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# An IoT Prototype for Monitoring and Control of Greenhouse Air Temperature, Nutrient Concentration, and Nutrient Solution Temperature Using DHT22, TDS, pH, and DS18B20 Sensors at Smart Farm Academy in Tapos Village, Tigaraksa District

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**Abstract.** We developed an ESP32 prototype for a hydroponic choy sum greenhouse at Smart Farm Academy in Tapos Village. The controller reads air temperature and humidity, nutrient solution temperature, pH, and total dissolved solids (TDS). An Android application displays current readings and pump history from Firebase. We summarized the thesis test tables for 24–30 October 2026 and compared the reported functional tests with the controller logic. Five misting examples lasted 900–901 s. In the seven nutrient dosing examples, final TDS exceeded initial TDS in four cases and reached the 509–577 ppm test band in one. The pH, TDS, and misting temperature evaluation values describe test scenarios. Pump-event timestamps provide separate evidence of command timing. The thesis reports that all ten black-box scenarios passed. At exactly 36.0 °C, the inspected firmware kept an idle misting pump off. One greenhouse operator rated the application 45/50. The prototype supported remote monitoring and timed pump operation. The available tests do not establish sensor accuracy or consistent attainment of the nutrient target.

***Keywords:*** *Hydroponics, Internet of Things, ESP32, Nutrient Dosing, Greenhouse Misting.*

## A. INTRODUCTION

Smart Farm Academy in Tapos Village, Tigaraksa District, Tangerang Regency, Banten, serves as a center for agricultural training and community development (Fansyuri, 2023). During our preliminary observations, the operator had to visit the greenhouse to check the air and nutrient solution. Each visit provided a snapshot, but there was no common record of temperature and pump activity. If the greenhouse had already cooled by the time the operator arrived, a single reading could reveal neither an earlier temperature excursion nor whether the misting pump had run. The operator therefore needed access to both current conditions and a time-stamped record of events.

Austria et al. (2023) developed an Internet of Things (IoT) system that monitored air conditions, pH, and water temperature in a hydroponic greenhouse. Abu Bakar Shedek and Mohamed Ali (2023) also incorporated temperature, humidity, pH, and total dissolved solids (TDS) sensors into a hydroponic system. These studies informed our choice of measurements. Air temperature provides the input for misting, water temperature characterizes the thermal state of the nutrient solution, pH indicates acidity, and TDS serves as a proxy for dissolved solute concentration. Four sensor types provide five measurements because the DHT22 measures both air temperature and relative humidity.

Savitri et al. (2023) used an ESP32 and Telegram to report temperature, humidity, and water level. Priyonggo et al. (2023) investigated microclimate control using an exhaust fan. At Tapos, the operator needed to mist the greenhouse, monitor water temperature, and manage both nutrient concentrates and pH-adjusting solutions. This required access to the latest readings, the current stage of pump operation, and a record of earlier actions.

More than one solution parameter can fall outside its target range at the same time. Low TDS calls for nutrient concentrates A and B, while high pH calls for a pH-lowering solution. Starting all pumps after the first reading would make subsequent measurements difficult to interpret while the solution was still mixing. The Tapos controller therefore sequences its actions. It dispenses A and B in turn, allows the solution to mix, and waits before making another dosing decision. Evaluating a cycle consequently requires readings taken at identifiable stages in that sequence.

Moreira et al. (2024) evaluated separate feedback loops for conductivity and pH. Mohd Nizam et al. (2026) compared nutrient controllers by their setpoint response and overshoot. At Tapos, nutrient and pH dosing share a mixer. We examined how the prototype sequences these actions, what the thesis test examples show about timing and target attainment, and how the site operator rated the monitoring interface.

## B. METHOD

### 1. System development using iterative prototyping

We developed the greenhouse monitoring and control system using an iterative prototyping method. The cycle comprises communication, quick planning, modeling and quick design, prototype construction, and deployment, delivery, and feedback (Kurniati, 2021). At Smart Farm Academy, observations and an interview with the greenhouse operator established two requirements: access to current conditions from outside the greenhouse and a record of when each pump operated. These requirements guided sensor selection, pump control logic, and the design of the Android dashboard and history screens.

We programmed the ESP32 in the Arduino IDE and developed and tested the Android application in Android Studio. Firebase Realtime Database synchronized sensor readings, crop settings, and actuator states between the controller and the application. The operator evaluated the working prototype at the study site. Figure 1 shows how feedback informs the next design iteration. Table 1 gives the eight implementation and evaluation steps reported in the thesis.

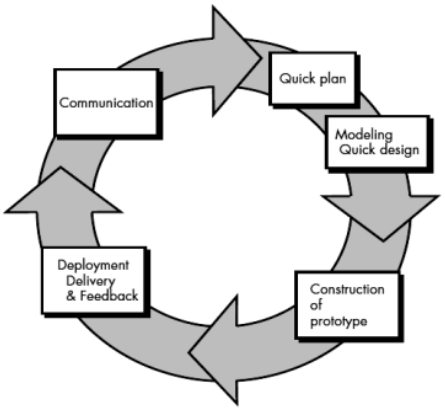



**Figure 1. Prototype Model**

**Table 1. System Approach used at Smart Farm Academy**

| Step | System Approach | Activity |
|---|---|---|
| 1 | Requirements analysis | Observe greenhouse checks and interview the site operator. |
| 2 | System design | Map the controller, sensors, relays, network, database, and monitoring dashboard. |
| 3 | Hardware implementation | Assemble the ESP32, sensors, pump relays, and misting nozzles. |
| 4 | Software implementation | Program sensor acquisition and display the readings on the dashboard. |
| 5 | IoT integration | Connect the ESP32, database, and dashboard over Wi-Fi. |
| 6 | Greenhouse temperature control | Use the air-temperature input to operate the misting system. |
| 7 | System testing | Test sensing, data transmission, the dashboard, and pump responses. |
| 8 | Evaluation and refinement | Review test outcomes against the operator's requirements. |

## 2. System Architecture

Figure 2 shows the data and control paths. The DHT22 senses greenhouse air. The DS18B20, pH probe, and TDS probe sense the nutrient solution. The ESP32 switches seven active-low pump outputs through a 5 V eight-channel relay board. Under the smartfarm root in Firebase, realtime holds current readings, history stores periodic snapshots, and eventPompa stores pump commands and timestamps. The control node holds active settings, while profilTanaman stores the crop profiles. The Android application reads the current state and history over the network.

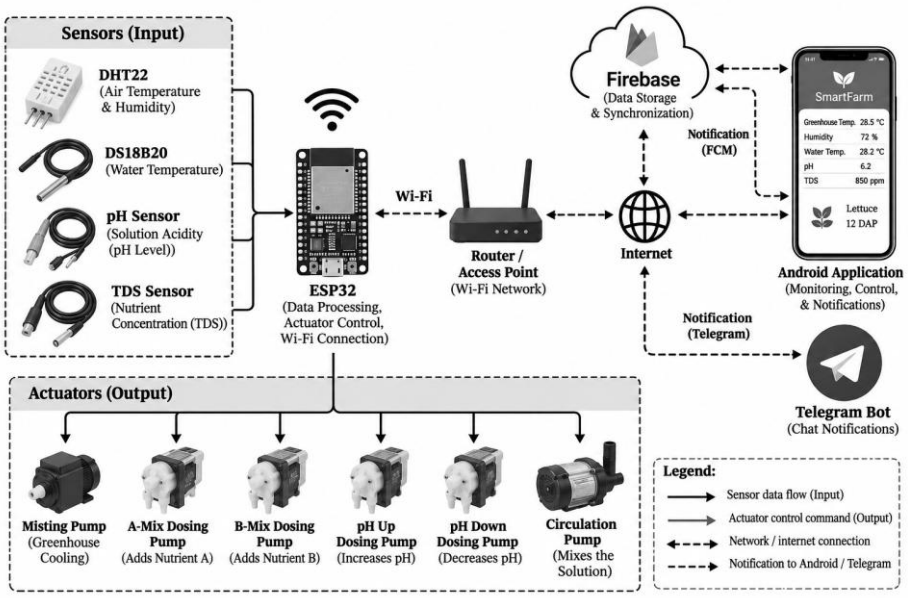



**Figure 2. Architecture of the Hydroponic Monitoring and Control System**

## 3. Study Site, Sampling, and Data Collection

The evaluation covered one greenhouse and one crop, choy sum, at Smart Farm Academy. We used the rows reported in the Chapter 4 sensor and actuator test tables for 24–

30 October 2026 (UTC+7). The DHT22 table contains seven evening air-temperature and humidity pairs. The DS18B20 and TDS tables each contain four entries per day. The pH table contains 22 entries at the times listed. The misting and dosing tables contain five and seven selected examples, respectively.

One operator who managed the greenhouse evaluated the Android application. For a separate check of pH pump operation, we inspected the 18 October event log. These earlier commands were excluded from the seven-day statistics.

## 4. Measurements and Analysis

Ranges and counts were calculated from the individual rows of the thesis test tables. The pH and TDS evaluation entries and the misting temperature endpoints are scenario values. We used these entries to evaluate control decisions and used event timestamps to check command duration. The firmware compensates TDS probe voltage to 25 °C at 2% per °C (DFRobot, 2026). Independent reference readings were unavailable for estimating sensor error. For each misting example, elapsed time was calculated from pump ON to OFF. Temperature decrease was calculated as initial minus final temperature. For each nutrient dosing example, we compared the tabulated initial and final TDS and checked whether the final value fell within the test band of 509–577 ppm. The pH and water temperature entries accompanying a dosing record describe its evaluation conditions.

Black-box testing compared test inputs with reported outputs. White-box testing traced branches and state transitions in the misting, nutrient dosing, and pH control routines. The user acceptance test (UAT) comprised ten statements rated on a five-point scale. We calculated the acceptance percentage by dividing the operator's total score by the maximum of 50 and multiplying by 100.

## 5. Automatic Control Sequence

Table 2 gives the choy sum settings in thesis Tables 4.4 and 4.5. Days after planting (DAP) select the intended crop profile. The dosing examples use 509–577 ppm, the first-stage band, as their test criterion. The seven examples do not verify successful transitions between crop stages.

**Table 2. Choy Sum Settings by Crop Age (Solution Temperature Set to 18–22 °C in Every Phase)**

| Crop age (DAP) | Minimum TDS (ppm) | Maximum TDS (ppm) | pH range |
|---|---|---|---|
| 0–6 | 509 | 577 | 5.5–6.5 |
| 7–13 | 731 | 773 | 5.5–6.5 |
| 14–20 | 961 | 983 | 5.5–6.5 |
| 21–26 | 1243 | 1277 | 5.5–6.5 |

Figure 3 summarizes the control design. In the inspected firmware, an idle misting pump starts above 36.0 °C when automatic control is enabled and the two-hour waiting period has elapsed. A cycle lasts 900 s. The circulation pump starts above 22 °C, stops at or below 18 °C, and retains its state between these limits. These are configured thresholds. The trial did not establish their agronomic suitability for Tapos.

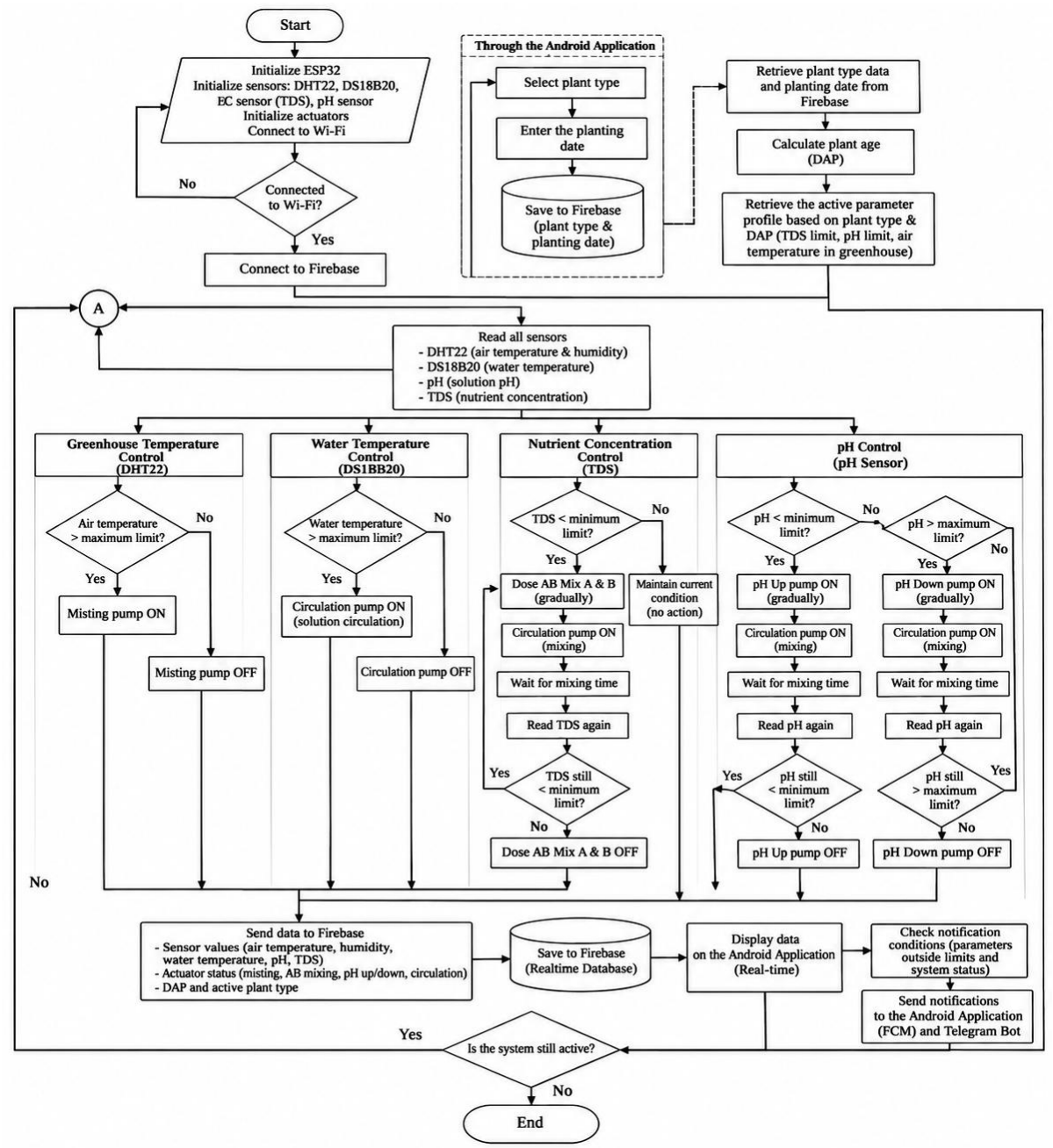



**Figure 3. Sensor Acquisition, Actuator Control, and Data Transmission**

In phase 1, a firmware TDS reading below 509 ppm initiates nutrient pump A followed by B, 120 s of mixing, and a 60 s settling period. The firmware specifies a 1,000 L tank and assumes 3.33 mL/s to command 5 mL per concentrate (about 1.5 s per pump). The operating fill volume and the delivered flow were not measured in this evaluation. Nutrient dosing takes priority over pH correction. When the pH routine is eligible, readings below 5.5 call for pH-up solution and readings above 6.5 call for pH-down solution.

## C. RESULT AND DISCUSSION

### 1. System integration and the Android application

A DHT22 reading illustrates the complete data path. The ESP32 processed the air temperature and humidity values from the sensor and sent them over Wi-Fi to Firebase. The Android dashboard displayed the latest values, and the operator could retrieve earlier readings

from the history screen. All four integration scenarios were reported to have passed: establishing Wi-Fi connectivity, receiving data from all four sensor types, updating the dashboard, and retrieving historical records. The operator could thus inspect both current and past conditions away from the sensor installation.

Figure 4 shows the four application screens. The dashboard displays sensor readings and connection status. The crop screen selects the active profile, the history screen retrieves readings and pump states, and the settings screen displays system configuration. The values shown illustrate the interface. Tables 3–5 report the sensor and actuator examples from the thesis.

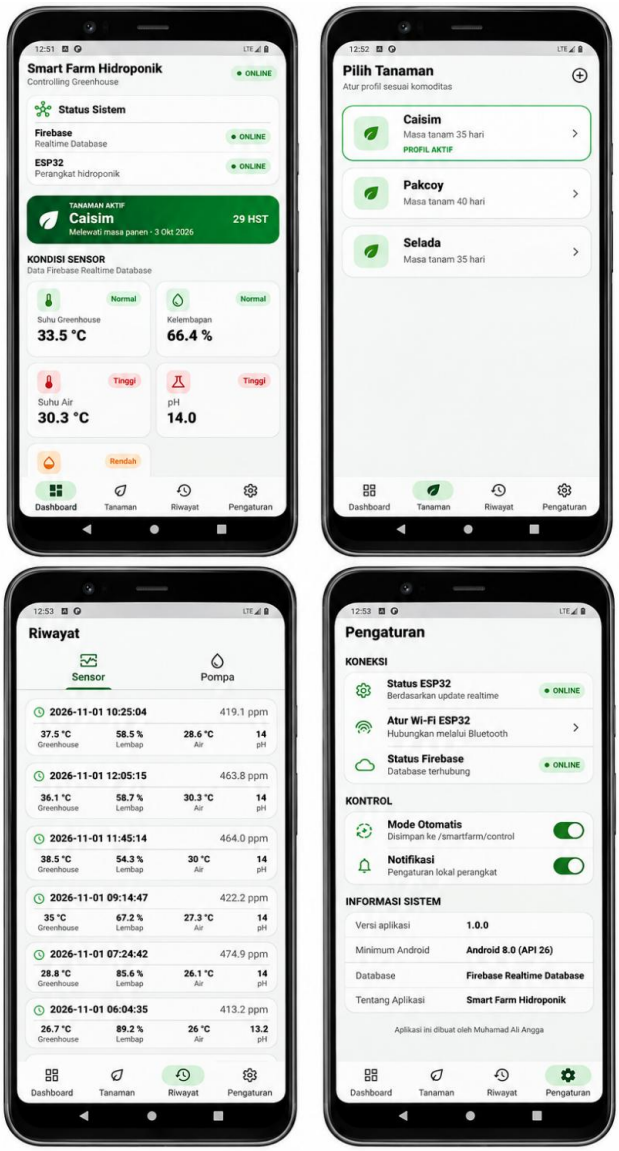



**Figure 4. Android Dashboard, Crop Selection, History, and Settings**

## 2. Sensor Readings

Table 3 summarizes the sensor test tables. The DHT22 entries are evening observations and do not describe daytime peaks. Figure 5 shows the solution temperature, pH, and TDS values at the sample times given in the thesis.

**Table 3. Sensor Readings and Nutrient Solution Classifications, 24–30 October 2026**

| Parameter | Entries | Range | Evaluation summary |
|---|---|---|---|
| Air temperature | 7 | 26.9–30.4 °C | Evening sample near 19:00 each day. |
| Relative humidity | 7 | 64.3–88.5 % | Same seven DHT22 observations. |
| Water temperature | 28 | 24.63–31.63 °C | Circulation marked ON in all 28 rows. |
| pH | 22 | 5.78–8.60 | 15 above 6.5 and 7 within 5.5–6.5. |
| TDS | 28 | 160.71–536.25 ppm | 22 below 509 ppm and 6 within 509–577 ppm. |

All 28 water temperatures exceeded the configured upper limit of 22 °C. The circulation pump was marked ON in every row. These samples do not test its shutdown at 18 °C. Sanaba et al. (2024) used a higher 25–27 °C range in a pak choy system. The test at Tapos did not establish a crop-specific optimum.

In the pH evaluation table, 15 of 22 entries exceeded 6.5 and seven fell within 5.5–6.5. None called for pH-up dosing. A high pH entry indicates a request for correction under the control rule. A separate pump-event example on 18 October records a pH-down command from 10:57:04 to 10:57:09. Its duration does not establish the change in reservoir pH.

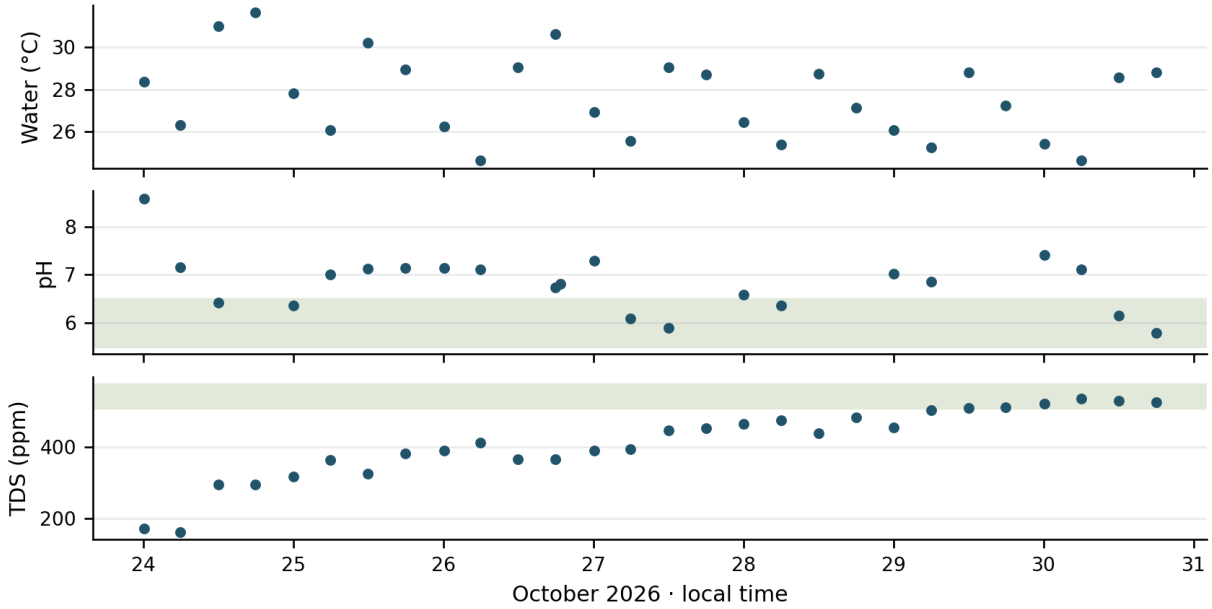



**Figure 5. Solution Temperature, pH, and TDS Entries from the Thesis Sensor Tests. Shading indicates the pH and TDS test bands**

### 3. Misting and Nutrient Dosing

Four of the five selected misting commands lasted 15 min, and one lasted 15 min 1 s (Table 4). Across the temperature pairs in the thesis evaluation, the decreases ranged from 3.4 to 7.1 °C and averaged 4.94 °C. Those differences describe the tabulated scenarios. Independent paired measurements would be needed to attribute a greenhouse temperature change to misting.

**Table 4. Five Misting Examples in the Thesis Evaluation (24–30 October 2026)**

| Date (Oct.) | ON | OFF | Start (°C) | End (°C) | Decrease (°C) |
|---|---|---|---|---|---|
| 24 | 09:30:06 | 09:45:06 | 36.1 | 32.7 | 3.4 |
| 25 | 12:00:04 | 12:15:05 | 39.9 | 32.8 | 7.1 |
| 26 | 10:07:09 | 10:22:09 | 36.1 | 31.7 | 4.4 |

| | | | | | |
|---|---|---|---|---|---|
| 27 | 12:33:27 | 12:48:27 | 36.1 | 31.5 | 4.6 |
| 30 | 13:19:17 | 13:34:17 | 36.7 | 31.5 | 5.2 |

Each of the seven thesis examples specifies 5 mL of concentrate A followed by 5 mL of concentrate B. Mixing lasted from 1 min 48 s to 1 min 59 s. Table 5 lists the initial and final values for each example. All seven entries have the status "recorded" in the thesis.

**Table 5. Seven Nutrient Dosing Examples from the Thesis Evaluation, with 5 mL Commanded Per Concentrate**

| Date (Oct.) | Water (°C) | TDS initial → final (ppm) | pH initial → final | Mixing (min:s) |
|---|---|---|---|---|
| 24 | 26.25 | 163.89 → 130.29 | 8.60 → 7.16 | 1:59 |
| 25 | 30.50 | 365.79 → 370.19 | 7.00 → 7.13 | 1:58 |
| 26 | 27.50 | 417.44 → 417.16 | 7.14 → 7.12 | 1:48 |
| 27 | 26.69 | 399.57 → 442.02 | 7.29 → 6.08 | 1:57 |
| 28 | 27.75 | 484.97 → 486.02 | 6.58 → 6.35 | 1:58 |
| 29 | 26.06 | 455.40 → 455.11 | 7.02 → 6.85 | 1:58 |
| 30 | 25.44 | 477.70 → 521.60 | 7.41 → 7.12 | 1:58 |

TDS increased in four of the seven rows and decreased in three. On 27 October it rose from 399.57 to 442.02 ppm but remained below 509 ppm. On 30 October it rose from 477.70 to 521.60 ppm, the only final value inside the test band. Six of the 28 scheduled TDS entries in Table 3 were in band. Those six entries and the seven dosing examples have different sampling times and answer different questions.

## 4. Control Logic and Functional Testing

Table 6 describes three firmware routines. For misting, we also executed the original control function in a host-side test with automatic mode enabled, valid settings, an idle pump, and no active cooldown. With the upper limit set to 36.0 °C, inputs of 35.9, 36.0, and 36.1 °C produced OFF, OFF, and ON, respectively.

**Table 6. White-Box Test Results for the Three Control Routines**

| Routine | Test conditions | Outcome in the code path |
|---|---|---|
| Misting | Controller ready at 35.9, 36.0, or 36.1 °C. Active cycle at 899 and 900 s. | The pump stays off at 35.9 and 36.0 °C, starts at 36.1 °C, and stops at 900 s. |
| Nutrient dosing | TDS of 508 or 509 ppm with the controller ready. Completion of each dosing stage. | 508 ppm starts pump A. At 509 ppm, dosing does not start. After A and B, the mixer runs and the controller waits. |
| pH correction | pH of 5.49, 5.50, 6.50, or 6.51. A separate test covers active nutrient dosing. | When correction is enabled, 5.49 triggers pH-up dosing and 6.51 triggers pH-down dosing. Neither pump starts at the limits or during nutrient dosing. |

Table 7 gives the ten black-box scenarios and the results reported in the thesis. The status column follows that test report. Table 6 separately summarizes selected white-box branches for misting, nutrient dosing, and pH correction.

**Table 7. Black-Box Functional Test Results**

| Id | Scenario | Reported Output | Thesis Result |
|---|---|---|---|
| BB-01 | Connect to Wi-Fi and Firebase | Data are transmitted and stored. | Passed |

| | | | |
|---|---|---|---|
| BB-02 | Required start at ≥36.0 °C | Misting was reported to start at the upper threshold. | Passed |
| BB-03 | Misting reaches 15 min | The pump stops after 15 min. | Passed |
| BB-04 | TDS below 509 ppm | Pumps operate in the specified sequence. | Passed |
| BB-05 | Nutrient dosing complete | The mixing pump runs for the specified duration. | Passed |
| BB-06 | TDS at 508, 509, and 577 ppm | The controller responds as specified at each test value. | Passed |
| BB-07 | Open the Android dashboard | The dashboard displays the sensor readings. | Passed |
| BB-08 | Open the history screen and select choy sum | Historical records and crop settings are accessible. | Passed |
| BB-09 | Disconnect and restore Wi-Fi | The device reconnects and resumes normal operation. | Passed |
| BB-10 | Supply an invalid sensor reading | The invalid reading does not start a pump. | Passed |

The thesis records BB-02 as passed with a requirement of ≥36.0 °C. Its white-box case WB-GH-03 specifies OFF at exactly 36.0 °C, consistent with the strict comparison in the inspected firmware. All five selected misting starts in Table 4 were above 36.0 °C. Those events therefore do not resolve physical pump behavior at the boundary.

## 5. User Acceptance

The site operator rated ten application-specific statements on a five-point scale. Five ratings were 5 and five were 4, totaling 45/50 (Table 8). This is an individual operator assessment using the study questionnaire.

**Table 8. User Acceptance Ratings from the Greenhouse Operator at Smart Farm Academy, Tapos Village**

| Item | Statement | Score (1–5) |
|---|---|---|
| UAT-01 | The Android application is easy to learn and use. | 5 |
| UAT-02 | The greenhouse temperature and humidity readings are clearly displayed. | 5 |
| UAT-03 | The water temperature, pH, and TDS readings are easy to understand. | 5 |
| UAT-04 | I can interpret the misting, nutrient dosing, and mixing pump states. | 4 |
| UAT-05 | The crop selection and planting date controls are easy to use. | 5 |
| UAT-06 | The application updates the readings so I can monitor conditions. | 5 |
| UAT-07 | The history screen makes it easy to review earlier readings. | 4 |
| UAT-08 | The application helps me check greenhouse conditions. | 4 |
| UAT-09 | The system workflow and features meet my needs as an operator. | 4 |
| UAT-10 | Overall, the system is useful in day-to-day operations. | 4 |

The operator gave 5/5 for the clarity of the displayed water temperature, pH, and TDS (UAT-03). The same operator scored pump-state interpretation and the history screen 4/5 each. These items describe the experience of one person at the study site and do not evaluate sensor accuracy.

Separating command timing from solution response changes the interpretation of the test results. The timer consistently stopped the five misting examples at about 15 min. By contrast, the nutrient sequence finished with a TDS value in the target band in only one of seven evaluation rows. Mixing time alone cannot establish how much concentrate reached the solution or how evenly it dispersed.

The firmware checks nutrient demand before permitting pH correction. Under persistent low TDS, the pH routine can be deferred even when pH exceeds 6.5. A test with both inputs outside their limits would distinguish that scheduling behavior from probe error. Reference-based checks across multiple solutions are also important for interpreting hydroponic pH and EC measurements (Cho et al., 2024; Rofiansyah et al., 2025).

The findings apply to the selected examples from one greenhouse. Quantifying physical control effects would require synchronized reference readings, measured pump delivery, actual reservoir fill volume, and testing across crop stages. The evening air samples alone do not characterize the heat load during the daytime misting cycles.

## D. CONCLUSION

The prototype linked four sensor types, the ESP32, Firebase, and an Android interface at Smart Farm Academy. The thesis reports ten successful functional scenarios, and one operator rated the application 45/50. The five selected misting commands lasted 900–901 s. In the seven nutrient dosing examples, TDS rose in four and reached the test band in one. These results document the monitoring workflow and control sequence. Independent measurements are needed to verify the changes in the greenhouse and nutrient solution.

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