Design and Implementation of a Non-Contact Control Panel Control System Based on STM32

Junhui Huang, Zhijian Chen, Siyi Liu
Guangdong AIB Polytechnic, Guangzhou, Guangdong, China

Abstract: The non-contact control panel system introduced in this paper uses the STM32F103C8T6 microcontroller as the core controller, integrating four diffuse reflective photoelectric switches and an ultrasonic distance measurement module to allow gesture-based driving of a DC motor start/stop, forward/reverse rotation, and continuous speed adjustment. The system architecture follows a four-layer design: a sensing layer used to detect hand proximity and direction, a control layer for gesture recognition and command generation, an execution layer that uses the L298N dual H-bridge motor driver with PWM to control voltage between 3V and 10V, and a power management layer that supplies constant 3.3V, 5V and 12V to every module through DC-DC converters. A 128×64 OLED display is used to provide real-time feedback on operational status, set parameters, and distances measured. The detection range for start/stop control is between 5 to 30 centimeters. The system has a measuring error of less than 1 centimeter. The system not only provides timely but also accurate gesture recognition, meets design requirements for motor control precision, and operates stably and reliably without any physical contact. This design offers an efficient, hygienic, and cost-effective control solution for applications requiring non-contact human-machine interaction.

Keywords: STM32F103C8T6; Photoelectric Switch; Gesture Recognition; Non-Contact Control; Ultrasonic Distance Measurement; DC Motor Control; PWM Modulation

1. Introduction

In various fields such as smart home, industrial control, medical equipment, and automated production, the control panel serves as a key component for achieving human-machine interaction. Its performance directly affects the user experience and system reliability. Traditional contact-based control panels are based on mechanical buttons, touch screens, or knob encoders in order to work, and they have intrinsic disadvantages which include wearing out of buttons, hygiene issues in public areas, and limited lifespan of mechanical components. Especially in special scenarios like clean rooms, humid environments, or hazardous areas, these limitations become more obvious. Non-contact control technology uses technologies such as photoelectric sensing, ultrasonic ranging, infrared detection, and capacitance proximity sensing to achieve intuitive human-machine interaction through gestures, distance detection, and spatial positioning, overcoming the inherent shortcomings of traditional contact-based solutions. At the same time, it also enhances user convenience and system durability [1]. The present paper constructs a holistic hardware and software system that is founded on the STM32F103C8T6 microcontroller, integrates ultrasonic ranging and multi-channel photoelectric sensing technologies, and designs a non-contact control panel system with relatively complete functions, stable performance, and controllable costs. The system is applicable to smart homes and small industrial applications [1].

2. System Design Approach

The non-contact control panel system uses STM32F103C8T6 as the core controller. It is composed of four functional modules: the operation panel (which includes photoelectric sensors), the measurement and control module, the display unit, and the DC fan load. Through non-contact gesture operation, the fan can be controlled, with control contents including start, stop, forward rotation, reverse rotation, and continuous speed adjustment. The overall design of the system follows a four-layer architecture of "sensing layer - control layer - execution layer - power management layer", and each layer has relatively clear and definite functions. Through standardized interfaces, they work together. The block diagram of the overall system design is shown in Figure 1.

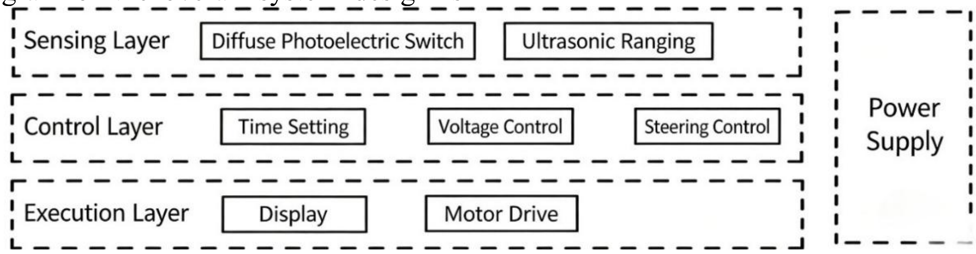

Figure 1. System Architecture Diagram

(1) Sensing layer

The diffuse reflection type photoelectric switch can determine whether the hand is close and send a switch quantity control signal. On the operation panel, there are 4 directional-arranged photoelectric switches. When the hand moves, it will sequentially trigger different switches, and the sequence in which these switches are triggered is the basis for the gesture recognition algorithm to identify the operation intention. The ultrasonic ranging module uses the pulse echo time-of-flight method to accurately measure the distance of the hand. Its working distance is 5 to 30 centimeters. The homemade ultrasonic circuit is shown in Figure 2. The transmitting circuit is a 10 μs trigger pulse that is amplified by a transistor and then applied to the 40 kHz ultrasonic emission probe. The receiving circuit uses two stages of operational amplifiers to amplify the weak echo signal, and then it is shaped by a comparator and output as a digital signal.

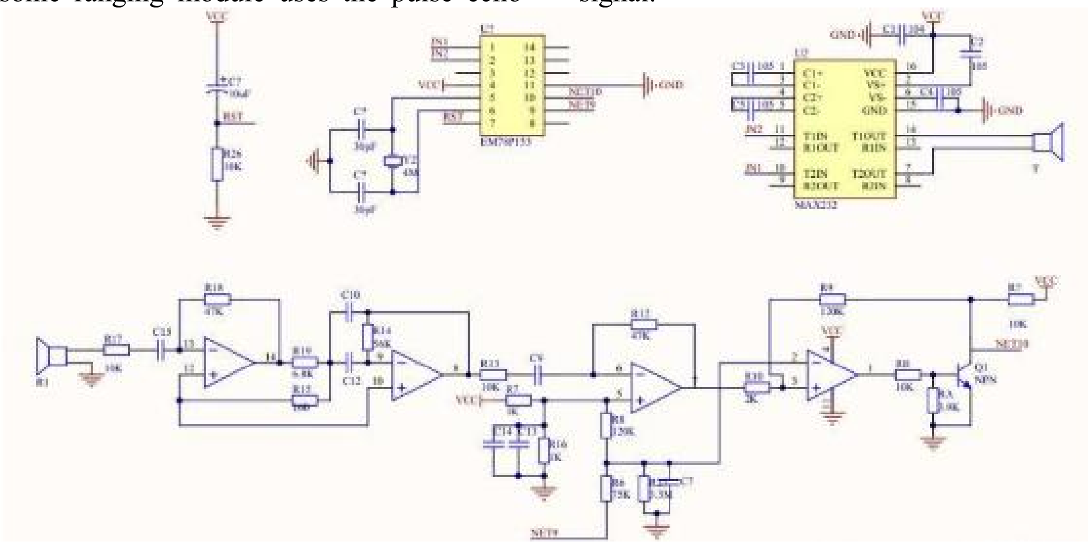

Figure 2. Ultrasonic Ranging Module Circuit Diagram

(2) Control layer

Sequential logic is used by the STM32 microcontroller to analyze and process sensor input data. The gesture commands are identified by this means. As an example, when waving left in front of the sensor array, the activation of a reverse trigger will occur, whereas a right wave will trigger a forward movement. The controller outputs direction control signals and PWM signals, aiming to achieve motor speed regulation. Through the use of hardware timer interrupts, precise timing management is achieved.

(3) Execution layer

The execution layer can display real-time status on a 128×64 OLED screen, including set time, remaining time, working voltage, operating distance, and other conditions. All control operations, such as start/stop, reversing, speed adjustment, and parameter settings, are accomplished using gestures themselves and do not require contact with any physical buttons. This indicates that the system has excellent non-contact functionality.

(4) Power management layer

The power management layer supplies constant and appropriate voltages to every functional layer. The DC-DC converter powered by a lithium battery serves as the primary power source. It provides 3.3V and 5V through the voltage reduction module, supplying 3.3V to the microcontroller and 5V to the sensors. The 12V supply is applied directly to power the motor drive module as well as the fan. This distributed power supply architecture ensures voltage stability for each module. The application of power domain isolation eliminates variations from the motor power, hence not causing any impact on the measurement accuracy of the sensors or the logical operations of the microcontroller.

3. Hardware Circuit Design

Figure 3 shows the main hardware block diagram of the non-contact control panel system. The system includes the main control chip STM32F103C8T6, the operation panel, an OLED display, and a measurement and control module. The operation panel contains S1–S4 diffuse reflective photoelectric switches and S5, a self-made ultrasonic distance measurement module. The measurement and control module includes the L298N motor driver module, a PWM-to-voltage conversion module, a DC fan load, and indicator lights. All these components together form the entire non-contact control panel system.

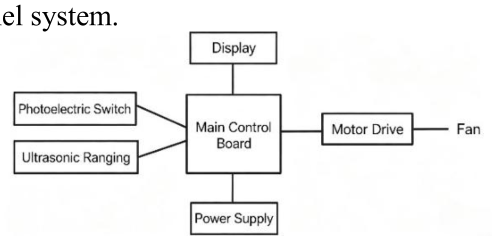

Figure 3. Hardware Diagram

(1) Ultrasonic ranging module

The ultrasonic distance measurement module consists of an emission circuit, a reception circuit, and a signal processing circuit, as illustrated in Figure 2. In the emission circuit, the GPIO of the single-chip microcontroller generates a 10 μs trigger pulse. The pulse is amplified by a transistor, which in turn drives the ultrasonic emission probe to emit 40 kHz ultrasonic waves. In the reception circuit, the ultrasonic reception probe captures the reflected echoes. The weak signal is amplified in the first stage by a two-stage amplifier circuit containing operational amplifiers. The amplifier output is then fed into a comparator to form a digital signal, which is then input into the single-chip microcontroller. The signal processing circuit uses capacitors to filter out noise interference, which guarantees the precision of the echo signal and meets the demands of a measurement interval of 5-30 cm and an error of less than or equal to 1 cm [2].

(2) Photoelectric switch selection

The diffuse reflection type photoelectric switch emits infrared rays and detects the reflected signals to indicate whether an object such as a hand is approaching or performing specific functions. As a result of the fast action of this switch and the fact that it offers trustworthy binary detection results, it is highly suitable for real-time gesture recognition applications.

In terms of layout and functionality, the four photoelectric switches on the operation panel present a specific directional distribution. When the hand moves in different directions, different photoelectric switches are triggered in sequence. The microcontroller detects changes in GPIO levels (i.e., transitions between high and low levels) to determine the direction of the gesture, such as swinging left, right, upward, or downward, and then executes control instructions including reversing the fan direction, adjusting the speed, or setting parameters.

The technical advantages are as follows: No complex driver circuits are required. The switches can be directly connected to the GPIO of the microcontroller for simple and reliable hardware design. Choosing a model with strong resistance to environmental light interference avoids the influence of indoor and outdoor lights, sunlight, etc., and allows normal operation in various lighting environments. Each sensor has an internal potentiometer for setting the detection distance to adapt to different installation requirements.

(3) Motor driver module

The L298N is the main chip. It is a dual H-bridge motor driver and can be used to control two DC motors running simultaneously. The dual H-bridge is controlled using logic levels to achieve individual bidirectional control for each motor channel, thereby reducing the complexity of interfacing with the STM32 microcontroller. In terms of performance parameters: the maximum continuous output current per channel is 2A, and the peak instantaneous output current can reach 3A. This current is sufficient to supply the power needed by a 12V DC fan. The chip transmits PWM signals to the enable pin, which makes it possible to smoothly control the voltage level. Considering the PWM duty cycle and the fact that there is approximately a 2V voltage drop at the output stage of the L298N, the fan speed can be continuously adjusted between 3V and 10V. This enables the fan speed to be continuously and smoothly adjusted [3].

(4) Display module

The OLED display has a resolution of 128×64. Due to its self-illuminating feature, it has low power consumption, generally not exceeding 20mA, short response time, and a wide viewing angle. The I2C communication can be connected with just two wires, making the wiring simple. Unlike ordinary LCD screens, OLED does not require a backlight module. It is easier to observe under different lighting conditions, has higher contrast, and can update countdowns, current distance information, and other parameters in a timely manner. This display is used to show the status of the fan, such as direction, power on/off, working parameters, such as voltage, set time, remaining time, operating distance, etc. The unit is in centimeters.

(5) Power module

The DC-DC lithium battery is the primary power source of the whole system. The DC-DC voltage reduction converter provides constant 3.3V and 5V to power the STM32 microcontroller (3.3V) and the sensor module (5V). A 12V battery directly powers the motor drive module and the DC fan. On the high-current motor path, no extra voltage conversion process is required. Under this power supply method, power domain isolation ensures that each module of every subsystem maintains a constant voltage level, preventing power fluctuations caused by the motor from interfering with the sensor measurement accuracy and the logic operation of the microcontroller.

3.1 Schematic Design

A complete schematic design includes the reset circuit, crystal oscillator circuit (8 MHz external crystal oscillator), power conversion circuit, sensor input conditioning circuit, motor control circuit, and output circuit. These and several other main parts are integrated into a complete whole, forming the hardware basis of the system, as illustrated in Figure 4. Such related circuits require corresponding hardware support to achieve precise gesture recognition, ensure reliable motor control, and guarantee stable system operation [4].

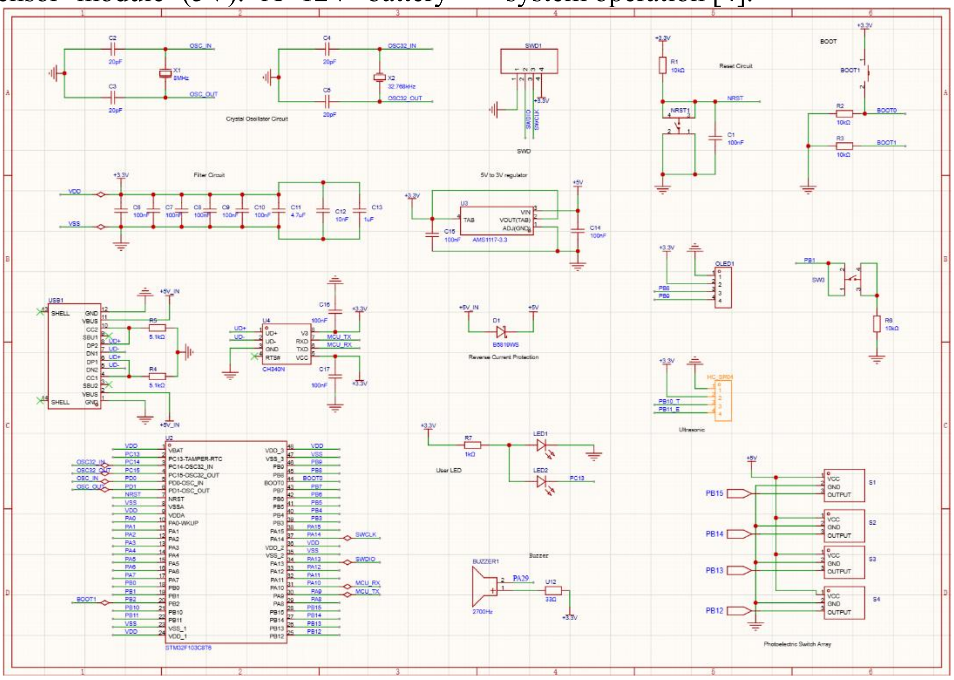

Figure 4. Schematic Design Overview

4. Theoretical Analysis and Design

(1) Core control principles

1) Ultrasonic ranging module principle analysis

The ultrasonic distance measurement module S5 measures distance by leveraging the propagation characteristics of ultrasonic waves in room-temperature air. The transmitting probe emits a 40 kHz ultrasonic pulse. When the ultrasonic wave hits the operator's hand, it will be reflected, and the receiving probe will receive the echo signal. The microcontroller uses a hardware timer to accurately record the time elapsed between emission and reception. According to the fundamental time-of-flight formula, i.e., $\mathbf{d = v \times t / 2}$, where **v** is the speed of sound in air (approximately 340 m/s at 20°C) and **t** is the measured round-trip time, the distance is calculated by dividing the product by 2 because the ultrasonic pulse travels the round-trip path [5].

$$d = \frac{vt}{2} \quad (1)$$

2) Relationship between fan voltage and PWM control

The fan voltage regulation is provided through the use of a PWM signal produced by the single-chip microcontroller to control the motor drive module. Since the output transistors of the L298N have an approximate saturation voltage drop of 2V, the effective output voltage U_{out} of the drive module and the PWM duty cycle D (between 0% and 100%) have a linear relationship. Its control equation is as follows:

$$U_o = U_i \times D - U_{drop} \quad (2)$$

3) Multi-step programming timing precision control technique

The STM32 timer peripheral is set to produce a periodic interrupt once per second. The interrupt service routine performs an accumulation or decrement operation. The value of the running count depends on the current running status. For example, when the program has accumulated 20 timer interrupts, the running time is triggered after 20 seconds. The timing error can be calculated based on the precision of the STM32 timer, which can reach 0.1 milliseconds, far exceeding the 1-second accuracy requirement [6].

(2) Gesture signal detection principle

The S1 to S4 photoelectric switches on the operation panel can detect the sequence and timing of the successive shading events caused by hand movement, thereby determining the waving direction. Based on the supplementary distance data obtained from the ultrasonic ranging sensor, when the single-chip microcomputer continuously detects changes in the GPIO pin level, it executes the entire gesture command parsing using a timing logic analysis method. This gesture parsing method takes into account both the sequence in which the sensors are triggered and the maximum allowable trigger time difference, so as to be able to reliably distinguish intentional gestures from random sensor triggers.

(3) Fan control principle

1) Motor rotation direction and start/stop

Based on the gesture instructions derived from the analysis, the microcontroller outputs corresponding control signals to the L298N motor drive module by means of dedicated GPIO pins. By setting the combination of high and low logic levels on the inputs to the drive module, the conduction state of the internal H-bridge circuit can be changed, thus allowing the fan to revolve in either direction, reverse, or stop. When rotating forward, the H-bridge provides power to the motor with a given polarity; when reversing, the opposite polarity is applied.

2) Voltage and speed regulation

As soon as the fan starts to operate, the single-chip microcontroller continuously sends PWM signals. This PWM signal has a variable duty cycle and is delivered to the enable input terminal of the L298N. By modulating the duty cycle of the PWM signal based on the desired speed, the average voltage supplied to the DC fan motor can be regulated. Consequently, it is possible to achieve a smooth, continuous, and stable transition between the minimum speed and the maximum rated speed without mechanical intervention switches or segmented adjustment methods.

5. Software Flow and Key Code Implementation

(1) Software flowchart

According to the overall functional design requirements of the project, the complete main program control flow is depicted in Figure 5. The software structure is modular. In the whole system, each functional module plays a different role. Some modules are used for system initialization, some for sensor data acquisition, some for gesture recognition, some for motor control, some for display updates, and some for timer interrupt service routines.

(2) Gesture recognition

If any one of the four photoelectric switches S1–S4 is activated by a hand approaching it, the program will record the sequence of activation and the time difference between them. Based on the timing sequence analysis, the appearance of S2 after S1 indicates a left-to-right movement, and the appearance of S4 after S3 indicates a right-to-left movement. This waving gesture can be effectively recognized to control functions such as starting forward rotation and reverse rotation. The OLED display will also show the current motor direction and start/stop status, providing users with immediate visual confirmation.

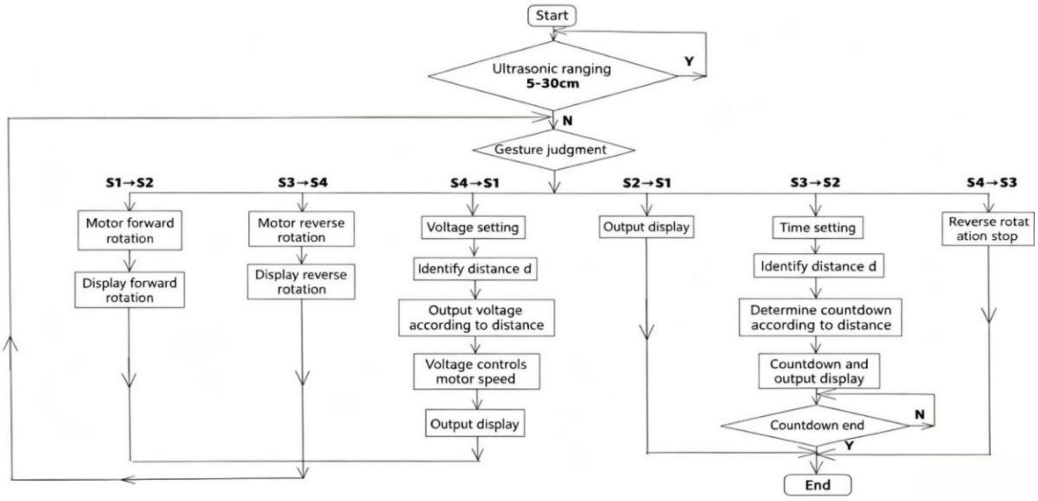

Figure 5. System Program Flowchart

The process of distance measurement and parameter setting is as follows: The ultrasonic sensor obtains a distance value every second to provide continuous real-time distance information. If it detects that S3 waves towards S2 (with d between 5 and 20 cm), then according to the pre-defined d-t relationship, a predefined table is used to calculate the running time t, and a countdown is displayed on the OLED. If it detects that S4 waves towards S1 (with d between 5 and 20 cm), then the desired working voltage is obtained according to the d-voltage mapping relationship, and the PWM duty cycle is changed to immediately adjust the fan voltage [7].

(3) Multi-step programming function

A specific gesture, such as pressing both S1 and S3 simultaneously, allows the user to enter the combined operation programming mode. In this mode, a user-defined sequence of actions including the motor direction, working voltage, and time is stored in the microcontroller. After the program has been written, the saved action sequence can be triggered by using the predetermined gesture. The program will then execute the recorded action commands in order according to the programmed sequence until the combined action is finished. This combined action function can perform complex multi-step operations without requiring the user to repeat the gestures.

6. Module Function Code Implementation

(1) Ultrasonic ranging module code

The ultrasonic module will send a 40 kHz ultrasonic pulse signal on the trigger signal line (Trig), and after sending, it will receive the reflected wave from the echo signal line (Echo). This module calculates the distance based on the propagation time of the sound wave, that is, the distance is equal to the speed of sound multiplied by the time and then divided by 2. Under standard room temperature and pressure conditions, the speed of sound is set at 340 m/s.

1. The code examples for triggering and initialization functions are shown in Figure 6:

```
void Ultrasonic_Start()
{
    GPIO_SetBits(Trig_Port, Trig_Pin);     // Set Trig pin high to start ultrasonic transmission
    Delay_us(45);                          // Keep trigger signal high for 45us (meets sensor timing requirement)
    GPIO_ResetBits(Trig_Port, Trig_Pin);   // Set Trig pin low to end the trigger
    Timer_Init();                          // Initialize timer to record Echo signal duration
}
```

Figure 6. Ultrasonic Ranging Initialization and Trigger

Ultrasonic_Start: Utilizing the pre-configured GPIO output pin, a trigger signal with a duration of exactly 45 microseconds at a high logic level is produced to restart the hardware timer. The initialization process then begins, allowing accurate measurement of the ultrasonic pulse transmission time, which can then be used for subsequent distance calculations.

2. The code example of the distance calculation function is shown in Figure 7:

```
uint16_t Ultrasonic_GetValue()
{
    Ultrasonic_Start();              // Start one distance measurement
    Delay_ms(100);                   // Wait 100ms for echo reception
    // Convert time to distance: Time is timer count value (unit: 0.0001s),
    // sound speed is 340 m/s, result is converted to cm
    return ((Time * 0.0001) * 34000) / 2;
}
```

Figure 7. Distance Calculation Function

After Ultrasonic_Start has been called, it should be waited for 100 milliseconds to finish the process of echo reception. The distance is calculated as ((Time x 0.0001) x 34000) / 2. The distance is expressed in centimeters. The formula is obtained on the basis of the law of the speed of the ultrasonic wave propagation (340 m/s) and the round-trip time. Initially, the measurement time must be transformed into seconds using the timer cycle coefficient, and this is done by multiplying it by 0.0001. Next, it is multiplied by the sound speed (34000 cm/s). Lastly, it is divided by 2 to offset the round-trip path [8]. First, multiply the timer cycle coefficient by 0.0001 to get the time in seconds, then multiply by the sound speed of 34000 cm/s, and finally divide by 2 to calculate the distance. Because ultrasonic wave propagation is a round-trip path, it is required to divide by 2 to offset [8].

(2) Fan PWM driver code

1. The code example of the fan pulse width modulation control function is shown in Figure 8:

```
void Set_Fan(float voltage)
{
    // Voltage range limitation: 3.0V~10.0V (prevents exceeding fan operating voltage range)
    voltage = (voltage < 3.0f) ? 3.0f : (voltage > 10.0f) ? 10.0f : voltage;

    // Calculate PWM duty cycle: based on 12V reference supply, duty cycle = (target voltage / 12V) * 100%
    float duty = (voltage / 12.0f) * 100.0f;

    // Map duty cycle to timer compare value (assuming timer period corresponds to count value 839, i.e., 8.39 times duty cycle)
    uint16_t pulse = (uint16_t)(duty * 8.39f);

    TIM_SetCompare1(TIM3, pulse); // Update compare value of TIM3 channel 1 to output corresponding PWM
}
```

Figure 8. Fan Speed Regulation Control Function

Set_Fan (): Changes the rotation rate of the DC fan according to the supplied voltage level. Also, restricts the voltage level to some limits. Regulates the input voltage in the safe operating range of 3.0V up to 10.0V to avoid burning out the fan motor caused by high voltage. The formula used to calculate the PWM duty cycle is duty = (voltage/12.0) x 100.0. The percentage of the resulting duty cycle is determined by the timer resolution. After some calculations, the given ratio will generate the appropriate pulse voltage amplitude. One particular way of calculation is: pulse = (uint16_t)(duty * 8.39), followed by `TIM_SetCompare1 to configure and update the clock. PWM waveform is outputted through compare register of TIM3 to give smooth control on fan speed [9].

(3) Sensor logic processing code

1. One example of a code with multi-layer conditional judgments and loop delays is illustrated in Figure 9:

During the triggering processing of the sensing layer, the ultrasonic ranging module will obtain the regular interval distance data between the hand and the screen. In case of this, the detection distance value is observed to be similar to the set threshold value, the internal stat the variables Count1 through Count4 and their corresponding confirmation flags cf1 through cf4 may change, hence processing the subsequent control logic and providing a reliable triggering signal.

Control layer response and branch logic - Case 1: After the execution of the swap operation between Count1 and Count2, either Motor_SetSpeed1() or Motor_SetSpeed3()will be executed to change the speed of the motor. Setting the fan to 10V with Set_Fan(10) will make the fan run at its highest rate of 10V, which is the maximum cooling performance.

Control layer response and branch logic - Case 2: When Count3 is activated, the system will make an interactive judgment on it. If Count3 interacts with Count4 first, the main task of this part is to complete some necessary preparatory work first, and then call Motor_SetSpeed2() to make the medium-speed motor run. Once the value of Count3 changes and is greater than a certain value, it will be compared with Count1. If the condition is met, it will call Motor_SetSpeed2() again to change the motor speed or make it run in another way.

Further, setting the fan voltage to 7V using Set_Fan (7) is also effective in attaining a medium-cooling speed. In some combinations, Motor_SetSpeed3() can be activated and combined with Set_Fan(10) for full-power operation.

For the control layer response and branch logic of Case 3: After Count4 is triggered, the system will judge the context it involves. If Count4 interacts with Count3 and Motor_SetSpeed3, Motor_SetSpeed3 will be executed, and Set_Fan(10) will be used to make the fan run at high speed. When Count4 interacts with Count2, Motor_SetSpeed2() will be called and combined with Set_Fan(13) to increase the fan voltage to meet the requirements of different fan voltages in specific working conditions.

Execution layer actions: When the fan speed control module receives the voltage signal given by the Set_Fan() function, it will automatically generate a corresponding duty cycle PWM signal. The WMsignal is used to control the fan speed. Meanwhile, the motor speed control functions Motor_SetSpeed1 to Motor_SetSpeed3 will also change the motor power output to adjust it and enable the equipment to work normally under different distance triggering conditions and complete power transformation and speed matching [10].

```
if(Count1 ==1){
for(int i=0;i<1500;i++){
    if(Count2 ==1){Motor_SetSpeed1();Set_Fan(10);Delay_ms(1000);Count1=0;Count2=0;cf1=0;break;}
    Delay_ms(1);
    }
}
if(Count2 ==1){
    for(int i=0;i<1500;i++){
    if(Count1 ==1){Motor_SetSpeed3();Set_Fan(10);Delay_ms(1000);Count1=0;Count2=0;cf1=0;break;}
    Delay_ms(1);
    }
}
if(Count3 ==1){
    for(int i=0;i<1500;i++){
    if(Count4 ==1){Motor_SetSpeed2();Set_Fan(10);Delay_ms(1000);Count3=0;Count4=0;cf1=0;break;}
    if(Count1 ==1){Motor_SetSpeed2();Set_Fan(7);Delay_ms(1000);Count3=0;Count1=0;cf1=0;break;}
    Delay_ms(1);
    }
}
if(Count4 ==1){
    for(int i=0;i<1500;i++){
    if(Count3 ==1){Motor_SetSpeed3();Set_Fan(10);Delay_ms(1000);Count3=0;Count4=0;cf1=0;break;}
    if(Count2 ==1){Motor_SetSpeed2();Set_Fan(13);Delay_ms(1000);Count2=0;Count4=0;cf1=0;break;}
    Delay_ms(1);
    }
}
```

Figure 9. Gesture Detection Interrupt and Cyclic Timing Processing

7. Conclusions and Future Work

This research focused on the design of a non-contact control panel around the STM32F103C8T6 core. During this process, a reflective photoelectric switch and an ultrasonic distance measurement module were integrated. Eventually, the functions of starting/stopping the DCfan, forward/reverse rotation, and speed adjustment were successfully achieved. The test results obtained show that this system responds promptly in gesture recognition, its control accuracy can meet the requirements proposed in the design, and it does not require contact during operation, possessing convenient and hygienic characteristics.

In future research, the gesture recognition algorithm can be further improved for better robustness. On this basis, in order to study the method of multiple devices working collaboratively, the application scope of this control board can be further expanded. It can be promoted and used in smart homes, small appliances, etc. with non-contact control technology. The lightweight application of this technology provides more practical references.

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