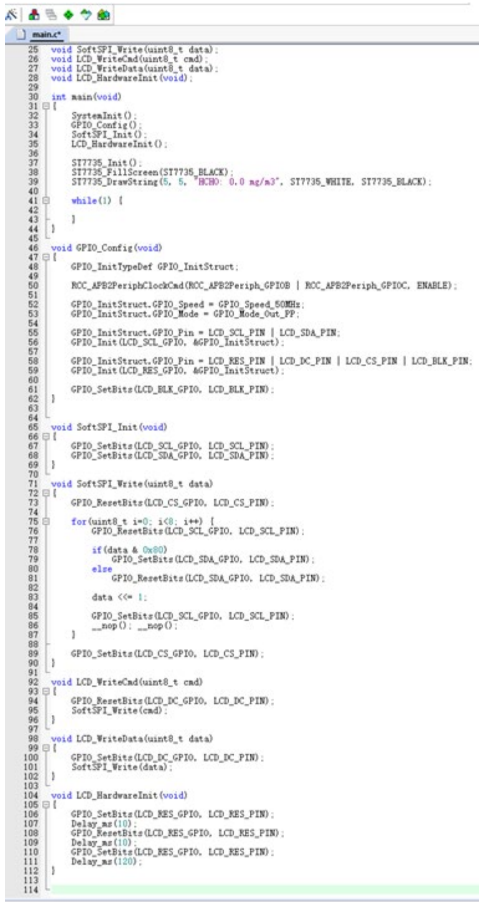

Figure 1. Code Diagram

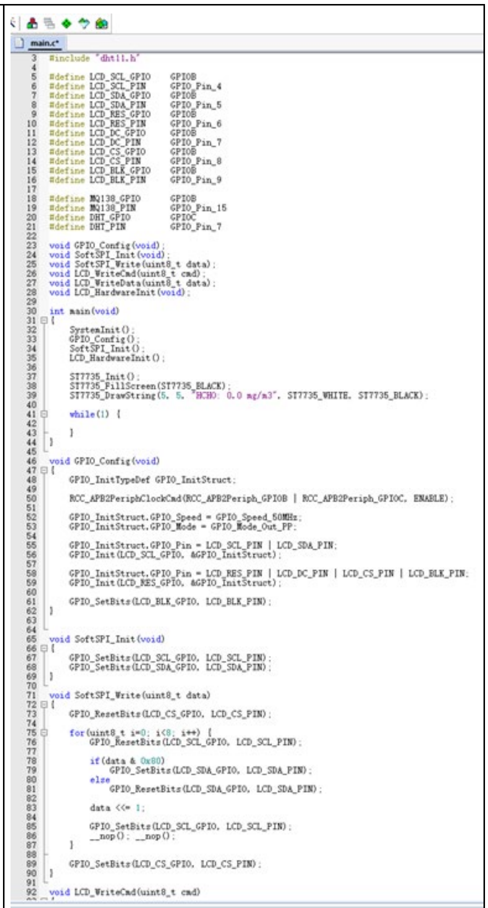

Figure 2. Code Diagram

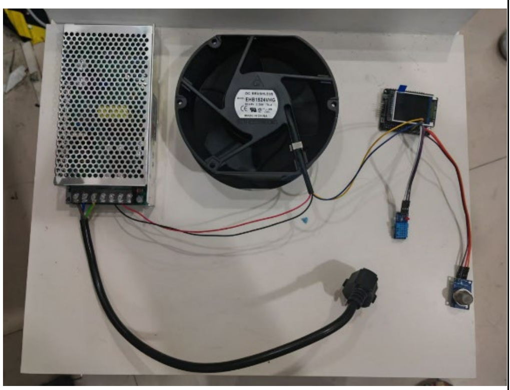

Figure 3. Hardware Wiring Diagram

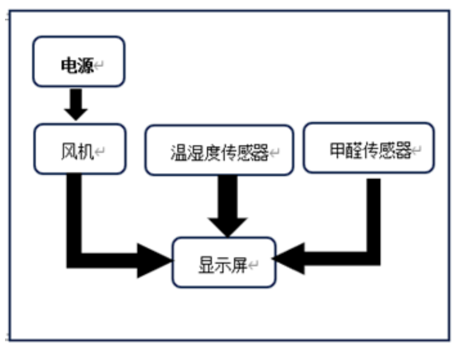

Figure 4

5. Water Curtain Main Structure

5.1. Initial Prototype Draft

By utilizing SolidWorks modeling and conducting fluid simulation, the airflow direction was verified. As can be seen from the figure, the airflow at the air inlet is smooth and stable, meeting the requirements for model spraying.

Limitations of the Prototype: The system's standalone exhaust function fails to ensure airborne particle concentrations stay within safe limits, creating a safety risk.

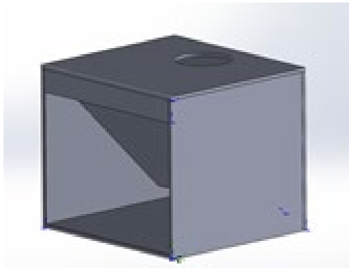

Figure 5. Prototype Device

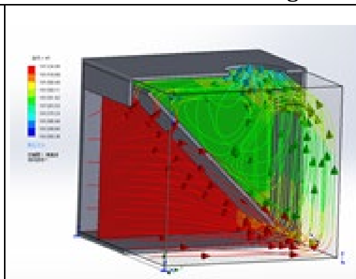

Figure 6. Fluid Simulation Verifies Negative Pressure Function

Figure 7. CAD Documentation

5.2. New System Architecture

Based on the prototype, improvements have been made by adding a water curtain function and relocating the fan to the rear. The structural design has been simplified as much as possible without compromising negative pressure functionality, making it easier for hobbyists to assemble and reducing both the entry barrier and cost.

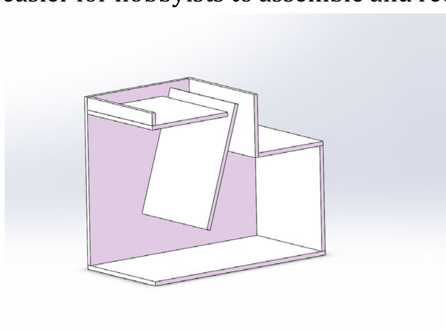

Figure 8. Structural Model of Water Curtain Framework

5.3. Main Frame Material Selection and Advantages

High-density PVC foam board is selected as the primary material. The designed model is exported into CAD drawings, which are then provided to suppliers for custom precision cutting：

1) Meets Strength Requirements: PVC foam board with appropriate thickness and density is fully capable of serving as the main structural material. This project specifically utilizes 10mm thick PVC foam board with a density of 0.6.
2) Low Cost: The entire air chamber assembly consumes less than 2 square meters of PVC foam board.
3) Customizable Shape: The material can be precisely cut into any required form based on CAD drawings, enabling high flexibility in design implementation.
4) Minimal Tolerance: The PVC foam boards, precision-cut by the manufacturer, exhibit extremely tight tolerances, ensuring a seamless and precise fit during assembly.

5.4. Completed Framework Physical Photo

Figure 9. Elevation View of Primary Assembly

Figure 10. Upper Header Tank

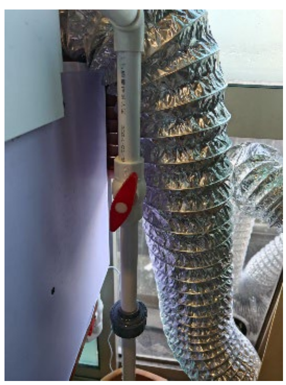

Figure 11. Flow Control Valve

Figure 12. Externally Mounted Tubular Fan

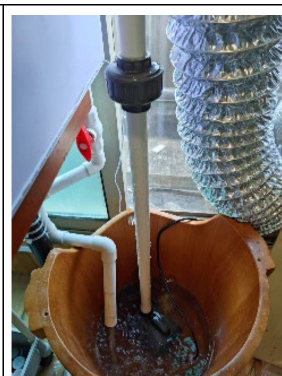

Figure 13. Pump and Reservoir Assembly

6. Functional Description

1) Air Quality Monitoring：The system incorporates real-time monitoring of both formaldehyde concentration in the air and operational noise levels.

2) Water Curtain Control: The system implements water pump switch control for activating/deactivating the pump, combined with water flow regulation through valve adjustment to manage the water curtain's flow rate.
3) Fan Control:
    - Power Control: Manages the activation and deactivation of the fan unit.
    - Speed Regulation (PWM): Dynamically adjusts fan rotation speed based on real-time air quality data.
4) Intelligent Linkage Control: Formaldehyde Concentration Linked to Fan Speed: Automatically adjusts fan rotation speed based on real-time formaldehyde levels.
5) Quick-Disconnect Water Pump: A quick-disconnect structure has been designed at the connection point between the water pump and the water pipe, facilitating rapid removal of the pump for cleaning and maintenance.
6) Additional Supplementary Notes: To form a stable and controllable water curtain, structural improvements have been made. Water from the pump flows into a storage tank at the top for accumulation. Once full, the water overflows and runs down the slanted plate shown in the front view, forming a stable and controllable water curtain.

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