ECE445

SENIOR DESIGN LABORATORY

DESIGN DOCUMENT

An Engineering Solution to a Local Indoor Safety Regulation System Problem

Team #26

Yichen Zhang [yichen36]

Wenyu Zhou[wenyu6]

Kaicheng Wu [kw36]

Advisor: Meng Zhang

April 5, 2026

Contents

目录

1. Introduction

1.1 Problem Statement

Indoor spaces such as apartments, dormitories, laboratories, and small offices are exposed to several common but important risks. The first category is environmental discomfort, including abnormal temperature and humidity conditions that may reduce comfort, affect equipment operation, or create unhealthy indoor conditions. The second category is safety threats, especially early-stage fire hazards indicated by smoke and unauthorized intrusion into a protected indoor area. In many practical situations, these risks do not occur independently. For example, a closed indoor environment may simultaneously experience poor ventilation, abnormal temperature rise, and smoke generation, while security monitoring is also required during unoccupied periods.

Existing low-cost indoor monitoring devices often focus on only one function. Environmental sensors may only display temperature and humidity values without providing active safety response. Basic smoke alarms may produce an alert but cannot coordinate with other system states. Camera-based monitoring systems may rely on cloud connectivity, introducing privacy concerns, network dependency, and higher latency. As a result, many existing systems lack integration, local decision-making capability, and timely automatic response. This makes them less suitable for scenarios where a reliable local response is more important than remote cloud functionality.

To address this problem, our project proposes an STM32-based local indoor safety regulation system. The system integrates temperature and humidity sensing, smoke detection, and camera-based intrusion detection into one embedded platform. Instead of treating these functions as isolated modules, the system combines them under a unified local controller that performs real-time monitoring, prioritization, and actuation. When an abnormal condition is detected, the system responds locally through alarm and regulation outputs without requiring internet access. In this way, the proposed design improves reliability, response speed, and functional integration for indoor safety applications.

1.2 Solution Overview & Visual Aid

We propose an STM32-based embedded safety system integrating four major functions: temperature monitoring, humidity monitoring, smoke detection for early fire warning, and camera-based intrusion detection. The core idea is to use one microcontroller as the local decision-making center. Environmental data and security-related signals are continuously collected and processed, and the controller determines which response should be triggered according to system priority and threshold logic. Smoke-related events are treated as the highest-priority condition because of their direct relationship to fire safety. Intrusion events trigger an alarm response, while environmental regulation functions can be used to improve indoor comfort when no higher-priority hazard exists.

The visual aid for this section should show the system in a realistic room scenario. A temperature/humidity sensor and a smoke sensor are placed in the room to collect environmental information. A camera monitors the entrance or protected indoor area to determine whether unauthorized human presence is detected. These sensing modules send data to the STM32 controller. Based on the controller's logic, local outputs such as a buzzer, warning LED, and environmental regulation devices are activated. The figure should emphasize that all sensing, decision-making, and response are performed locally..

1.3 High-Level Requirements List

(1) Environmental Monitoring Requirement

The system shall measure indoor temperature with an accuracy of ±1° C and relative humidity with an accuracy of ±5% RH. Updated environmental readings shall be available to the control logic at least once per second.

(2) Smoke Detection Requirement

The system shall detect smoke concentration changes and generate a fire-warning event within 2 seconds after exposure to a controlled smoke source. Smoke sensitivity shall be adjustable by threshold setting, and the successful detection rate shall be at least 95% over repeated trials.

(3) Intrusion Detection Requirement

The system shall detect human presence within a range of 3 m using the camera-based subsystem. Detection latency shall be no more than 1 second, and detection accuracy shall be at least 90% under normal indoor lighting conditions.

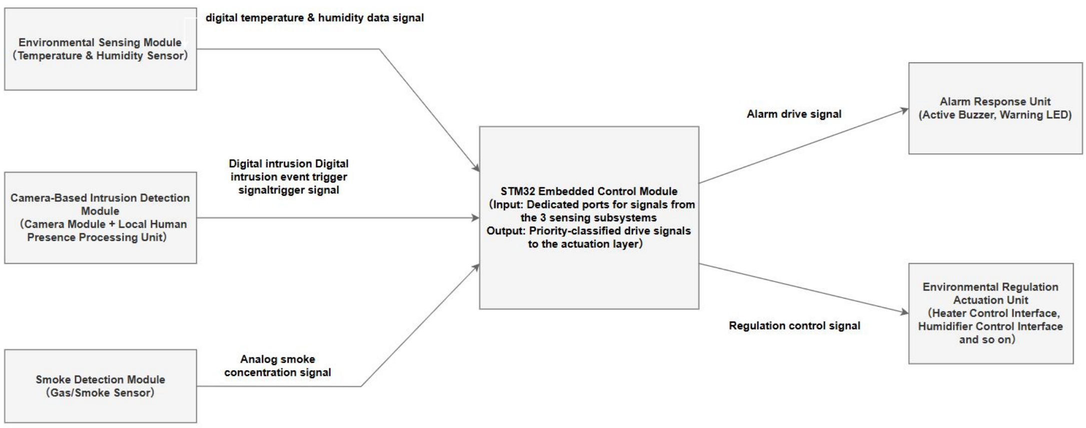
(4) System Response Requirement

The alarm subsystem shall activate within 500 ms after a valid hazard event is confirmed. Smoke-related events shall always have higher priority than environmental regulation tasks. The full system shall operate continuously for at least 24 hours without crash or logic failure.

2. Design

2.1 Block Diagram

The complete system is composed of four main subsystems: the environmental sensing module, the smoke detection module, the camera-based intrusion detection module, and the embedded control and response module. The environmental sensing module measures temperature and humidity in real time. The smoke detection module monitors air conditions related to early fire risk. The intrusion detection subsystem uses a camera to determine whether a person is present in a protected indoor area. All sensing outputs are sent to the STM32 microcontroller, which serves as the central control unit. The controller compares the input signals against thresholds or detection conditions and then drives the response module, which may include a buzzer, LED alarm, and regulation outputs such as heater or humidifier control.



2.2 Subsystem

2.2.1 Environmental Sensing Module

Function

The environmental sensing module is responsible for collecting real-time indoor temperature and humidity data and providing these measurements to the embedded controller. This module provides contextual information that may help interpret abnormal room conditions. For example, unusual temperature increase may indicate environmental change related to a potential hazard, while low humidity may trigger indoor regulation output if no higher-priority safety event is present.

In the current design, the environmental sensing module uses a temperature and humidity sensor such as the DHT22. The sensor communicates with the STM32 controller, which periodically samples the data and stores the latest readings. The controller compares these measurements to preset threshold values and determines whether the room is within the desired operating range. If temperature or humidity falls outside the acceptable range and no smoke or intrusion event is active, the embedded controller may trigger a local regulation response.

Requirements

The module shall measure temperature over the range 0–50°C with system-level accuracy of ±1°C.

The module shall measure relative humidity over the range 20%–90% RH with system-level accuracy of ±5% RH.

New valid temperature and humidity data shall be delivered to the STM32 controller at least once every 1 second.

The sensor readings shall remain stable during continuous operation, with no more than ±0.5°C drift in measured temperature and ±3% RH drift in measured humidity over a 2-hour steady-environment test.

Verification

Place the sensor next to a calibrated thermometer in controlled indoor conditions and compare 20 repeated measurements. The average temperature error must remain within ±1°C.

Compare humidity readings against a calibrated reference hygrometer across several indoor humidity conditions. The average humidity error must remain within ±5% RH.

Log sensor data timestamps and verify that updated readings are received by the controller at least once per second for a 30-minute test.

Keep the system in a stable indoor environment for 2 hours and record drift. The measured drift must satisfy the limits stated above.

2.2.2 Smoke Detection Module

Function

The smoke detection module is responsible for early fire-warning capability. Its main task is to detect smoke concentration changes in indoor air and send a fire-related warning signal to the embedded controller before a more severe hazardous condition develops. Because smoke is directly tied to safety, this module is assigned the highest priority in the system logic.

A gas/smoke sensor such as the MQ-2 is used to detect the presence of smoke-related particulate or gas concentration changes. The analog output of the sensor is read by the STM32 through an ADC channel. The controller compares the sensor reading against an adjustable threshold. When the threshold is exceeded for a sufficient confirmation interval, the controller classifies the condition as a smoke event and immediately triggers the response module. The threshold is made adjustable so that the system can be tuned for different indoor spaces and different acceptable sensitivity levels. This follows your original skeleton very closely, which already defines smoke detection within 2 seconds, adjustable threshold, and at least 95% reliability.

Requirements

1. The module shall detect a valid smoke event within 2 seconds of controlled smoke exposure.

2. The detection threshold shall be adjustable through firmware or analog configuration.

3. The module shall be sensitive enough to detect early-stage smoke under normal indoor conditions without requiring visibly dense smoke.

4. Over 10 repeated tests, the successful detection rate shall be at least 95%.

5. During normal no-smoke operation, the false alarm rate shall be no more than 1 false trigger per hour under stable indoor conditions.

Verification

1. Expose the sensor to a controlled smoke source and record the time between smoke introduction and alarm trigger. The measured delay must be no more than 2 seconds.

2. Adjust the threshold across several predefined values and verify that the trigger point changes accordingly while the controller still reads the correct analog level.

3. Perform 10 repeated smoke detection tests under similar conditions. At least 95% of the tests must result in successful detection.

4. Run the system continuously for 1 hour under normal no-smoke indoor conditions. The module shall not produce more than one false alarm.

5. Record ADC values before, during, and after smoke exposure to confirm that the triggered event corresponds to an observable signal rise rather than random noise.

2.2.3 Embedded Control Module

Function

The embedded control module is the decision-making center of the system. It receives sensor data from the environmental sensing module and smoke detection module, and it also receives a processed intrusion-detection signal from the camera subsystem. Based on these inputs, the controller executes real-time decision logic and determines which response should be activated. The STM32 microcontroller is selected because it provides sufficient I/O capability, analog data acquisition, low-power real-time control, and straightforward implementation for local embedded decision-making.

The control logic is designed with explicit priority. Smoke detection has the highest priority because it corresponds to possible fire risk. Intrusion detection is the next priority because it represents a direct security threat. Environmental regulation operates only when no higher-priority hazard is active. A simplified version of the control logic is as follows:

1. If smoke is detected, activate fire alarm immediately.

2. Else if human intrusion is detected, activate security alarm.

3. Else if temperature is lower than threshold, activate heater control.

4. Else if humidity is lower than threshold, activate humidifier control.

5. Else remain in monitoring state.

6. This module is also responsible for system stability, threshold comparison, output timing, and fail-safe behavior.

Requirements

1. The controller shall process each valid system input update and generate the correct output decision within 100 ms.
2. The controller shall maintain correct priority ordering: smoke > intrusion > environmental regulation.
3. The controller shall operate continuously for at least 24 hours without crash, freeze, or logic fault.
4. When multiple conditions are present simultaneously, the controller shall always activate only the highest-priority required response.
5. After power-up, the controller shall enter stable monitoring mode within 5 seconds.

Verification

· Inject simulated temperature, humidity, smoke, and intrusion signals into the controller and measure input-to-output decision delay. The delay shall be no more than 100 ms.

· Create combined test cases, such as smoke plus low humidity, and confirm that only the smoke response is activated.

· Run the full control system continuously for 24 hours and confirm that the controller does not crash or lose output functionality.

· Use at least 10 predefined logic test cases to verify correct response priority under single-condition and multi-condition inputs.

· Measure the startup process after power is applied and confirm that the system enters normal monitoring mode within 5 seconds.

2.2.4 Response & Actuation Module

Function

The response and actuation module is responsible for converting controller decisions into visible or audible local responses. In the current design, the most important actuation outputs are a buzzer and a warning LED, which provide immediate local alert for both fire-related and intrusion-related events. Additional regulation outputs, such as heater or humidifier control, may also be driven by this module if the system is operating in environmental regulation mode.

This module is designed to emphasize local, immediate action. A smoke event should produce a strong and unmistakable alert. An intrusion event should also trigger a clear alarm response. Environmental regulation outputs are secondary and should only operate when the system is not handling a more critical event. The response module therefore works closely with the priority logic in the embedded control module.

Requirements

1. The system shall generate an audible alarm with a sound pressure level of at least 70 dB measured at a distance of 1 meter.
2. The system shall activate the alarm within 500 ms after detection of a hazardous condition (smoke or intrusion).
3. The alarm shall remain continuously active until a manual reset signal is received, regardless of whether the hazard condition persists.
4. The system shall activate the ventilation fan within 1 second after smoke is detected.
5. The system shall ensure that alarm and actuation signals are stable without intermittent interruption during operation.

Verification

· Measure the sound level using a sound level meter placed 1 meter away from the device. The measured value shall be ⩾ 70 dB.

· Inject a simulated hazard signal and measure the delay between detection input and alarm activation using a timer or oscilloscope. The delay shall be ⩽ 500 ms.

· Trigger an alarm condition, remove the hazard, and observe system behavior. The alarm shall remain active until a manual reset button is pressed.

· Introduce a smoke signal and measure the time required to activate the ventilation fan. The activation delay shall be ⩽ 1 second.

· Run the system continuously under alarm conditions for at least 10 minutes and confirm that no signal interruption or instability occurs.

2.3 Schematics

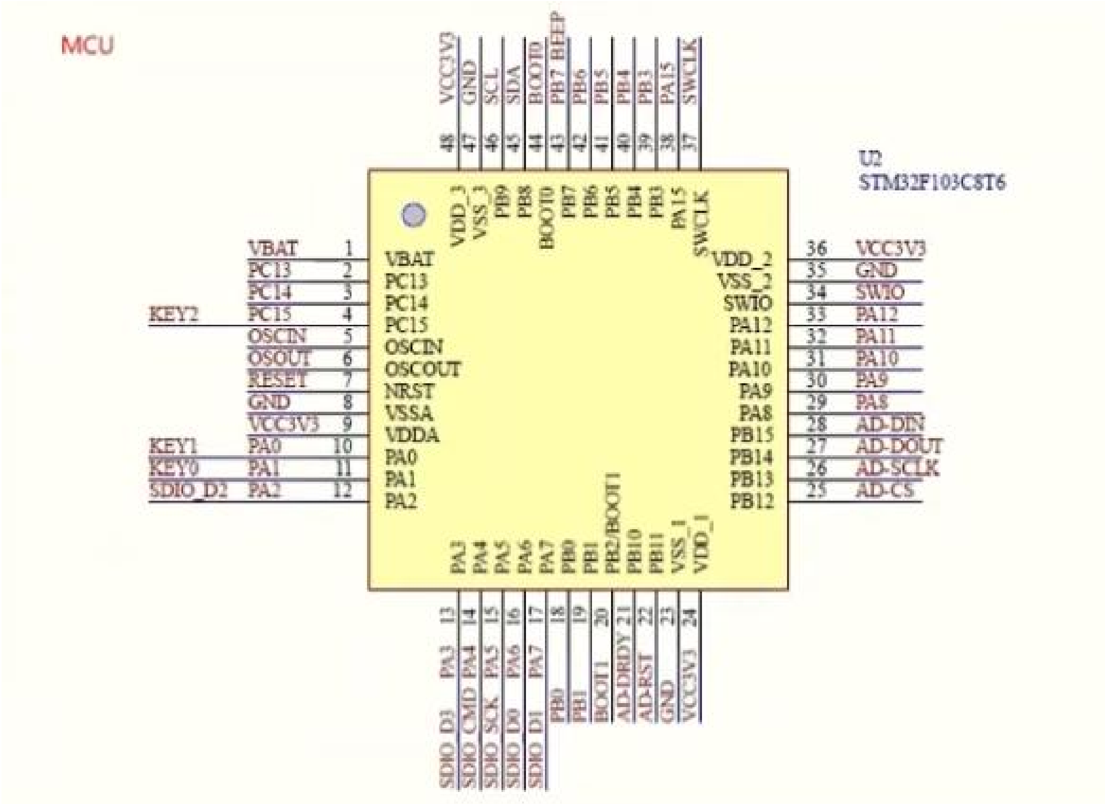


Figure 1. STM32 core connection and power interface

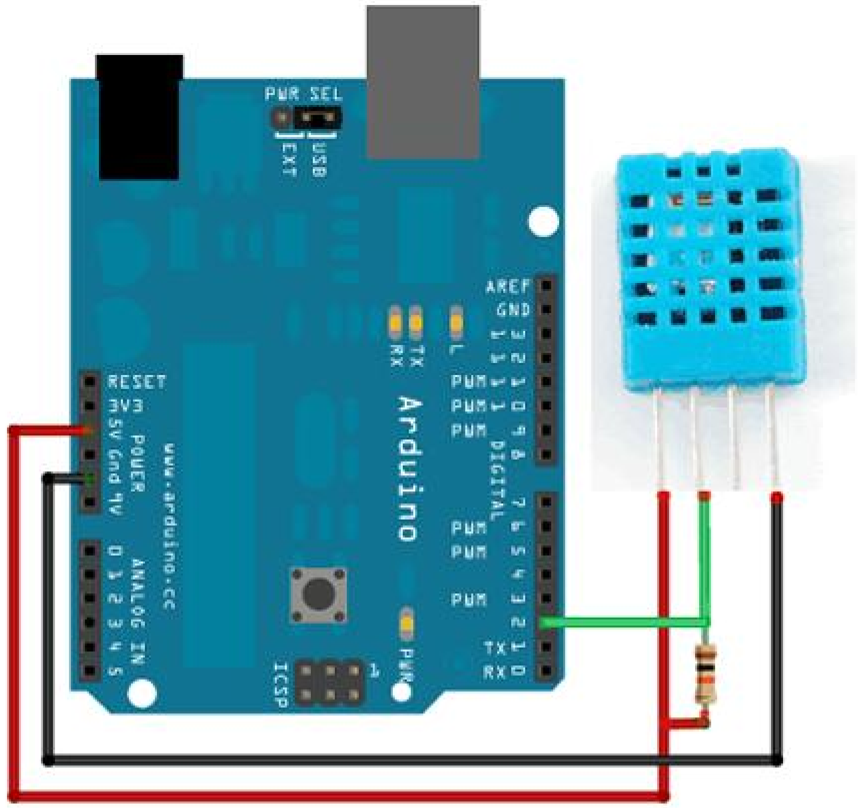


Figure 2. Interface circuit for temperature and humidity sensors

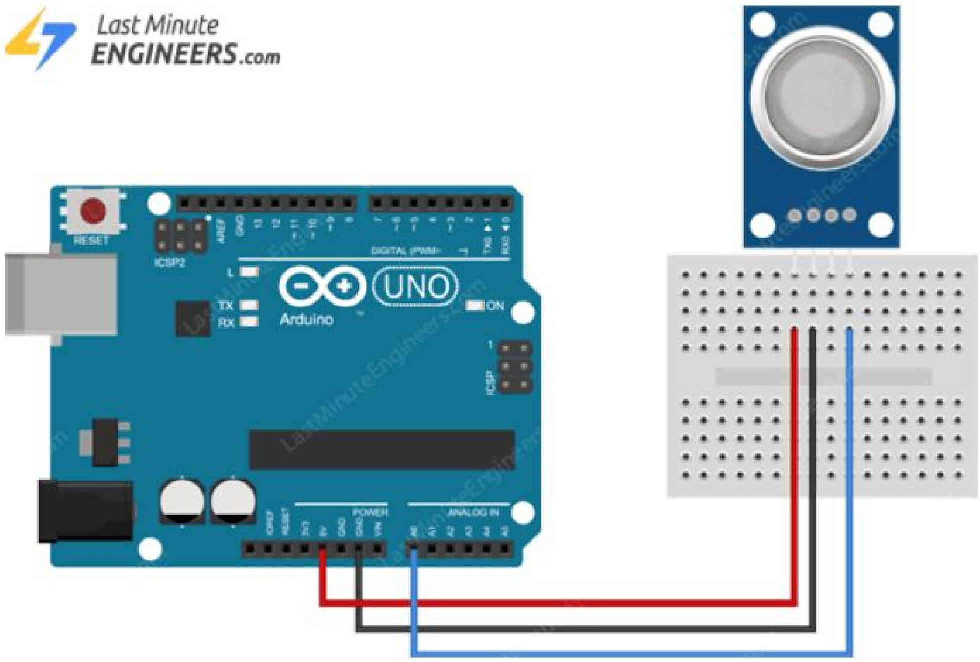


Figure 3. Analog interface circuit of MQ-2 smoke sensor

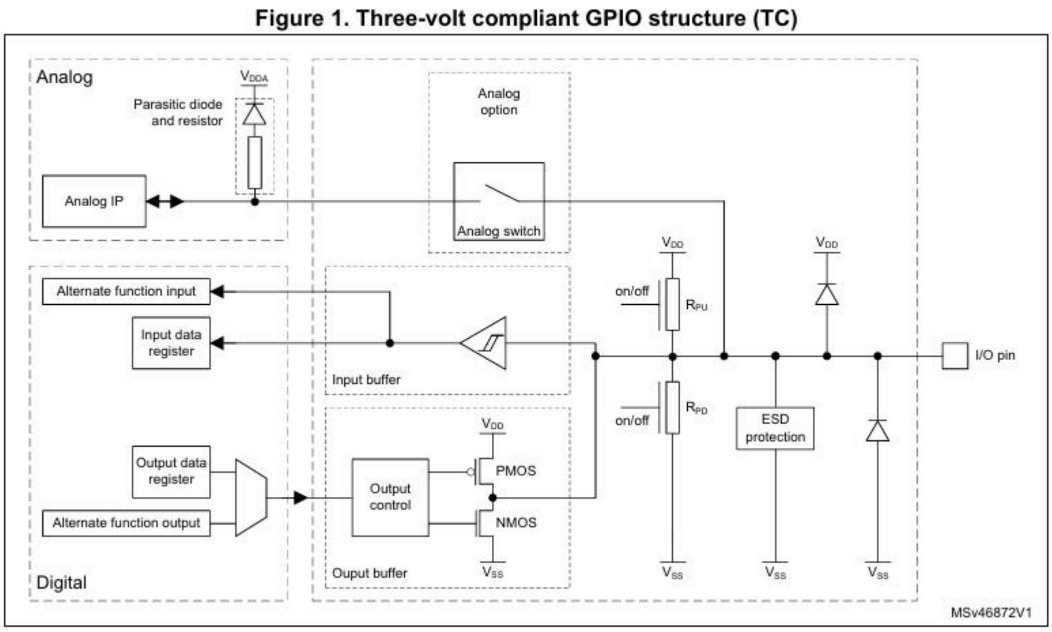
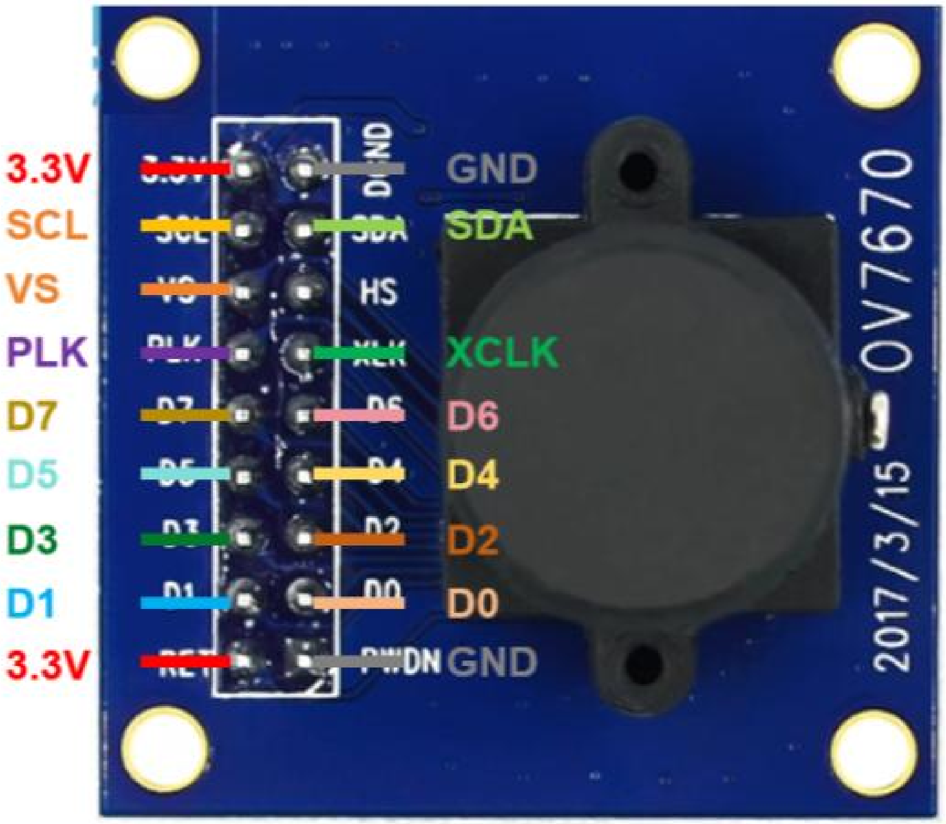


Figure 4. Alarm output circuit for the alarm bell and warning LED



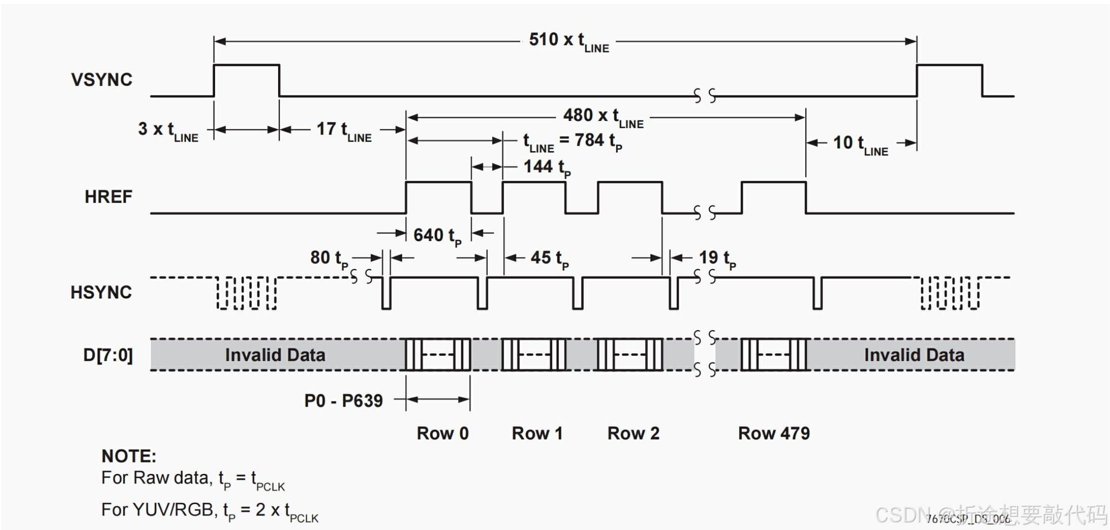


Figure 5. Camera signal path or intrusion detection communication interface

2.4 Tolerance Analysis

Critical Function: Temperature Control

Let:

- Desired temperature = T_d
- Measured temperature = T_m

- Sensor error = ±1°C

Impact Analysis

- Worst-case deviation:

$$|T_d - T_m| \leq 1°C$$

System Response

- Control logic includes tolerance band:
- Heater activates if $T_m < T_d - 1°C$

Conclusion

System remains stable despite sensor inaccuracies and avoids oscillation (rapid switching)

3.Cost

Component	Quantity	Total (RMB)
STM32 Microcontroller Board	1	¥10
Temperature & Humidity Sensor (DHT22)	1	¥10
Smoke Sensor (MQ-2)	1	¥10
Camera Module	1	¥100
Ventilation Fan	1	¥15
Buzzer + LED	1	¥5
LCD Display (1602)	1	¥12
PCB + Electronic Components	1	¥40
Power Supply Module	1	¥20
Total Cost		**≈ ¥222**

4. Schedule

Week	Task
Week 1	Component selection
Week 2	Sensor + smoke testing
Week 3	Camera detection algorithm
Week 4	Circuit design
Week 5	PCB fabrication
Week 6	STM32 integration
Week 7	System integration
Week 8	Testing & debugging
Week 9	Optimization
Week 10	Final demo

5. Ethics and Safety

5.1 Ethics

This project is intended to improve indoor safety and comfort through local monitoring and response. Therefore, the ethical design goal is not surveillance for unnecessary personal monitoring, but responsible hazard detection and local protection. Since the system includes camera-based intrusion detection, privacy must be considered carefully. The design should minimize unnecessary storage or transmission of image data. Whenever possible, camera data should be processed locally and used only for real-time presence detection rather than long-term recording. This is consistent with the project's local, privacy-preserving direction already indicated in the original skeleton.

The system should also be transparent in behavior. Users should know what conditions trigger alarms, what thresholds are used, and how the system prioritizes smoke, intrusion, and environmental regulation. This helps avoid misleading operation and aligns with the IEEE Code of Ethics principle of protecting public safety, avoiding harm, and maintaining honesty and clarity in engineering practice. In addition, the system should not create a false sense of absolute security. It is a prototype local safety regulation system, not a complete replacement for certified commercial fire or security infrastructure.

5.2 Safety

Electrical safety is important because the system contains powered sensing and alarm circuits. All exposed conductors should be insulated, and the power supply path should include proper protection against short circuits or wiring mistakes. The controller and sensors should operate at safe low voltages appropriate for embedded electronics.

Fire-related safety is central to the project. Since the system handles smoke detection, its response path must be reliable and immediate. Controlled smoke testing should be performed carefully in a safe environment, and the system should never create ignition risk during demonstration. Alarm outputs must be clearly distinguishable and sufficiently noticeable.

Operational safety is also necessary. If the controller crashes or the camera subsystem fails, the design should default to a fail-safe monitoring state or indicate fault clearly. Manual reset should always be available so that the user can recover the system safely. Relevant safety considerations should be discussed with reference to general electrical and electronics standards such as OSHA-style laboratory safety guidance and FCC-related electronics compliance awareness, exactly as your original skeleton already suggests.

References

[1] STMicroelectronics, *STM32 Reference Manual*, 2024
[2] IEEE, *Code of Ethics*, 2020
[3] Sensor datasheets (DHT22, MQ-2)