Hardware

iGEM ·WW1

1. Overview

This project has designed a portable immunochromatographic test strip reader (iGEM Reader) for automated detection and quantification of the grayscale information of the two T-lines on the test strip, thereby achieving objective and standardized interpretation of test results. The device uses the ESP32-CAM as the core controller, integrating camera sampling, image analysis algorithms, OLED status display, and LED indicator lights to form a complete embedded detection system.

Traditional immunochromatographic test strips rely on subjective interpretation by human eyes, which is easily influenced by lighting conditions and personal experience. This device captures images of the test strips through a camera, and the algorithm automatically calculates the T1/T2 grayscale ratio to provide an objective judgment of colonization/infection, enhancing the consistency and reproducibility of detection.

2. Device Design

2.1 Overall structure and composition

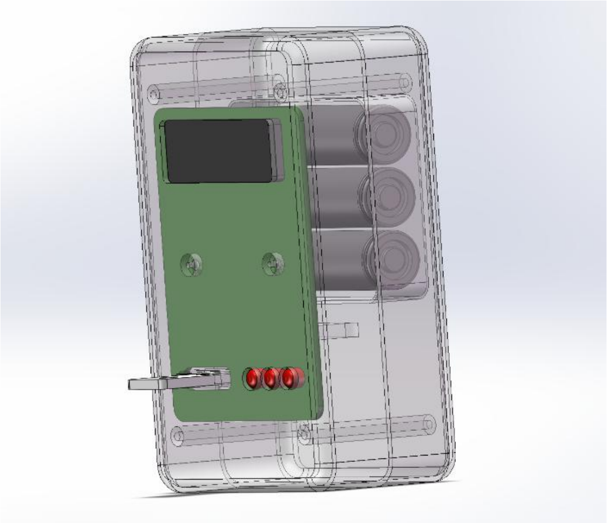
The device consists of the following core modules：

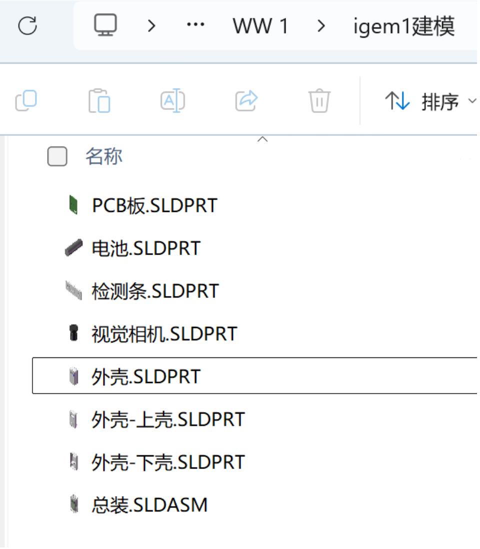
Module	Size	Function
Master Control Module	ESP32-CAM	System control, image capture, data processing
Camera	OV2640 (grayscale mode)	Capture test strip images
Display	0.96" OLED Module (4-pin)	Real-time display of device status and results
Status LEDs	Green / Yellow / Red × 3	Indicate standby, processing, and error states
Trigger Switch	Push button (IO13)	Detect test strip insertion
Power Supply	Lithium battery	Device power source

2.2 3D modeling

SolidWorks was used for parametric 3D modeling. The following parts and the full assembly were completed:

- Housing (upper housing / lower housing): Refer to the appearance of blood glucose meters, featuring a good ergonomic structure for handheld use
- Test strip guide slot: Ensure consistency in the position of the test strip during camera sampling to improve detection repeatability
- PCB board, camera module, battery: 3D modeling and spatial layout of internal components
- General drawing





··· WW 1 > igem1建模

名称

PCB板.SLDPRT

电池.SLDPRT

检测条.SLDPRT

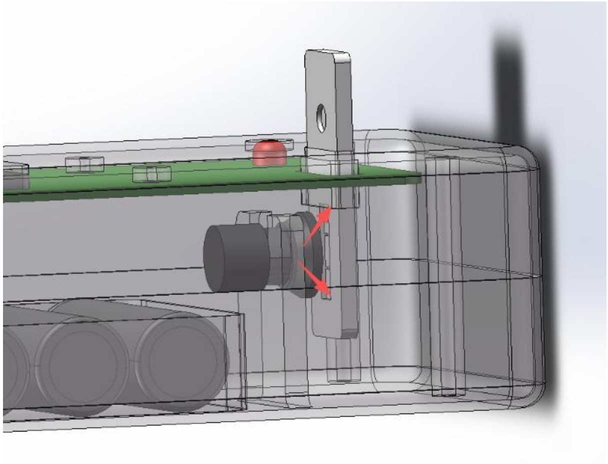
视觉相机.SLDPRT

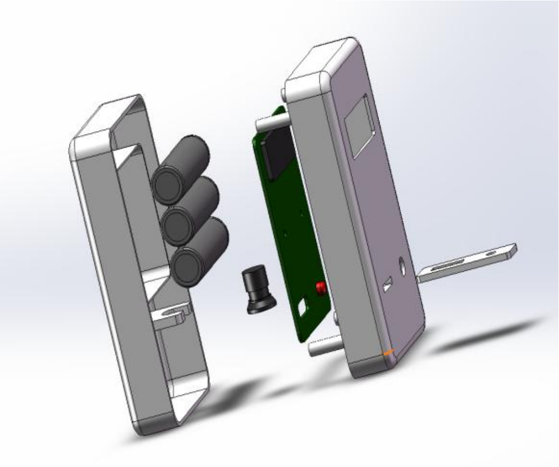
外壳.SLDPRT

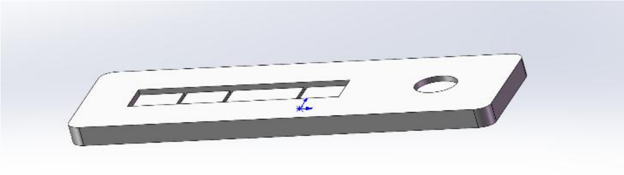
外壳-上壳.SLDPRT

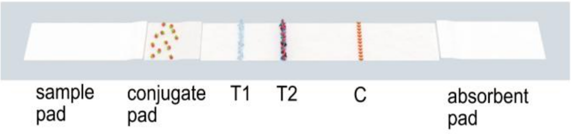
外壳-下壳.SLDPRT

总装.SLDASM









3. Circuit Design

3.1 Circuit Overview

The circuit is centered on the ESP32-CAM (AI-Thinker module), with peripheral connections to an OLED display, three-color LED indicators, a test strip trigger switch, and a lithium battery power circuit. The OLED display communicates via I2C bus (address 0x3C). The push button uses active-low input with internal pull-up to GND. Each LED is connected to its corresponding GPIO through a current-limiting resistor.

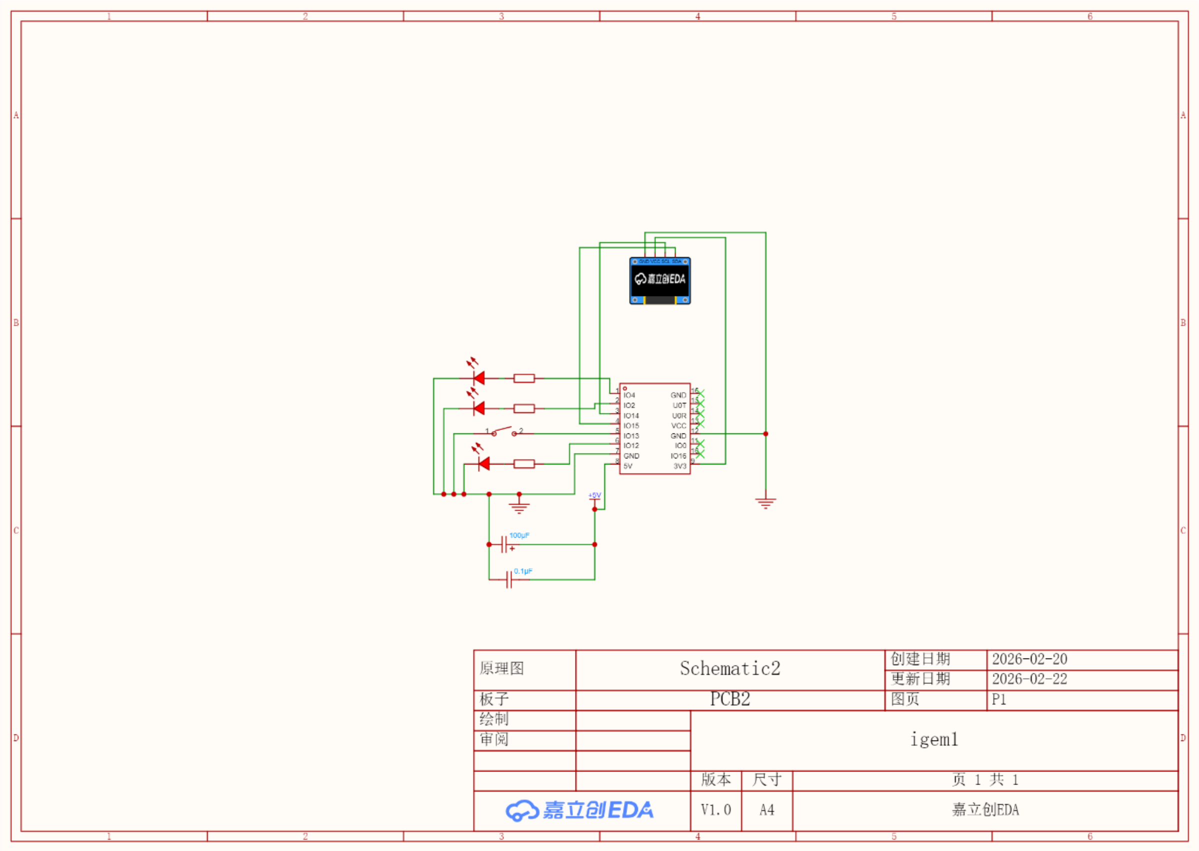
3.2 Pin Assignment

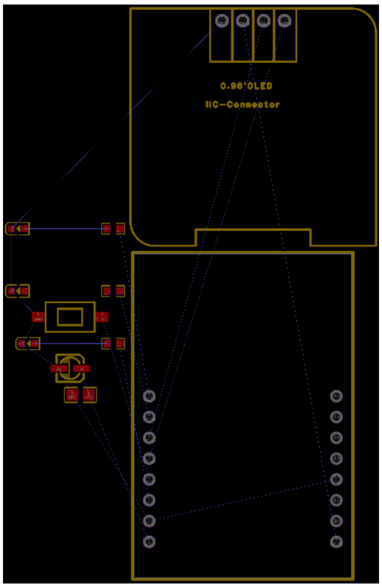
Pin	Function
IO12	Green LED (standby / success)
IO4	Yellow LED (processing)
IO2	Red LED (error / fault)
IO13	Test strip insertion switch (active low, pulled to GND)
IO14	OLED SCL (I2C clock)
IO15	OLED SDA (I2C data)
Internal fixed	OV2640 camera data / control signals (module-internal wiring)

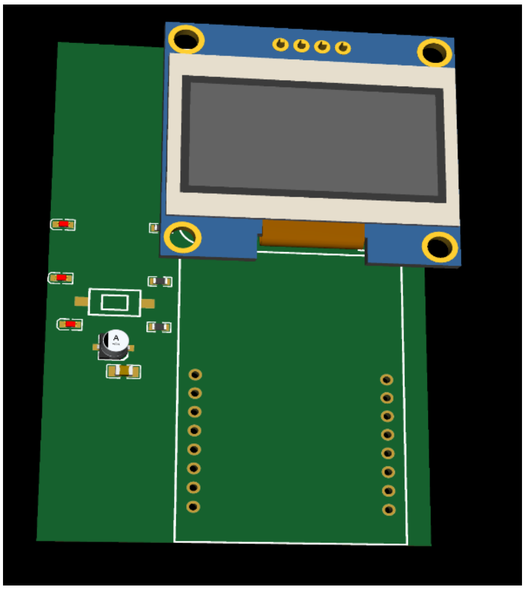
3.3 EDA Design Files

The complete circuit schematic and PCB layout have been designed using Lattice EDA, with the following design outputs

- Circuit schematic diagram: Shows the connection relationship between various components
- PCB layout: Printed circuit board wiring and pad design
- PCB 3D effect diagram: 3D rendering







4. Firmware & Algorithm

4.1 State Machine Workflow

The device firmware implements a three-state state machine:

`Standby → Processing → Result Display → Standby`

1. **Standby:** Green LED on, OLED displays "Insert strip...", polls button for strip insertion

2. **Processing:** On detecting active-low signal, yellow LED lights up, waits 1s for strip to stabilize, then invokes the image capture and analysis algorithm
3. **Result Display:** On success, green LED blinks and OLED shows T1/T2 ratio with positive/negative verdict; on failure, red LED stays on for 4s and OLED shows ERROR

4.2 T1/T2 Grayscale Ratio Algorithm

The core algorithm captures a QVGA (320×240 px) grayscale image and locates two regions of interest on the test strip: the T1 line region (rows 100–109) and the T2 line region (rows 150–159). The mean grayscale intensity of each region is computed, and their ratio is calculated as:

```
T1/T2 ratio = avg(T1_zone) / avg(T2_zone)
```

Decision rule:

- T1/T2 ≥ 0.5 → NEGATIVE (normal colonization state)
- T1/T2 < 0.5 → POSITIVE (infection state)

Tips：The area needs to be set based on the location of the physical cameras, and the judgment rules also require experimental data from wet teams. Here, we are just making a hypothesis

4.3 Code

Due to the inability to produce physical objects, the ESP32-CAM is shipped with only C language support and requires additional installation to set up a Python environment. Therefore, the program provides two versions: C++ (Arduino framework) and MicroPython, which are respectively compatible with different development environments.

5. Future Work

- Physical fabrication and assembly to validate real-world detection performance
- Calibrate T1/T2 pixel region coordinates against actual hardware for improved algorithm accuracy
- Integrate robust image preprocessing (denoising, auto-focus, adaptive thresholding)
- Explore wireless data transmission (ESP32 Wi-Fi / BLE) for cloud-based data storage and analysis