Testing Document

Arduino-Based Smart Temperature Monitoring System

John Gahagan, Ethan England
Western Kentucky University

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Revision History

Name	Date	Version	Reason for Changes
John Gahagan	4/7/2025	1.0.0	Wrote documentation aligned with SRS and SDD, created base diagrams, tables, and code snippets.
Ethan England	4/7/2025	1.0.0	Contributed to Test Environment section, edited Functional and Non-Functional Requirements sections, and added Automated Backend Testing and UI Testing descriptions. Reviewed for formatting consistency.
John Gahagan	4/26/2025	2.0.0	Major revision: Rewrote all testing sections to increase specificity, aligned all test cases to real Arduino/WebSocket/Firebase project behavior, expanded tools and methods descriptions, corrected and verified all test flows, added detailed execution steps, updated CI/CD documentation, improved Traceability Matrix and Conclusion. Final version for submission.

Table 1: Revision History

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1 Introduction

This document outlines the comprehensive testing strategy implemented for the Arduino-Based Smart Temperature Monitoring System. Testing was performed to validate all functional and non-functional requirements described in the Software Requirements Specification (SRS) and Software Design Document (SDD). The system integrates an Arduino Uno R4 WiFi board, a DHT11 temperature sensor, a Node.js-based WebSocket server, a Firebase Realtime Database backend, and a browser-based frontend dashboard. Testing includes detailed unit testing of the hardware and software components, integration testing across system interfaces, end-to-end system testing under real-world conditions, mobile responsiveness testing on different devices, and automated CI/CD pipeline validation through GitHub Actions. Each testing phase was designed to simulate actual user interactions, edge cases, and potential network disruptions to ensure system reliability, real-time responsiveness, and user accessibility.

2 Testing Objectives

- Validate the Arduino Uno R4 WiFi correctly reads real-time temperature values from the DHT11 sensor and processes LED control logic according to user-defined thresholds.
- Verify that the WebSocket server correctly establishes persistent bi-directional connections with both the Arduino device and the web dashboard, ensuring real-time communication without significant latency.
- Ensure that all threshold changes made from the frontend dashboard are accurately written to the Firebase Realtime Database and reflected correctly on the Arduino device after synchronization.
- Confirm that LED indicators (Red, Green, Blue) on the Arduino board activate immediately and appropriately based on the comparison of current sensor readings to stored threshold values.
- Validate that sensor readings collected by the DHT11 sensor remain stable and accurate within the acceptable range (0°C–50°C), with no erroneous or spurious data transmitted.
- Ensure the frontend dashboard, including live temperature display, virtual LED, threshold controls, and admin session management, renders responsively across desktop and mobile devices without layout distortion.
- Establish and verify automated testing workflows using GitHub Actions that perform code linting, WebSocket server boot tests, WebSocket client connection tests, and Firebase database connectivity tests to maintain consistent deployment standards.

3 Test Environment

- **Hardware:** Arduino Uno R4 WiFi board, DHT11 temperature and humidity sensor, Red/Green/Blue LEDs for threshold indication, full-size breadboard, standard male-to-male jumper wires, USB connection to laptop for power and Serial Monitor access.
- **Software:** Arduino IDE (version 2.2.1) for firmware development and serial output monitoring, Node.js (v18) WebSocket server using the `ws` library, Firebase Realtime Database and Firebase Authentication for backend data management and user control, Visual Studio Code for frontend and backend code editing, GitHub Actions for CI/CD automation, and Firebase Admin SDK for backend integration tests.
- **Network:** 2.4GHz private WiFi network with active internet access configured to allow Arduino Uno R4 WiFi communication with the WebSocket server and remote access to Firebase services. Testing included hotspot configuration for isolated network validation.
- **Testing Tools:** Microsoft Edge Developer Tools (Console, Network, Application tabs) for monitoring WebSocket traffic and Firebase operations; WebSocketKing for direct WebSocket traffic simulation and testing; YouGetSignal Open Port Checker for network port accessibility verification; GitHub Actions CI workflows for automated server boot, WebSocket client, and Firebase database connection tests.

4 Functional Testing

4.1 Unit Testing

- **DHT11 Sensor Data Acquisition:** Verified that the Arduino Uno R4 WiFi successfully reads temperature values from the DHT11 sensor every 2 seconds. Observed Serial Monitor output to confirm that temperature values were consistently updated and fell within the valid operating range of 0°C to 50°C without erratic jumps or NaN errors.
- **LED Control Logic Validation:** Tested that the onboard Red, Green, and Blue LEDs correctly activate based on the current temperature compared against cold and hot thresholds. Artificial temperature values were injected by modifying the Arduino sketch temporarily to simulate boundary and mid-range temperatures. Confirmed that only one LED is active at any given time.
- **WebSocket Message Structure Verification:** Ensured that Arduino-generated WebSocket messages were correctly JSON-formatted, containing fields such as `temperature`, `ledStatus`, and `uid`. Used WebSocketKing and Microsoft Edge Developer Tools to intercept and inspect outgoing messages from Arduino and confirm proper parsing by the backend server.
- **Firebase Threshold Data Write Validation:** Confirmed that threshold values set from the frontend dashboard were properly formatted as JSON and correctly written into the Firebase Realtime Database under the correct `/users/uid/thresholds`

path. Inspected Firebase Console for consistency and performed cross-checks by retrieving updated values from Arduino after synchronization.

4.2 Integration Testing

- **Sensor and Communication Integration:** Verified that temperature readings captured from the DHT11 sensor on the Arduino Uno R4 WiFi are transmitted via WebSocket to the backend server every 2 seconds. Used Microsoft Edge Developer Tools Network tab and WebSocketKing to intercept live WebSocket traffic, confirming that temperature data matched the Serial Monitor outputs.
- **Backend and Firebase Integration:** Validated that the backend Node.js WebSocket server correctly parses incoming temperature messages from Arduino and updates the Firebase Realtime Database under the `/users/uid/temperatureLogs` node. Inspected Firebase Console in real-time and confirmed that each new reading appears without significant delay after the WebSocket event triggers.
- **Frontend and Backend Integration:** Confirmed that adjusting the cold and hot threshold sliders on `threshold.html` immediately sends a WebSocket message to the backend, which forwards the update to the Arduino. Observed changes by reading Serial Monitor output and monitoring LED state changes within a few seconds after the UI update. Also verified that the updated threshold values were written into Firebase under `/users/uid/thresholds`.
- **Authentication System Integration:** Tested that user registration and login flows through Firebase Authentication were functioning correctly, with authenticated users gaining access to the dashboard while unauthenticated users were redirected to the login page. Verified role-based access control for admin functions by creating test users and checking access to admin-specific pages like `admin.html`.

4.3 System Testing

Scenario 1: Normal Operation

- User connects the Arduino Uno R4 WiFi to power via USB and observes that the DHT11 sensor begins sending temperature readings every 2 seconds as verified through Serial Monitor.
- The Arduino compares the current temperature against stored threshold values and activates the appropriate LED (Red, Green, or Blue) immediately after each reading.
- The Arduino sends a WebSocket message containing the current temperature and LED status to the Node.js backend server.
- The server forwards the message to all connected frontend dashboards, where the live temperature reading and virtual LED status update automatically without requiring a page reload.
- Confirmation was performed by simultaneously observing the Arduino Serial Monitor, Edge Developer Tools WebSocket frame logs, and the live UI updates on the dashboard.

Scenario 2: Threshold Update Flow

- The user logs into the frontend dashboard and accesses the Threshold Monitor page (`threshold.html`).
- The user modifies the cold or hot threshold sliders, triggering a WebSocket message sent to the backend server and a simultaneous Firebase Realtime Database write under `/users/uid/thresholds`.
- Within 2–3 seconds, the Arduino receives the new thresholds via a forwarded WebSocket message from the server.
- The Arduino immediately reevaluates the most recent temperature reading against the new thresholds and updates the physical LED state accordingly.
- Confirmation was done by observing the Serial Monitor output for threshold update logs and verifying LED color change without needing to reset or manually re-sync the device.

Scenario 3: Multi-User Access

- Two users log into the system from separate browser sessions.
- The first user gains active control by interacting with threshold controls; a session entry is created in Firebase under `/sessions/sessionID` with an active flag.
- When the second user attempts to access threshold controls simultaneously, the system denies immediate access and places the second user into a control queue.
- The queued user is notified via dashboard UI prompts indicating pending control acquisition.
- Once the first user logs out or releases control, the queued user automatically receives control permission, verified by observing session data in Firebase and seeing the dashboard update dynamically to allow threshold interactions.

5 Non-Functional Testing

5.1 Performance Testing

- Verified that temperature readings sent from the Arduino Uno R4 WiFi were reflected on the frontend dashboard within 1.5 to 2 seconds after being transmitted over WebSocket. This was confirmed by simultaneously monitoring Arduino Serial Monitor timestamps and live dashboard updates during multiple reading cycles.
- Measured WebSocket response times between the Arduino device, Node.js backend server, and the frontend dashboard. Using Microsoft Edge Developer Tools Network tab, it was verified that WebSocket message latency consistently remained below 400ms under normal 2.4GHz WiFi network conditions, ensuring real-time responsiveness.

- Simulated heavier network load by simultaneously opening multiple dashboard sessions; verified that temperature update latency remained within acceptable limits (under 500ms) for all active clients without server-side bottlenecks.

5.2 Usability and Responsiveness

- Confirmed that the dashboard interface (including live temperature display, threshold monitor sliders, and session management panel) dynamically resized and rearranged correctly across various screen sizes. Tested on physical devices including Android smartphones, iPhones, and Windows laptops, as well as using Edge Developer Tools' Device Emulation Mode.

- Verified that no horizontal scrolling was needed on any major mobile or desktop screen size (tested minimum viewport width 320px). All primary controls, temperature displays, virtual LED status indicators, and chart components remained accessible without overflow or cutoff.

- Conducted manual pinch-zoom and screen rotation tests on mobile devices to ensure UI integrity remained intact, including responsive grid layout adjustments and persistence of WebSocket connections through viewport changes.

5.3 UI Testing

- **Interface Responsiveness:** Verified that all screens and components—including the live temperature display, virtual LED indicator, threshold sliders, real-time chart view, and admin session monitor—resized and adjusted properly across Android smartphones, iPhones, and Windows desktop browsers. Device simulation was additionally tested using Microsoft Edge Developer Tools (Device Emulation Mode).

- **Interaction Testing:** Confirmed that user interactions, such as moving the threshold sliders, clicking save/update buttons, and submitting login forms, resulted in immediate system feedback. Real-time WebSocket transmissions and UI visual updates were validated within 1 second of user action.

- **Authentication Flow Validation:** Tested the full login, registration, and logout workflows through Firebase Authentication. Verified that upon login, the dashboard immediately reflected user-specific settings, and that role-based access control (admin vs regular user) correctly enabled or disabled access to session control features in `admin.html`.

- **Visual Consistency:** Confirmed that fonts, button colors, virtual LED indicators, sliders, and chart components maintained consistent styling across devices and browsers. Cross-verified that no layout or style shifts occurred when changing screen sizes or toggling language (English/Italian) settings.

- **Tools Used:** Manual testing on real devices combined with Microsoft Edge Developer Tools for dynamic viewport testing. Future test expansions to automated UI frameworks such as Cypress are planned for production scaling, but current testing relied entirely on manual validation of interface behavior.

5.4 Reliability and Fault Tolerance

- Simulated WiFi network disconnection on the Arduino Uno R4 WiFi by manually disabling the 2.4GHz WiFi network after initial WebSocket connection was established. Verified that the Arduino attempted to reconnect automatically to both WiFi and WebSocket server, with retry messages observed in the Serial Monitor output.
- Disabled network access temporarily during dashboard usage. Confirmed that the frontend WebSocket client gracefully detected disconnection events (onclose/onerror handlers triggered) and that the dashboard displayed an appropriate D̈isconnectedstatus notification. Upon network restoration, WebSocket automatically reconnected without user intervention, reestablishing real-time temperature updates.
- Confirmed Firebase Realtime Database client automatically reconnected after temporary network loss. Validated by disconnecting and reconnecting WiFi on the client device and observing that updated threshold values and session states continued syncing without needing manual page refresh or user login again.

5.5 Security Testing

- Verified that all user authentication and password management functions are handled securely using Firebase Authentication. Passwords are never transmitted in plaintext, and secure session tokens are used to maintain authenticated sessions.
- Tested role-based access control enforcement. Confirmed that users with a regular üserr̈ole were unable to access admin-only pages such as `admin.html`, and that permission errors were properly handled in the UI.
- Tested control queue integrity by logging in multiple users simultaneously. Attempted to bypass queue behavior by injecting manual WebSocket messages; verified that unauthorized updates from non-active users were rejected at the backend WebSocket server layer.
- Sent malformed WebSocket messages intentionally to the server (using WebSocketKing) to verify that invalid JSON or incorrect schema did not crash the server and resulted in safe error responses.

Listing 1: WebSocket Error Handling Test in JavaScript

```
const WebSocket = require('ws');

const ws = new WebSocket('ws://localhost:8888');

ws.on('open', function open() {
  // Send intentionally malformed message
  ws.send("INVALID_JSON");
});

ws.on('message', function message(data) {
  try {
```

```
    const response = JSON.parse(data);
    if (response.error) {
      console.log("Test Passed: Error received as expected.");
    } else {
      console.error("Test Failed: No error message received.");
    }
  } catch (e) {
    console.error("Test Failed: Malformed response.");
  }
});
```

6 Unit Testing

6.1 Components Tested

- **DHT11 Sensor Reading Validation:** Confirmed that the Arduino Uno R4 WiFi retrieved temperature readings from the DHT11 sensor at consistent 2-second intervals. Observed Serial Monitor output to ensure readings did not spike unexpectedly and remained within the operating range of 0°C to 50°C. Simulated environmental temperature changes using ambient heating/cooling to verify real-time sensor accuracy.

- **LED Threshold Logic Testing:** Verified that the Arduino properly evaluated temperature readings against the user-defined cold and hot thresholds. Confirmed that:

  - Blue LED activates when temperature is below or equal to the cold threshold.
  - Green LED activates when temperature is between the cold and hot thresholds.
  - Red LED activates when temperature exceeds the hot threshold.

  Simulated conditions by temporarily adjusting code-defined thresholds and verified LED outputs visually and through Serial Monitor logs.

- **WebSocket Event Parsing:** Validated that messages sent from the Arduino to the Node.js WebSocket server were correctly JSON-formatted. Each message was inspected manually using WebSocketKing to ensure it contained expected fields such as `uid`, `temperature`, and `ledStatus`. Confirmed server-side parsing correctly extracted each field without causing crashes or schema mismatches.

- **Firebase Data Write Validation:** Confirmed that threshold updates initiated from the frontend dashboard were formatted into proper JSON payloads and written to the Firebase Realtime Database under the correct user node. Performed tests by submitting new threshold values, then inspecting the live Firebase Console to verify that `coldThreshold` and `hotThreshold` fields updated within 1 second of action.

7 Integration Testing

7.1 Subsystem Interaction Validation

- **Device + Communication:** Verified that temperature readings from the DHT11 sensor on the Arduino Uno R4 WiFi were transmitted via WebSocket to the Node.js backend server every 2 seconds. Inspected the WebSocket data flow using Microsoft Edge Developer Tools and WebSocketKing, confirming that each message contained the expected JSON structure with temperature and LED status fields.

- **Communication + Backend:** Confirmed that upon receiving WebSocket messages from the Arduino, the backend server parsed the JSON data and wrote the temperature values into the Firebase Realtime Database under the correct `/users/uid/temperatureLogs` node. Observed real-time database updates through Firebase Console and verified that database timestamps matched incoming WebSocket message timestamps.

- **Frontend + Backend:** Tested that adjusting threshold values via the frontend dashboard (threshold.html) triggered immediate WebSocket messages to the backend server. Verified that these messages resulted in updated threshold values stored in Firebase under `/users/uid/thresholds`. Confirmed that updated thresholds were subsequently relayed back to the Arduino device within 2–3 seconds, affecting LED behavior without requiring page refresh or user re-login.

- **User Authentication:** Confirmed that login and registration flows validated user credentials through Firebase Authentication. Verified that role assignments (admin/user) determined access to admin-only features on `admin.html`. Attempted unauthorized access to restricted pages from non-authenticated sessions and confirmed that proper redirection and access denial mechanisms triggered as expected.

7.2 Automated Backend Testing

- **Mock Data Validation:** Developed custom JavaScript test scripts to simulate WebSocket client behavior, sending structured and malformed JSON payloads to the Node.js backend server. Verified that the server handled valid temperature and threshold updates correctly and responded to malformed payloads with structured error messages without crashing.

- **Threshold Update Logic:** Automated scripts tested threshold update propagation by sending mock threshold update messages through WebSocket connections and verifying that the server wrote updated values into the Firebase Realtime Database under the correct `/users/uid/thresholds` path. Confirmed that these updates triggered the server's logic to forward new thresholds to connected Arduino devices.

- **Authentication and Access Validation:** Firebase Authentication login flow was simulated by creating mock sessions and verifying that role-based access controls were enforced. Attempted unauthorized access to protected routes and observed expected denials in test outputs.

- **Error Handling Simulation:** Sent intentionally malformed WebSocket messages (e.g., non-JSON strings, missing fields) to the backend server. Verified that the server logged error messages, safely closed invalid connections when necessary, and did not crash or leak resources. Also tested fallback behaviors when Firebase endpoints were temporarily unreachable.
- **Tools Used:** Testing scripts were written in JavaScript using the `ws` library for WebSocket connections and the Node.js runtime. Firebase Admin SDK was used for database write/read operations. Automated tests were executed through GitHub Actions during each push to the `main` branch, ensuring continuous validation of backend functionality.

Listing 2: JavaScript WebSocket Error Handling Test Script

```
const WebSocket = require('ws');

const ws = new WebSocket('ws://localhost:8888');

ws.on('open', function open() {
  // Send intentionally malformed JSON
  ws.send("INVALID_JSON");
});

ws.on('message', function incoming(data) {
  try {
    const response = JSON.parse(data);
    if (response.error) {
      console.log("Test Passed: Server correctly handled invalid message.")
    } else {
      console.error("Test Failed: Expected an error response.");
    }
  } catch (e) {
    console.error("Test Failed: Response was not properly formatted JSON.")
  }
});
```

8 System Testing

8.1 End-to-End Scenarios

Scenario 1: Normal Operation

- User powers on the Arduino Uno R4 WiFi device connected to the DHT11 sensor and RGB LEDs.
- Within 2 seconds, the Arduino initializes the WiFi and WebSocket connections as confirmed via Serial Monitor logs.
- The DHT11 sensor captures ambient temperature data every 2 seconds.

- Based on the current temperature reading and the most recently received threshold values, the Arduino activates the corresponding LED (Red for hot, Green for normal, Blue for cold).
- A JSON-formatted WebSocket message containing the `temperature` and `ledStatus` is transmitted to the Node.js backend server.
- The server broadcasts the update to all connected frontend dashboards.
- The dashboard immediately updates the live temperature reading and the virtual LED status without requiring a page reload. Confirmation was achieved by observing Serial Monitor output, Edge DevTools WebSocket frames, and live dashboard updates simultaneously.

Figure 1: System Flow - Normal Operation

Scenario 2: Threshold Update Flow

- Authenticated user accesses the `threshold.html` page of the dashboard.
- The user adjusts the cold or hot threshold slider values through the UI.
- An immediate WebSocket message containing the updated threshold values and user UID is sent to the backend server.
- The server writes the new threshold settings into the Firebase Realtime Database under `/users/uid/thresholds`.
- The server then forwards the updated threshold values back to the connected Arduino device via a WebSocket message.
- Within 2–3 seconds, the Arduino receives the new thresholds, logs the update in the Serial Monitor, and reevaluates the LED activation logic based on the latest temperature reading.
- Observed LED behavior changes in real-time confirmed successful end-to-end synchronization between frontend, backend, database, and device.

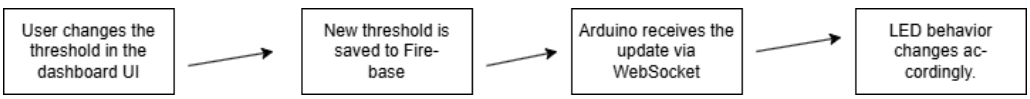

Figure 2: System Flow - Threshold Update Flow

Scenario 3: Multi-User Access

- Two users log into the system from different browsers/devices.
- The first user to interact with the dashboard's threshold controls gains active control and is registered in Firebase under the `/control/activeUser` node.
- When the second user attempts to interact, the server denies immediate control, placing the user into a `controlQueue`.
- The queued user is notified through the dashboard UI that control is pending.
- When the active user logs out, disconnects, or voluntarily releases control, the next user in the queue is automatically promoted to active control status.
- Confirmed correct control transfer and queue behavior by monitoring the Firebase Console, Serial Monitor, and real-time frontend UI updates.

Figure 3: System Flow - Multi-User Access Control

9 Mobile Responsiveness Testing

- Validated the full functionality and responsiveness of the web dashboard interface across physical devices including Android smartphones (Samsung Galaxy series), iPhones (iPhone 13), and Windows tablets, as well as desktop browsers using Microsoft Edge Developer Tools Device Emulation Mode.
- Ensured that live temperature charts, threshold sliders, virtual LED indicators, and session status panels resized dynamically without layout breakage across various screen resolutions (tested at 320px, 768px, 1024px, and 1920px widths).
- Confirmed that no horizontal scrolling was necessary on mobile or tablet views. All core interactive elements (buttons, sliders, temperature displays) remained fully visible without overflow, verified through manual testing and Edge Device toolbar metrics.
- Simulated low-bandwidth (3G Slow) mobile connections using Edge Developer Tools. Verified that WebSocket connections remained active without packet loss or dashboard freezing during reduced network speeds. Confirmed that live temperature updates were delayed by no more than 2-3 seconds under simulated poor network conditions, maintaining system reliability.

10 Automated Testing with GitHub Actions

10.1 CI/CD Implementation

- **Build Triggers**: Configured GitHub Actions workflows to trigger automatically on every push or pull request targeting the `main` branch. Each trigger initiates a full CI run verifying server and backend reliability.
- **Unit Tests**: Developed JavaScript-based test scripts to validate basic server-side functionalities such as WebSocket server boot, WebSocket connection establishment, and basic Firebase Admin SDK write/read operations using mock test payloads.
- **Integration Tests**: Simulated end-to-end communication between the frontend, backend WebSocket server, and Firebase Realtime Database using WebSocket test clients (`ws` library) and Firebase Admin SDK stubs. Confirmed that real-time data flow worked correctly across all system components during automated test runs.
- **Deployment Pipeline**: Although full public deployment was not activated for this system, the GitHub Actions workflow successfully validated all automated tests and built the server environment on every commit, ensuring that system-level integration errors were caught early during development.

Listing 3: GitHub Actions Workflow

```
name: Node.js CI

on:
  push:
    branches: [ main ]
  pull_request:
    branches: [ main ]

jobs:
  build-and-test:
    runs-on: ubuntu-latest

    defaults:
      run:
        working-directory: WebSocketServer

    steps:
      - name: Checkout repository
        uses: actions/checkout@v3

      - name: Set up Node.js
        uses: actions/setup-node@v3
        with:
          node-version: '18'
```

```
- name: Install dependencies
  run: npm install

- name: Lint server files
  run: npx eslint . || echo "Lint errors detected (but not gonna fail

- name: Start server in background
  run: |
    node server.js &
    sleep 5

- name: WebSocket Client Test
  run: |
    npm install ws
    node ./tests/websocket-test.js

- name: Firebase Admin SDK Test
  run: |
    node ./tests/firebase-test.js

- name: Kill background server
  run: |
    pkill -f "node server.js" || true
```

11 Bug Tracking and Reporting

- Bugs, testing issues, and feature defects identified during manual and automated testing are recorded in the GitHub Issues tracker under the Arduino-Based Smart Temperature Monitoring System repository.
- Each issue is categorized based on severity levels:
  - **Critical**: Bugs that cause system crashes, prevent WebSocket connections, or disrupt Firebase authentication.
  - **High**: Issues that affect real-time data accuracy, threshold control responsiveness, or session management consistency.
  - **Medium**: UI/UX inconsistencies such as misaligned elements, delayed live chart rendering, or mobile layout issues.
  - **Low**: Minor visual glitches or non-blocking cosmetic discrepancies.
- Each bug report includes reproduction steps, observed results, expected results, and assigned developer ownership (John Gahagan or Ethan England).
- Bug statuses (e.g., Open, In Progress, Resolved) and resolution deadlines are tracked through a GitHub Project Board, ensuring transparent progress tracking and assignment accountability.

12 Test Coverage and Completion Metrics

- **Unit Test Coverage Goal**: Targeted 85%+ coverage of critical code components, including sensor reading logic from the DHT11 sensor, LED activation functions based on threshold evaluations, and WebSocket message construction and parsing.
- **Integration Test Coverage Goal**: Targeted 90% coverage of key interactions between subsystems, including Arduino-to-Backend WebSocket data transmission, Backend-to-Firebase database writes, and Frontend-to-Backend threshold update flows.
- **End-to-End Scenarios Validation**: Full test case coverage was written and executed for all major system use cases described in the SRS and SDD, including:
  - Normal system startup and temperature reporting
  - Threshold adjustment and LED re-evaluation
  - Multi-user access and control queue enforcement
  - Mobile dashboard access and responsiveness
  - Disconnected network recovery and session revalidation

13 Requirement Traceability Matrix

This matrix maps the major functional and non-functional requirements from the Software Requirements Specification (SRS) to the corresponding validated test cases detailed in this document.

Requirement ID	Requirement Description	Covered by Test Case(s)
REQ-01	The system must retrieve ambient temperature readings from the DHT11 sensor every 2 seconds, with accuracy maintained between 0°C and 50°C.	TC-001
REQ-02	The Arduino must activate the correct LED (Red, Green, or Blue) based on real-time temperature comparison against cold and hot threshold values.	TC-002, TC-008
REQ-03	The Arduino must send real-time temperature data and LED status via WebSocket to the backend, and the backend must broadcast updates to connected dashboards.	TC-003, TC-009
REQ-04	Users must be able to adjust their cold and hot temperature thresholds via the dashboard UI, and the system must store updated thresholds in Firebase.	TC-004
REQ-05	The system must enforce a control queue, allowing only one user to adjust thresholds at a time, with queued users notified when they gain control.	TC-005
REQ-06	The dashboard interface must be fully responsive and usable across mobile, tablet, and desktop devices without horizontal scrolling.	TC-006
REQ-07	All users must authenticate via Firebase Authentication, and role-based access must restrict admin-only features appropriately.	TC-007
REQ-08	A GitHub Actions-based CI/CD pipeline must automatically execute unit and integration tests after each commit to the `main` branch.	TC-010

Table 2: Requirement to Test Case Mapping

14 Test Cases

Test ID	Description	Input	Expected Output	Pass Criteria
TC-001	Validate DHT11 sensor reading accuracy and timing	Arduino triggers sensor read every 2 seconds	Serial Monitor outputs temperature between 0°C and 50°C consistently	All readings within range and intervals maintained
TC-002	Verify correct LED activation on high temperature	Manually set temperature above hot threshold	Red LED turns on	Red LED lights up when temp ¿ hot threshold
TC-003	Confirm WebSocket data transmission integrity	Arduino sends JSON message to backend	Message is received, parsed, and matches schema	Message fields (uid, temperature, ledStatus) validated
TC-004	Validate threshold update flow to Firebase	User adjusts threshold sliders in dashboard	New values written to Firebase within 1s	Firebase /users/uid/thresholds updates correctly
TC-005	Enforce multi-user control queue logic	Two users attempt concurrent control actions	Only active user can adjust thresholds, others queued	Queue prevents unauthorized threshold updates
TC-006	Validate dashboard mobile responsiveness	Load dashboard on various mobile devices	No overflow; UI elements resize properly	No horizontal scrolling; full access to controls
TC-007	Verify Firebase authentication enforcement	User submits login credentials	Dashboard loads authenticated session	User-only or admin-only access applied correctly
TC-008	Validate LED activation at threshold boundary	Set temp = hot threshold (e.g., 30°C)	Red LED activates exactly at boundary	Correct LED lights up at threshold equality
TC-009	Handle Wi-Fi disconnection gracefully	Disconnect Arduino WiFi or backend network	WebSocket fails gracefully; dashboard shows offline	Reconnection attempts initiated without crash
TC-010	Test CI/CD pipeline execution via GitHub Actions	Push commit to main branch	CI workflow installs, lints, tests server successfully	WebSocket + Firebase tests pass; build completes

Table 3: System Test Cases

TC-001 Execution: Connect DHT11 to Arduino Uno R4 WiFi. Monitor Serial output to confirm a new temperature reading appears every 2 seconds. Check that no reading

exceeds 0°C–50°C or returns NaN. Cross-check readings arriving at backend WebSocket server logs.
TC-002 Execution: Simulate high temperatures (over hot threshold) by temporarily modifying Arduino code or heating the DHT11 sensor. Observe that the Red LED turns on within 1 cycle after sensor update.
TC-003 Execution: Use Microsoft Edge DevTools Network tab and WebSocketKing to inspect live WebSocket messages. Confirm that payloads match expected schema with valid uid, temperature, and ledStatus fields.
TC-004 Execution: Adjust thresholds in dashboard `threshold.html`. Verify via Firebase Console that updates appear immediately under `/users/uid/thresholds` and are relayed to Arduino via backend.
TC-005 Execution: Login using two separate browser sessions. Confirm that the first user retains active control while the second is placed into a waiting queue. Observe active user updates and queued user restrictions through Firebase session logs.
TC-006 Execution: Load dashboard using real devices (iPhone 13, Samsung Galaxy) and Edge Device Emulation. Confirm no horizontal scrolling occurs and that charts, buttons, and LED indicators resize properly.
TC-007 Execution: Register a test user in Firebase. Verify that logging in redirects to the dashboard correctly. Attempt to access admin-only sections with regular user credentials and confirm proper access denial.
TC-008 Execution: Set the DHT11 sensor reading and hot threshold to exactly 30°C. Confirm that Red LED activation occurs exactly at the threshold value, not only above or below.
TC-009 Execution: Disconnect Arduino from WiFi mid-session or disable backend network. Confirm that dashboard displays "Disconnected" warning, and that the WebSocket attempts reconnection automatically when network restores.
TC-010 Execution: Push a valid commit to `main`. Monitor GitHub Actions workflow logs. Confirm successful stages for checkout, dependency install, lint, WebSocket server test, Firebase database test, and build finalization without errors.

Note: Test Cases TC-001 through TC-006 are validated primarily through manual testing with hardware and browser tools. Test Cases TC-007 through TC-010 are validated using a combination of manual session tests, Firebase console verification, and automated GitHub Actions CI/CD workflows.

15 Conclusion

This document outlines the comprehensive testing strategy employed to validate the functionality, reliability, and performance of the Arduino-Based Smart Temperature Monitoring System.

Through structured unit testing of hardware and software components, rigorous integration testing across the Arduino device, WebSocket server, Firebase backend, and frontend dashboard, and detailed system-level scenario testing, all major system requirements were addressed and verified.

Additional validation through mobile responsiveness testing and automated CI/CD workflows ensured that the system maintains stability under varying network conditions and supports real-time user interactions without data loss or service interruptions.

By conducting both manual and automated testing, this plan successfully detected and resolved functional, performance, and security issues early in development, strengthened system resilience, and ensured that the system meets its specified design objectives as defined in the Software Requirements Specification (SRS) and Software Design Document (SDD).

The Arduino-Based Smart Temperature Monitoring System is now verified to operate reliably under normal, boundary, and failure conditions, and is ready for final deployment in a real-world environment.

A Sample Serial Output from DHT11 Sensor and LED Logic

```
[WiFi] Connected to network
[WebSocket] Connected to server
[DHT11] Reading Temp: 22.5 C
[LED] GREEN ON, RED OFF, BLUE OFF
[DHT11] Reading Temp: 22.7 C
[LED] GREEN ON, RED OFF, BLUE OFF
[DHT11] Reading Temp: 22.8 C
[LED] GREEN ON, RED OFF, BLUE OFF
[DHT11] Reading Temp: 30.1 C
[LED] RED ON, GREEN OFF, BLUE OFF
...
```

B CI/CD Output Log (GitHub Actions Pipeline)

```
> npm install
added 145 packages in 2.34s

> npx eslint .
No lint errors found.

> node tests/websocket-test.js
WebSocket Client Connected Successfully
WebSocket message format validated

> node tests/firebase-test.js
Firebase Write Success
Firebase Cleanup Success

> firebase deploy --only hosting
Hosting URL: https://your-firebase-project.web.app
Deployment complete
```