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Greenhouse Status Monitoring System Design

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Abstract

In this engineering project, a robust multi-sensor environmental monitoring system for smart greenhouse applications has been designed, implemented, and evaluated. The developed architecture focuses on acquisition and real-time processing of key environmental indicators, including ambient temperature, relative humidity, light intensity, soil moisture, and carbon monoxide concentrations. Data collected via precise hardware sensors is integrated through an ATmega2560 and ESP8266 dual-processor system, enabling local actuator control as well as cloud-based telemetry. Hardware interfaces are coupled with cellular (GSM/GPRS) and local server infrastructure to maintain stable operations and support full modular expansion.

Keywords: Greenhouse Monitoring, Embedded Instrumentation, Environmental Sensing, Microcontrollers, Smart Agriculture, Internet of Things (IoT).

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1 Introduction

In modern agricultural practices, optimizing crop yield while minimizing resource consumption requires real-time monitoring and automation of critical environmental parameters. This project details the design and deployment of an integrated greenhouse status monitoring system capable of dynamic parameter sensing, automated actuator response, and remote telemetry.

The overall architecture utilizes an array of dedicated sensors interfaced with a primary processing hub. Hardware components selected for implementation include:

1. **Central Processing Unit:** Arduino Mega 2560 (ATmega2560) paired with an onboard ESP8266 Wi-Fi co-processor.
2. **Cellular Telemetry Module:** SIM800L GSM/GPRS module.
3. **Environmental Sensors:**
   - SHT20 Temperature and Relative Humidity Sensor.
   - GL5549 Photoresistor (LDR) Light Sensor.
   - YL-69 Capacitive/Resistive Soil Moisture Sensor.
   - MQ-7 Carbon Monoxide Gas Sensor.
4. **Power & Regulation Management:** MT3608 DC-DC Boost Converter paired with a 3.7 V / 1200 mAh Li-Po battery.
5. **Data Logging & Display:** Character LCD (HD44780 with I2C module) and MH Micro-SD Card module.
6. **Actuation & Drive Units:** L298 Dual H-Bridge Motor Driver for pump and fan control.
7. **Modular Co-Processor:** Arduino Nano (ATmega328P) for offloaded auxiliary control tasks.

2 Setup and Hardware Integration Specifications

2.1 Arduino Mega Microcontroller (ATmega2560 + ESP8266)

The core controller is an Arduino Mega 2560 board integrated with an 8-bit AVR ATmega2560 microcontroller operating at a 16 MHz clock frequency, yielding operational execution rates up to 16 MIPS.

The board features 54 digital input/output pins, of which 15 provide 8-bit Pulse Width Modulation (PWM) outputs. The analog section consists of 16 channels multiplexed to a 10-bit Analog-to-Digital Converter (ADC). The resolution metrics for the conversion channels are defined as follows:

$$\text{ADC Resolution} = \frac{V_{\text{ref}}}{2^{10}} = \frac{5.0\ \text{V}}{1024} = 4.88\ \text{mV} \tag{1}$$

$$\text{PWM Step Resolution} = \frac{V_{\text{ref}}}{2^{8}} = \frac{5.0\ \text{V}}{256} = 19.53\ \text{mV} \tag{2}$$

Hardware Communication Protocols

- **I2C Bus:** Pins 20 (SDA) and 21 (SCL).
- **SPI Bus:** Pins 50 (MISO), 51 (MOSI), 52 (SCK), and 53 (SS).
- **Hardware UART Ports:**
  - Serial 0: Pins 0 (RX0) and 1 (TX0) – Reserved for USB Debugging.
  - Serial 1: Pins 19 (RX1) and 18 (TX1) – SIM800L Communication.
  - Serial 2: Pins 17 (RX2) and 16 (TX2) – Secondary expansion.
  - Serial 3: Pins 15 (RX3) and 14 (TX3) – ESP8266 Inter-processor link.

Table 1: ...

Parameter	Design Specification	Measured Value
Input Supply Voltage Range	7.0 – 12.0 V	5.0 V (USB) / 9.0 V (Jack)

2.2 SIM800L GSM/GPRS Cellular Module

The SIM800L unit manages external SMS alerts and remote GPRS network connections. Peak transmission bursts require up to 2.0 A of current, which cannot be supplied directly by standard voltage regulators. To eliminate brownout resets, an MT3608 boost converter was set to provide a stable 4.2 V supply rail. In addition, a 470 nF decoupling capacitor array was mounted across V_{CC} and GND to attenuate switching ripple in the $1 - 10$ MHz frequency spectrum.

Table 2: SIM800L Terminal Pin Connections

Module Pin	Target Destination	Functional Description
V_{CC}	MT3608 Boost Output (4.2 V)	System Power Line
GND	Common Ground	Power & Signal Ground
TXD	Arduino Pin 19 (RX1)	Module Transmit to MCU Receive
RXD	Arduino Pin 18 (TX1 via divider)	MCU Transmit to Module Receive (3.3 V Level)

A resistor voltage divider (1 kΩ and 2 kΩ) was placed on the Arduino TX1 output pin to shift the 5 V logic signal down to the safe 3.3 V input standard required by the SIM800L.

Table 3: Essential AT Command Definitions

AT Command	Target Function	Expected Module Response
`AT`	Serial Link Verification	`OK`
`AT+GMR`	Firmware Revision Query	`SIM800L R14.18`
`AT+RST`	Software System Reset	`OK`
`AT+CSQ`	RF Signal Quality Check	`+CSQ: 20,0`
`AT+CBC`	Power Voltage Inspection	`+CBC: 0,75,3800`

2.3 MT3608 DC-DC Step-Up Boost Converter

The MT3608 module elevates lower input battery voltages to stable operating thresholds at high conversion efficiencies ($> 93\%$).

Table 4: MT3608 Boost Regulator Parameters

Operating Parameter	Specified Value
Input Voltage Range	2.0 – 24.0 V DC
Output Voltage Range	5.0 – 28.0 V DC
Switching Frequency	1.2 MHz
Configured Output Voltage	4.2 V DC
Max Burst Output Current (Transmission)	2.0 A
Peak Transmission Power Output	8.4 W

2.4 Environmental Sensors Hardware Configurations

2.4.1 SHT20 Temperature & Relative Humidity Sensor

The SHT20 utilizes an I2C protocol to report calibrated ambient data.

Table 5: SHT20 Operational Characteristics

Specification	Operating Range	Accuracy Level
Temperature Range	$-40°C$ to $+125°C$	$\pm 0.3°C$
Relative Humidity Range	0% to 100% RH	±2.0% RH
Supply Input Voltage	3.3 V	Current Draw: 1.0 mA

2.4.2 GL5549 Photoresistor Light Sensor

Ambient illuminance is measured using a CdS photoresistor configured in a voltage divider arrangement.

Table 6: GL5549 Photoresistor Specifications

Parameter	Value
Light Resistance (at 10 lux)	$100 - 200$ kΩ
Dark Resistance (in complete darkness)	10 MΩ
Max Power Dissipation	100 mW
Operating Supply Rail	3.3 V

2.4.3 YL-69 Soil Moisture Sensor

The YL-69 sensor uses probe conductivity to evaluate volumetric water content. To provide linear voltage readings across varying soil densities, a 10 kΩ pull-down resistor was tied to the analog signal line (A0) to create a balanced voltage divider.

2.4.4 MQ-7 Carbon Monoxide Gas Sensor

The MQ-7 sensor detects CO gas concentrations ($10 - 10,000$ ppm) through a SnO_2 semiconductor surface. It operates on a 5 V heater cycle and requires a 24-hour initial burn-in period for stable measurement baseline calibration.

2.5 Actuation Units & Peripherals

2.5.1 L298 Dual H-Bridge Driver

The L298 driver decouples microcontroller logic lines from heavy inductive motor loads, providing directional control and speed adjustments via PWM for both the irrigation pump and ventilation fan.

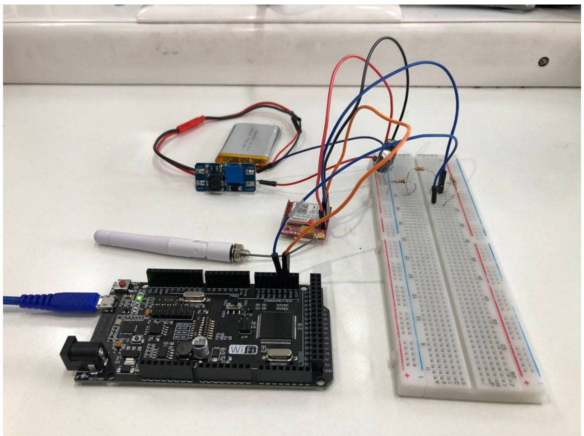
Table 7: L298 Driver Interface Routing

L298 Terminal	**Arduino Connection**	**Assigned Function**
ENA	Digital Pin 9 (PWM)	Fan Speed Modulation
IN1 / IN2	Digital Pins 8 / 7	H-Bridge Direction Control
GND	Common System Ground	Reference Ground Line

2.5.2 HD44780 16x2 Character LCD with I2C Module

System status displays are rendered on an HD44780 screen using an PCF8574 I2C expansion backpack. This reduces the total control lines required from 6 digital pins down to 2 shared I2C bus lines (SDA/SCL).

3 Module Setups, Sensor Plots, and Board Layouts



(a) SIM800L Hardware Module Setup

```
Temperature: 26.96 C, Humidity: 25.78 %
Temperature: 26.97 C, Humidity: 25.70 %
Temperature: 26.96 C, Humidity: 25.66 %
Temperature: 26.97 C, Humidity: 25.68 %
Temperature: 26.97 C, Humidity: 25.74 %
Temperature: 26.98 C, Humidity: 25.95 %
Temperature: 26.98 C, Humidity: 26.47 %
Temperature: 26.99 C, Humidity: 26.51 %
Temperature: 26.99 C, Humidity: 26.47 %
Temperature: 26.99 C, Humidity: 26.27 %
Temperature: 27.00 C, Humidity: 26.14 %
Temperature: 26.99 C, Humidity: 26.07 %
Temperature: 27.00 C, Humidity: 26.19 %
Temperature: 27.01 C, Humidity: 26.39 %
Temperature: 27.01 C, Humidity: 26.47 %
Temperature: 27.04 C, Humidity: 26.23 %
Temperature: 27.05 C, Humidity: 26.04 %
Temperature: 27.05 C, Humidity: 26.04 %
Temperature: 27.04 C, Humidity: 26.07 %
Temperature: 27.04 C, Humidity: 26.11 %
```

(b) SHT20 Acquisition Output Data

Figure 1: Cellular telemetry setup and thermal sensor operational verification.

SHT20 Pinout

Most SHT20 modules have **4 pins** (sometimes labeled differently):

SHT20 Pin	Label (Alt Names)	Function	Connect to Arduino Mega
1	VCC	Power supply (3.3–5V)	**5V**
2	GND	Ground	**GND**
3	SDA	I2C data line	**Pin 20 (SDA)**
4	SCL	I2C clock line	**Pin 21 (SCL)**

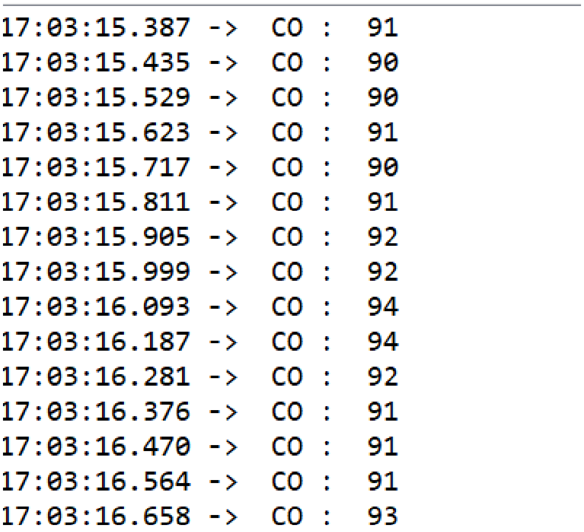
✅ The Mega has dedicated **I2C pins**: SDA = pin 20, SCL = pin 21.

(a) SHT20 Hardware Pin Configuration

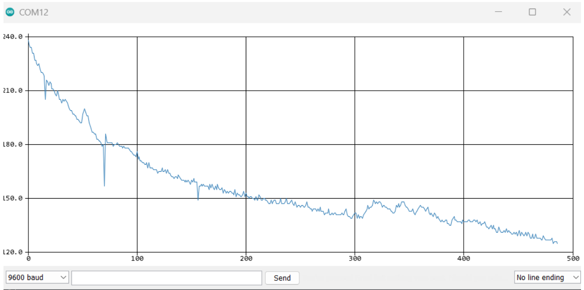
```
Soil Moisture (Raw): 76
Soil Moisture (Raw): 74
Soil Moisture (Raw): 75
Soil Moisture (Raw): 75
Soil Moisture (Raw): 75
Soil Moisture (Raw): 9
Soil Moisture (Raw): 9
Soil Moisture (Raw): 10
Soil Moisture (Raw): 8
Soil Moisture (Raw): 8
Soil Moisture (Raw): 9
```

(b) Soil Moisture Sensor Time Series Data

Figure 2: Sensor interface wiring and soil hydration data tracking.

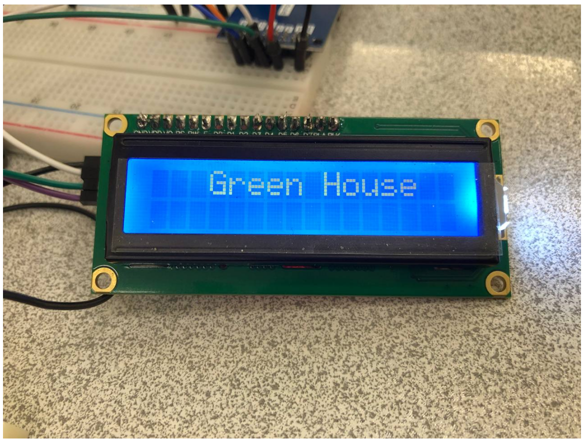


(a) MQ-7 Real-time Sensor Output

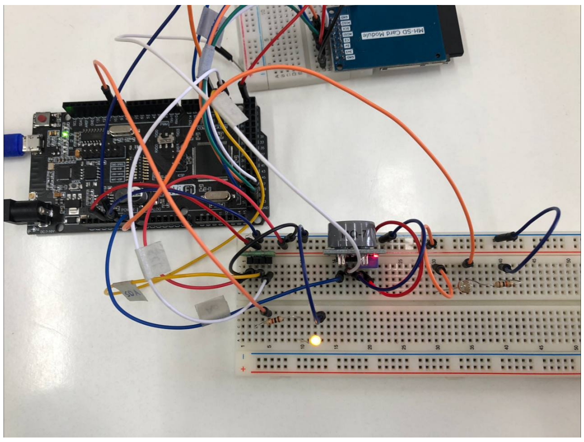


(b) MQ-7 Concentration Trend Curve

Figure 3: Carbon monoxide monitoring signals and dynamic trends.

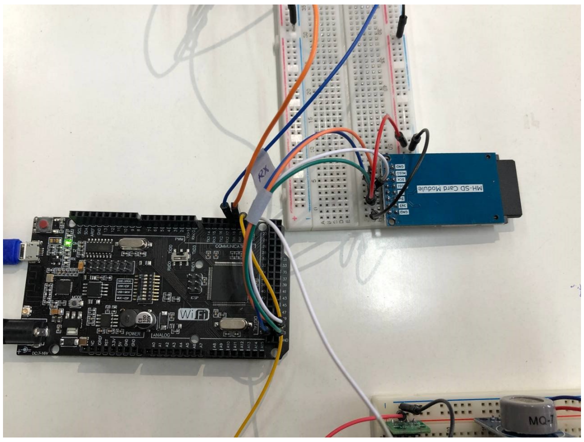


(a) Character LCD Operational Visuals



(b) LDR Hardware Calibration Setup

Figure 4: User interface and ambient lighting sensing stages.



(a) Micro-SD Card Module Setup

```
Data written to SD card.
Temperature: 27.99 C, Humidity: 25.43 %
Data written to SD card.
Temperature: 27.97 C, Humidity: 25.43 %
Data written to SD card.
Temperature: 27.98 C, Humidity: 25.43 %
Data written to SD card.
Temperature: 27.96 C, Humidity: 25.43 %
Data written to SD card.
Temperature: 27.95 C, Humidity: 27.74 %
Data written to SD card.
Temperature: 27.96 C, Humidity: 29.05 %
Data written to SD card.
```

(b) Telemetry Data Logged in CSV Format

Figure 5: Onboard data logging and secondary memory validation.

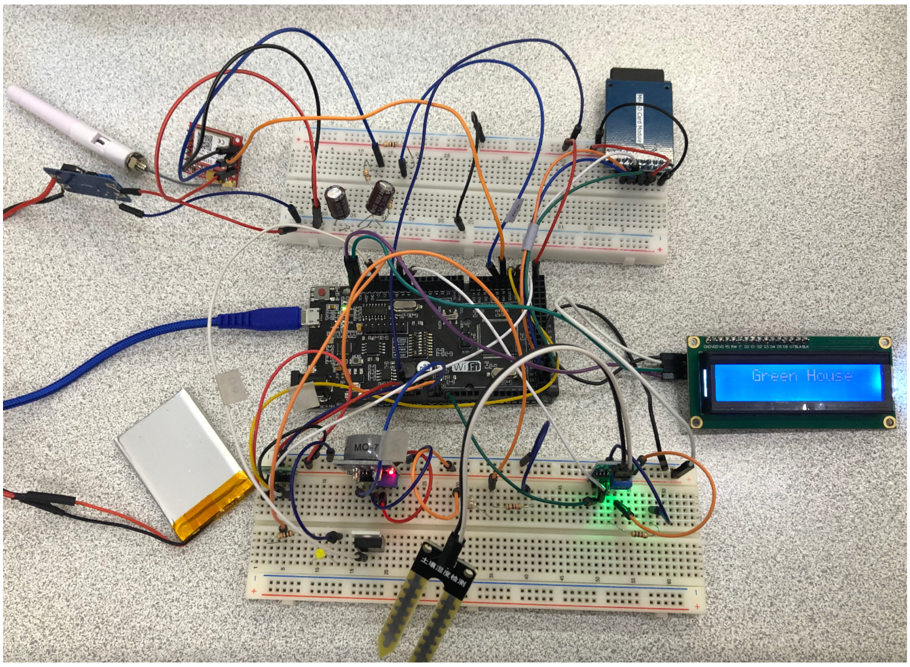


Figure 6: Fully Integrated Greenhouse Hardware Assembly Prototype.

4 Phase Two: Advanced Control and IoT Integration

4.1 Local Server Architecture & Postman Testing

To manage sensor data payloads, a local server stack was established. Communication interfaces were validated using Postman to send and receive standard HTTP methods (`GET`, `POST`, `PUT`, `DELETE`). Local host network addresses were proxied through a secure tunneling service to provide a public gateway URL:

https://rad-queijadas-015096.netlify.app/

4.2 Cloud Dashboards via Blynk IoT Integration

Remote monitoring and threshold notification workflows were integrated using the Blynk IoT platform.

- The ATmega2560 captures analog sensor metrics and streams formatted data packets to the ESP8266 via high-speed Serial lines.
- The ESP8266 connects to the Blynk Cloud gateway over an encrypted TLS connection using a unique authentication token.
- System parameters (temperature, soil hydration, gas concentrations) are parsed and rendered as live visual widgets on mobile interfaces.

4.3 PCB Design in Altium Designer

To replace point-to-point breadboard connections with a reliable industrial layout, a dual-layer Printed Circuit Board was designed using Altium Designer. Differential pair routing was used for sensitive analog signal paths, and low-impedance copper ground planes were poured around high-power motor drivers and battery regulation sub-circuits.

4.4 Dual-Processor Communication Protocol

The system divides workload management between the onboard microcontrollers:

- **ATmega2560:** Manages sensor sampling, actuator switching, LCD menus, and local automated safety routines.
- **ESP8266:** Dedicated to network socket handling, TCP/IP stack management, and cloud streaming.

Data transfer between processors uses hardware `Serial3` on the ATmega2560 tied directly to the primary hardware `Serial` port on the ESP8266.

Hardware DIP Switch Mode Configurations

- `Switches 5, 6, 7 ON`: ESP8266 Firmware Flashing Mode.

- `Switches 5, 6 ON`: Standalone ESP8266 Execution Mode.
- `Switches 3, 4 ON`: ATmega2560 Firmware Flashing Mode.
- `Switches 1, 2, 3, 4 ON`: Dual Concurrent Operating Mode (ATmega2560 + ESP8266).

4.5 Integrated Subsystem Actuators

4.5.1 Automated Dosing & Irrigation Pump

A miniature pump powered by a 12 V DC motor driving a 10 mL syringe structure delivers automated irrigation. The motor driver triggers the pump whenever soil moisture metrics fall below targeted operational limits.

4.5.2 Thermal Ventilation Assembly

A 12 V DC high-flow fan is driven by PWM signals from the motor driver to regulate ambient air exchange when internal temperatures exceed configured thermal ceilings.

4.5.3 IR Remote Menu Navigation

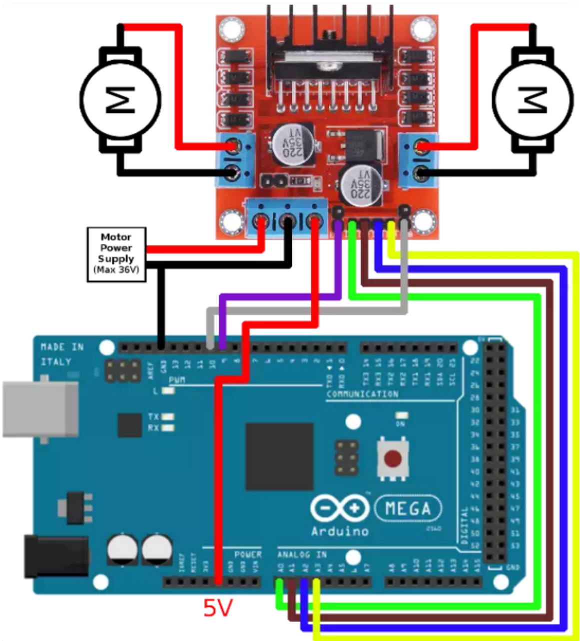
An IR receiver coupled with the 16×2 LCD display provides an intuitive localized interface:

- `CH+` / `CH-` Buttons: Scroll through high-level system categories.
- Numeric Keys (`0 - 9`): Access sub-menus for manual actuator control and parameter limit updates.
- `PREV` Key: Return to root display screens.

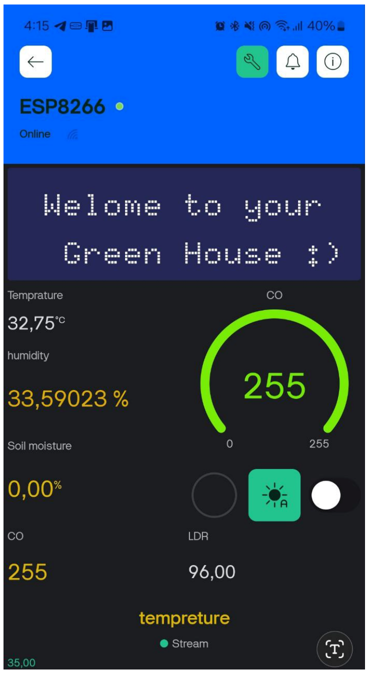
4.6 Physical Enclosure Fabrication

A scaled desktop greenhouse structure was constructed using a lightweight timber frame enclosed with high-transmittance acrylic (Plexiglas) sheets, providing accurate environmental isolation and realistic light transmission for sensor calibration.

5 Integrated System Visual Gallery

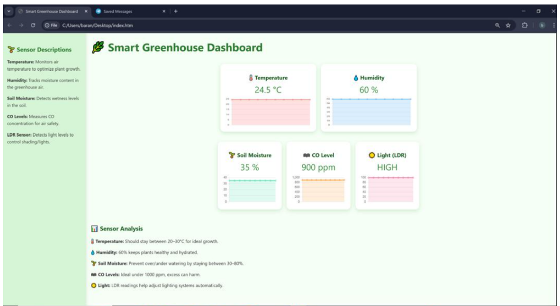


(a) L298 Motor Driver Hardware Interface

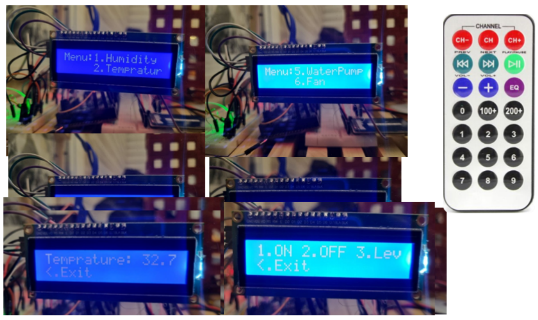


(b) Blynk Mobile Dashboard Interface

Figure 7: Actuator interface and network server console outputs.

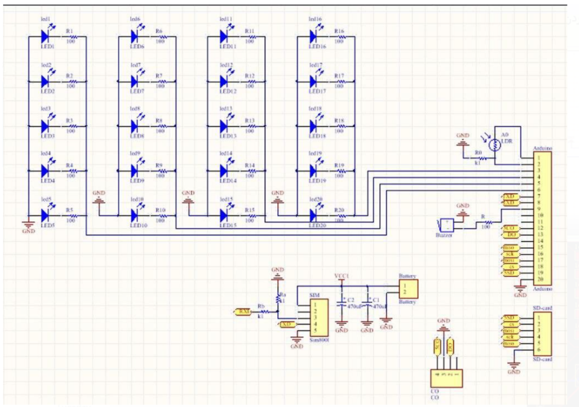


(a) Backend Local Server Data Console

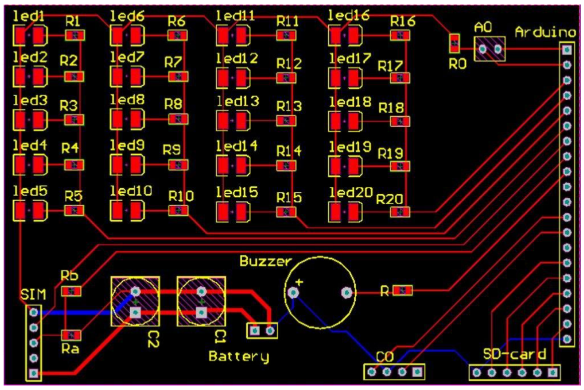


(b) LCD Navigation Menu Structure

Figure 8: Cloud management interface and localized LCD navigation map.

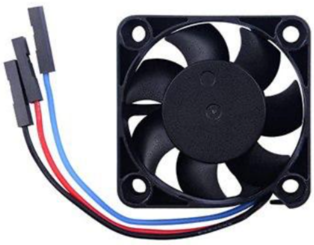


(a) Altium PCB Routing (Top Layer)

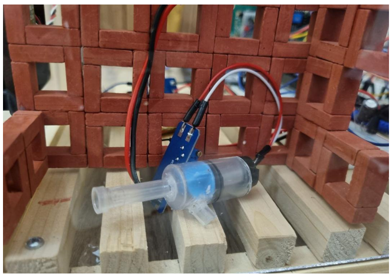


(b) 3D Board Layout Model

Figure 9: Printed Circuit Board CAD trace designs and layout renderings.



(a) Ventilation Fan Unit



(b) Miniature Water Pump

(c) Fabricated Prototype Frame

Figure 10: Hardware physical actuators and completed greenhouse frame assembly.