THE UNIVERSITY OF BRITISH COLUMBIA

IoT Monitoring of Aquaponic and Hydroponic Food Production

Verification and Validation

UBC Electrical and Computer Engineering Capstone 121

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Contents

Revision History

Date	Author	Sections	Change
2020-10-05	JL	1.0 - 4.0	Creation of document skeleton
2020-10-16	MD	1.0 - 4.0	First draft
2020-11-28	CB	2.0 - 4.0	Added subsystem specifics test outlines
2021-01-15	CB	3.0	Restructuring document to reflect design and requirements
2021-02-19	CL	1.0 - 6.0	Added section 6.0 Validation and minor changes to earlier sections to be consistent with the requirements documentation
2021-02-19	JL	2.0 - 3.0	Reworded overview section to be more concise. Updated testing section to be more concise, and match updated functional requirements. Removed some outdated tests due to changed requirements.
2021-04-11	JL	1.0 - 3.0	Major revisions to all sections for Milestone 4.

1 Overview

This document outlines the verification and validation plans for our project, an IoT hydroponic or aquaponic monitoring system. The verification tests and results included in this document seek to prove that our project meets its requirements. For more information about these requirements, please see the included *Requirements* document.

The design of our project informs the structure of the verification testing and results below. Our hydroponic and aquaponic monitoring system contains three main subsystems seen in Figure 1: a sensing and control system, cloud infrastructure, and a mobile software application. As such, our verification tests and results will be organized under each of these subsystems.

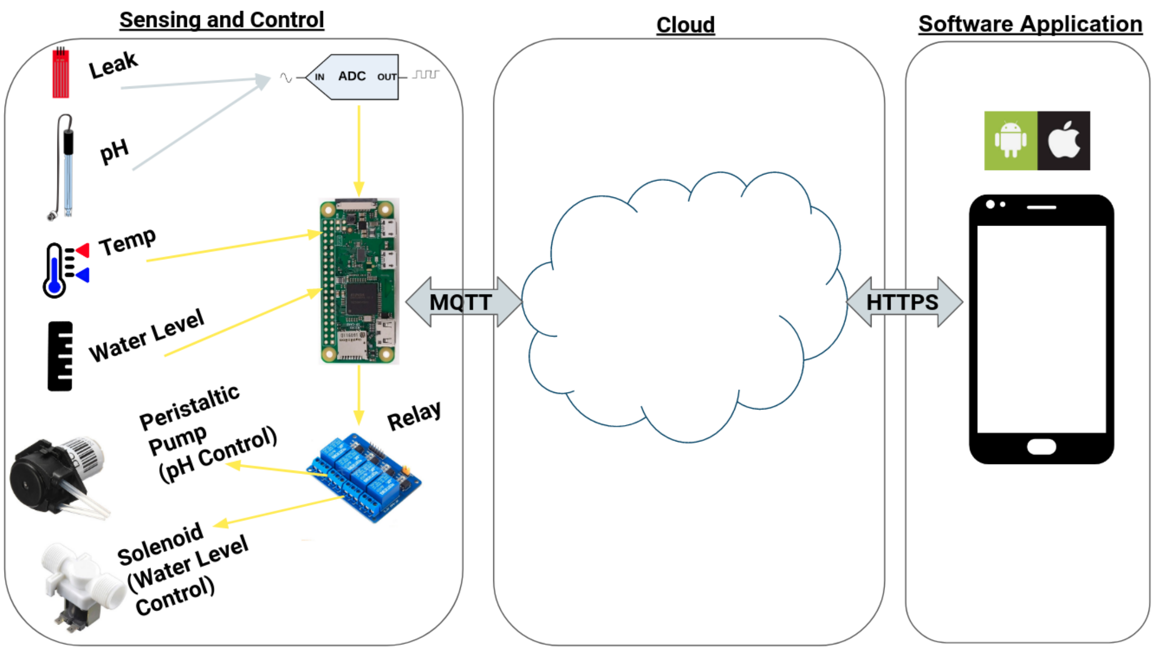

Figure 1: System Level Block Diagram

Additionally, this document outlines our project's validation plan, to ensure the project meets our client and user's needs. To see our validation tests and results, please see section 3.

Finally, please note that this document assumes that the reader is familiar with the setup of our design described in *System Installation* document. As well, we assume that the reader is familiar with the design described in the *Design* document. If this is not the case, we strongly recommend reading those documents before reading the tests described here.

2 Verification

This section provides verification tests and results for the following main subsystems in our design:

- Sensing and Control System
- Cloud Infrastructure
- Software Application

2.1 Sensing and Control System Verification

The sensing and control system has two functions. First, it measures important system variables including water pH, level, temperature, and leakage. It then sends these measurements to the Cloud Infrastructure so users can monitor their aquaponic or hydroponic system. Second, the sensing and control system automatically controls pH and water level to ensure user's aquaponics or hydroponics systems remain healthy. Please consult Figure 2 below and the *Design* document for more details about the sensing and control system.

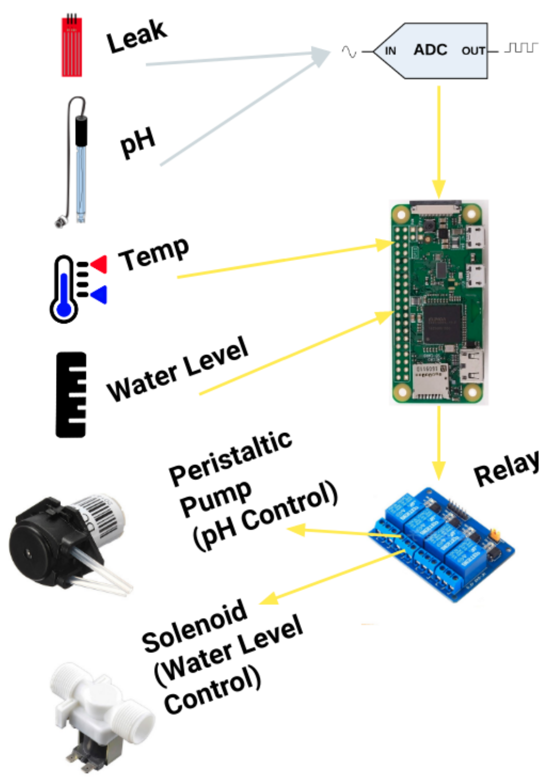

Figure 2: Overview of the sensing and control subsystem.

For an overview of all the verification tests performed on the sensing and control subsystem, please consult Table 1 below. Each of these tests in described in further detail in the proceeding subsections.

Table 1: Sensing and Control Verification Test Overview.

Test	Purpose	Requirement(s)	Result
SCT_1	Sensors measurements can be made and send to the Cloud Infrastructure	F_2	PASSED
SCT_2	pH and water level are maintained in healthy ranges automatically	F_4	PASSED
SCT_3	Operates on backup power	F_5	PASSED
SCT_4	The sensing and control system is water resistant	NF_4	PASSED

$\mathbf{SCT_1}$: Sensors measurements can be made and send to the Cloud Infrastructure

Purpose

Be able to send sensor measurements to users. Also, to test whether sensors can be read.

Procedure

1. Run the sensing and control system
2. Follow the testing procedure in CT_1 to ensure messages are recieved by the cloud correctly. Otherwise, the test FAILED.

Result

The test **PASSED**.

$\mathbf{SCT_2}$: pH and water level are maintained in healthy ranges automatically

Purpose

To make sure that pH and water level are controlled to be within healthy levels.

Procedure

1. Place the pH probe in an acidic solution.

2. Place the one end of the peristaltic pump in a basic solution and the other in the same solution as the pH probe.
3. Run the sensing and control system, and ensure that the pH stabilizes at the target pH set in the mobile application.
4. Place the water level sensor outside of water.
5. Ensure that the solenoid turns on periodically to simulate adding more water to the hydro/aquaponics system.

Result

The test **PASSED**.

SCT_3: Operates on backup power

Purpose

To ensure that our system can remain operational in the case of a power failure.

Procedure

1. Connect 2AA batteries into the 5V boost converter board.
2. Verify that the boost converter is able to output 5V DC with a multimeter. If not, test FAILED.
3. Simulate the 5V boost converter shutdown circuit's functionality, as seen in Figure 3.

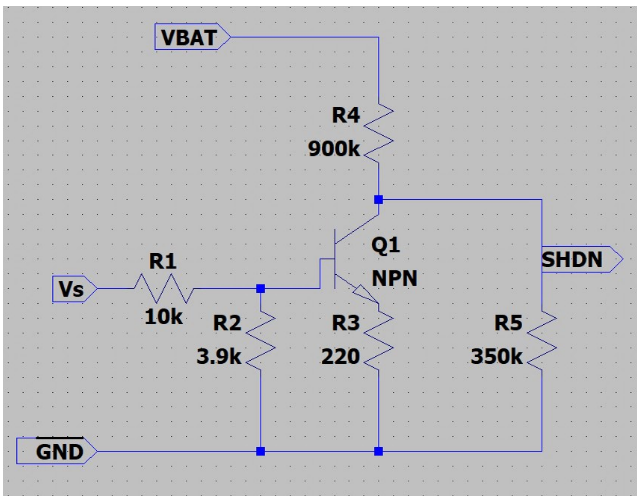

Figure 3: Boost converter shutdown circuit. This circuit disables the AA batteries when 12V is present.

4. Ensure that the circuit simulation outputs a low voltage when the 12V power supply is present and a 'high' voltage (above 0.8V) when the 12V power supply is absent. A plot of this behaviour can be seen in figure 4. If this behavior is not seen, the test FAILED.

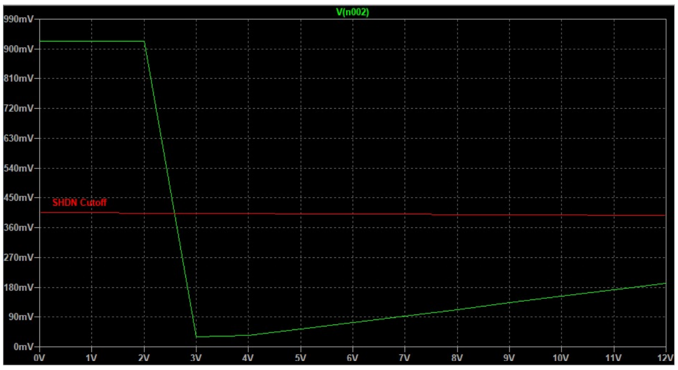

Figure 4: 5V boost converter shutdown circuit output vs source voltage. We see that once the source voltage (normally 12V) drops below 3 V, the SHDN signal goes high.

5. Construct the physical circuit.
6. Attach a multimeter voltage probe to the 5V rail and GND.
7. Plug in the 12 V power source
8. Connect 2AA batteries to the 5V boost converter.
9. Ensure that when 12V is present, the voltage rail read 4.7V. Otherwise, the test FAILED.
10. Ensure that when the 12V power supply is disconnected, or unplugged, the voltage rail should now read 5V. Otherwise, the test FAILED.

Result

The test **PASSED**.

$\mathbf{SCT_4}$: The sensing and control system is water resistant

Purpose

The purpose of this is to ensure that the sensing and control system is water resistant. This is important for aqua/hydroponics systems that are around water, or are perhaps placed outside.

Our system must comply with a rating of IP64. This means that the enclosure must be protected from low pressure water jets in any direction.

Procedure

1. Spray the enclosure with a shower head for 15 minutes from all directions
2. Ensure not liquid was able to enter the enclosure. If not, the test FAILED

Result

The test **PASSED**.

2.2 Cloud Infrastructure Verification

The cloud infrastructure connects the software application with the sensing and control system. This means that it provides the following functionality:

- Passing data beztween the software application and the sensing and control system.
- Sending notifications to the software application if there are issues detected by the sensing and control system.
- Saving sensor measurements in a database.

For an overview of the Cloud Infrastructure, please see Figure 5 below:

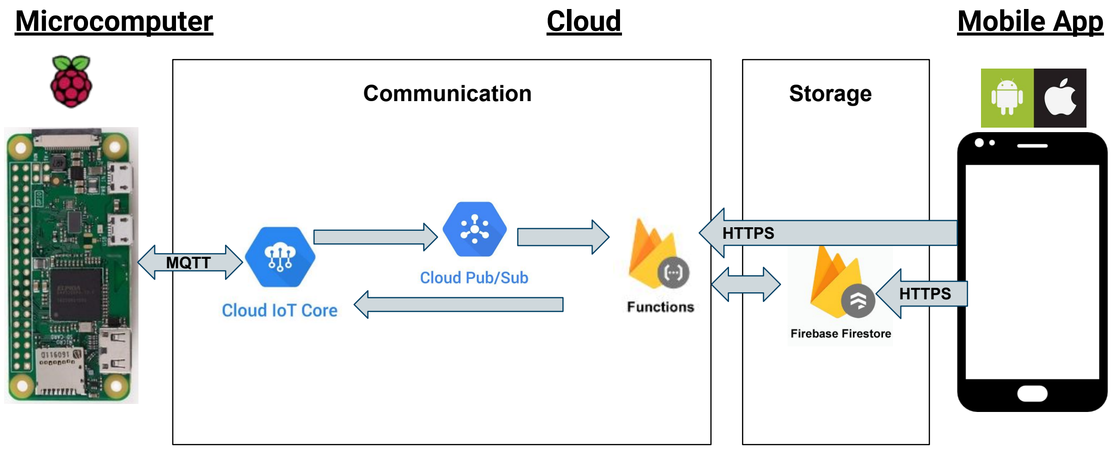

Figure 5: Overview of the cloud infrastructure.

For an overview of the tests performed on the cloud infrastructure system, please see Table 2 below.

Table 2: Cloud Infrastructure Verification Test Overview.

Test	Purpose	Requirement(s)	Result
CT_1	Messages from sensing and control system are saved in a database	F_1, F_2	PASSED
CT_2	Detects when sensor readings are outside the normal range	F_3	PASSED
CT_3	Send configuration messages to the sensing and control system	F_3	PASSED

CT_1: Messages from sensing and control system are saved in a database

Purpose

Ensures that sensor measurements from an aqua/hydroponic system are saved properly. This allows the mobile application to display the status and history of an aqua/hydroponic system.

Procedure

1. Set the sensor update interval to be 1 minute using the mobile application.
2. Run the sensing and control system so sensor measurements being made
3. Go to the Firebase web console for the project.
4. Select the Firestore Database tab.
5. Select the Status collection to display the most recent sensor readings stored in the database.
6. Verify that sensor measurement are updating every 1 minute. If not, test FAILED.
7. Select the History collection to display past measurements of an aqua/hydroponic system.
8. Verify that new sensor measurements are being written to the database every 1 minute. If not, test FAILED.
9. Verify that all sensor measurements are saved in the database. If not test FAILED.
10. Test PASSED if no failures detected above.

Result

In Firestore, updates can be seen as new data flashes as orange when recieved. This can be used to check whether messages have been updated in the Status and History collections. See Figure 6 for an example of what this looks like.

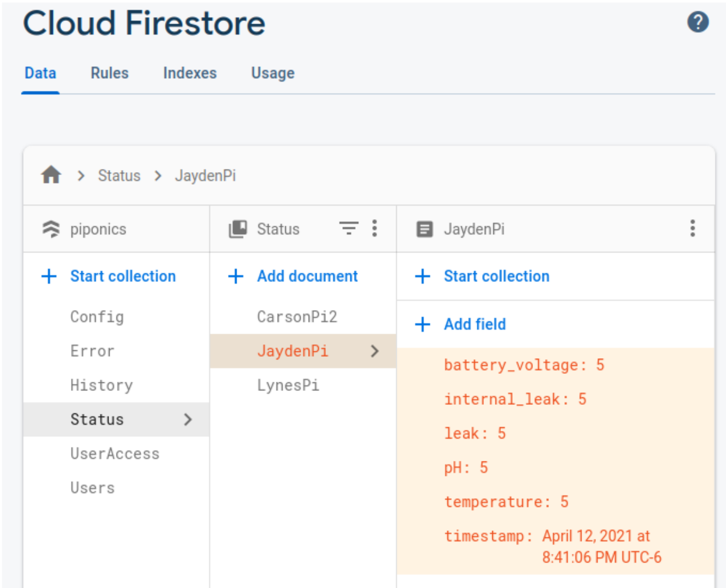

Figure 6: Firestore database updating during CT_1

After running this test, it **PASSED**.

$\mathbf{CT_2}$: Detects when sensor readings are outside the normal range

Purpose

Ensures abnormal sensor readings are detected. For example, the system should detect if there is a leak or if the temperature is too low.

Procedure

1. Go to the Firebase web console for the project.
2. Select the Firestore Database tab.
3. Select the Error collection to display whether an error is detected on a given aqua/hydroponic system.
4. Place the pH probe in an acidic solution.
5. Ensure that the PH_LOW field is true. If not, test FAILED.
6. Place the water temperature sensor in ice water. Ensure that the the TEMP_LOW field is true. If not, test FAILED.
7. Repeat the same process for all sensors to generate errors. Ensure that the appropriate errors are detected. If not, test FAILED.

8. If no failures detected above, test PASSED.

Result

Please see Figure 7 below for a demonstration of the test. As you can see, the system has detected that the water temperature is low, and there are multiple leaks.

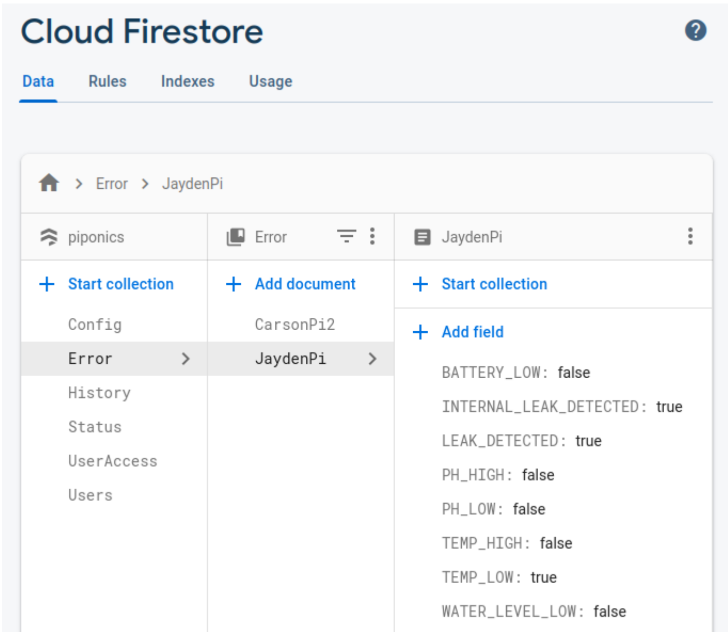

Figure 7: Firestore database Error collection updating during CT_2

All tests **PASSED**.

CT_3: Send configuration messages to the sensing and control system

Purpose

Allows the mobile application to configure settings like the sensor sampling rate and the target pH. This test verifies this functionality.

Procedure

1. Go to the Firebase web console for the project.
2. Select the Firestore Database tab.
3. Select the Config collection to display the configuration settings of an aqua/hydroponic system.

4. Run the sensing and control system and view the logs being outputted in terminal

5. Change the values of each of the configuration values in the Firestore database.

6. Ensure the sensing and control system prints a message with the new configuration values. If values are incorrect or not recieved, test FAILED.

Result

The test **PASSED**.

2.3 Software Application Verification

The software application allows users to monitor their aquaponic or hydroponic system. This includes viewing sensor readings, adjusting system settings, and recieving notification if errors are detected. Please see Figure 8 for demo screenshots of the software application. For more details about the design of the mobile application, please see the included *Design* document.

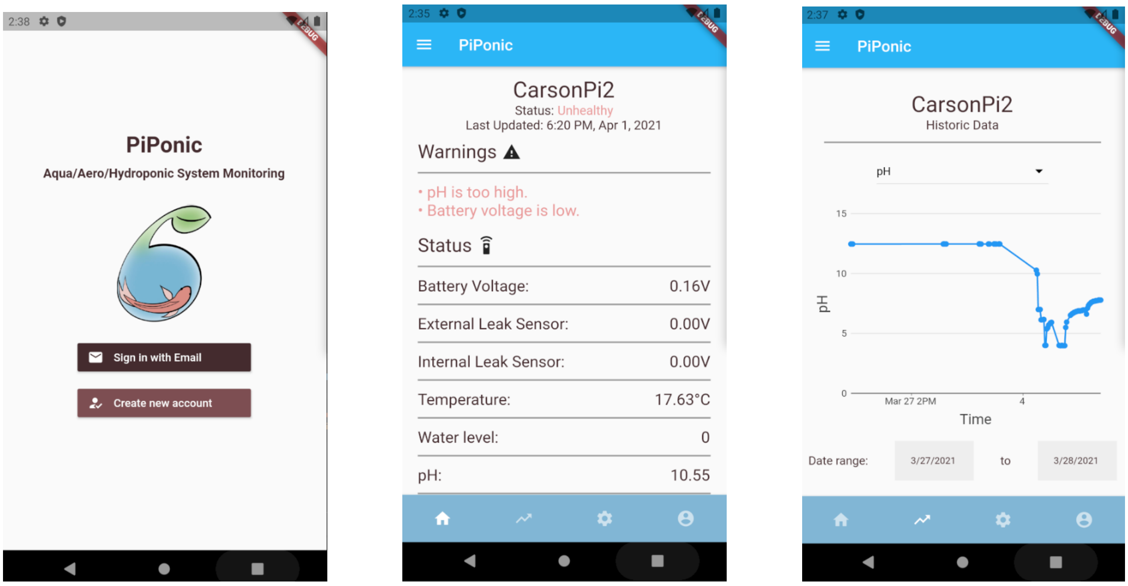

Figure 8: Screenshots demonstrating the software application.

For an overview of all the verification tests performed on the software application, please see the Table 3 below.

Table 3: Software Verification Test Overview.

Test	**Purpose**	**Requirement(s)**	**Result**
ST_1	Software application displays most recent sensor readings stored in the cloud	F_1	PASSED
ST_2	Software application displays charts of previous sensor readings	F_2	PASSED
ST_3	Software application can set normal range of aquaponics or hydroponics system variables	F_3	PASSED
ST_4	Software application recieves notifications if sensor readings are outside of a normal range.	F_3	PASSED
ST_5	Software application can be used to calibrate the pH sensor	F_6	PASSED
ST_6	Software application has an appropriate login system	NF_2	PASSED

In the following subsections, we will describe each software application test in detail.

$\mathbf{ST_1}$: Software application displays most recent sensor readings stored in the cloud

Purpose

To ensure aquaponic and hydroponic growers can monitor most recent updates from their system. Therefore, helps verify requirement F_1.

Procedure

1. View the most recent data stored in the database. To do this, open the Firebase web console for the project.
2. Select the Firestore Database tab.
3. Select the Status collection to display the most recent sensor readings stored in the database.
4. Check that the values displayed on the mobile application status page match the values in the database. If not, test FAILED.
5. Check that the mobile application status page displays all of the values stored in the database. If not, test FAILED.
6. Check that the "Last Updated" timestamp is correctly updated on the app's status page. If not, test FAILED.
7. Check that all systems in the database pass the above three tests. If not, test FAILED.
8. If no failures detected above, test PASSED.

Result

See the following screenshot of the database and the mobile application status page for an example of how this test is conducted. This example demonstrates the test using the system called *CarsonPi2*:

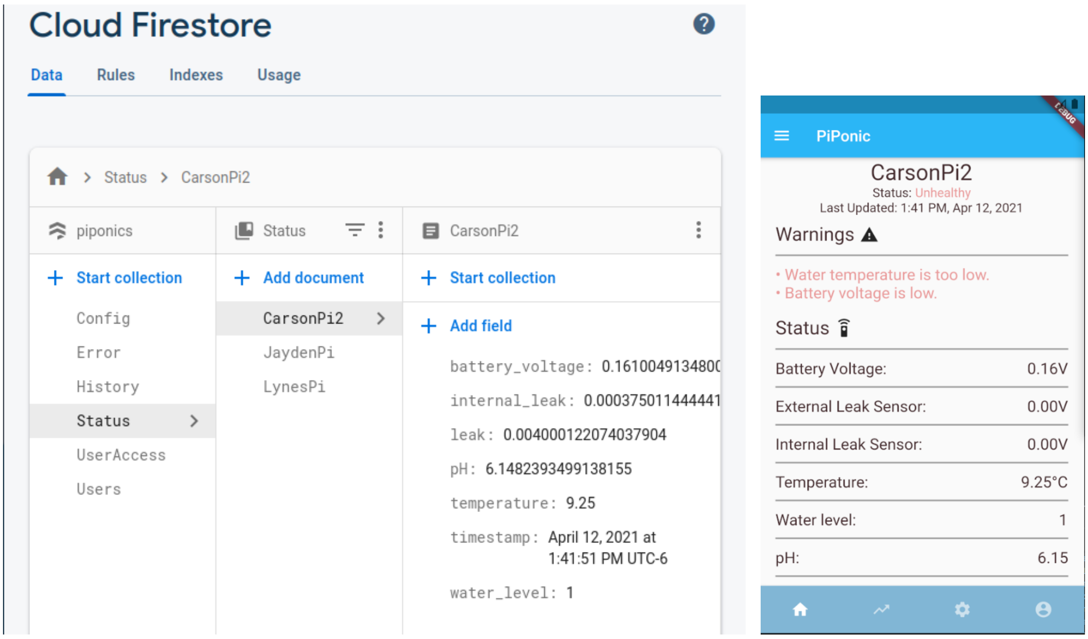

Figure 9: Screenshots taken during test ST_1

These screenshots demonstrate that the test **PASSED**.

ST$_2$: Software application displays charts of previous sensor readings

Purpose

To allow aquaponic and hydroponic growers to analyze system trends over time. Therefore, helps verify requirement F_2.

Procedure

1. Turn the sensing and control system on for 24 hours, allowing the sensor measurements to be recorded.
2. Using the "Status Page" note down the sensor measurements every hour for some 8 hours during that 24 hour period.
3. Open the "Charts Page" on the mobile application by selecting the arrow icon on the bottom panel.
4. For each sensor reading, verify that the sensor values match your recorded values during the 8 hour period. If not, test FAILED.
5. If sensor measurements for each sensor is not displayed for the previous 24 hour period, test FAILED.
6. If no failures detected above, test PASSED.

Result

Below you can see an example of the test running, with the screenshot of the temperature plot in Figure 10. This test also PASSED for all other sensors.

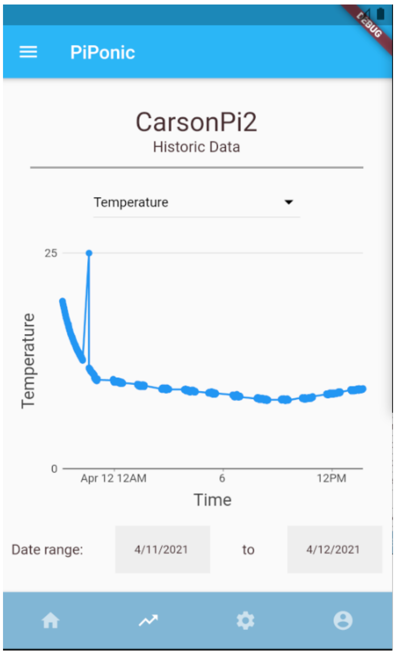

Figure 10: Software application “Charts Page” displaying temperature during test ST_2.

Note that the single spike in temperature was expected as the temperature sensor was temporarily moved to hot water. The final result is that the test **PASSED**.

ST_3: Software application can set normal range of aquaponics or hydroponics system variables

Purpose

This test ensures that users can configure their system's healthy range. This is used to detect when a system may be unhealthy and report that to a grower.

Procedure

1. Open the Firebase web console for the project.
2. Select the Firestore Database tab to see database values.
3. Select the “Config” collection to see system configuration values

4. Select the gear icon on the bottom tab of the mobile application to open system settings.

5. Click on "General Settings" and adjust the sensor measurement interval slider. Click Submit. Ensure that the *update_interval_minutes* field in the database is updated accordingly. Otherwise, test FAILED.

6. Click on pH Settings and adjust the sliders and click submit. Like the point above, ensure the database is updated accordingly. Otherwise, test FAILED.

7. Adjust a slider in the "pH Settings" page, then click cancel. Ensure that slider values return to their previous values. Otherwise, test FAILED.

8. Repeat the two tests above, only for the "Temperature Settings" page.

9. The test PASSED if no failures were detected above.

Result

See the images below for samples of this test, where database values are verified with app configuration settings:

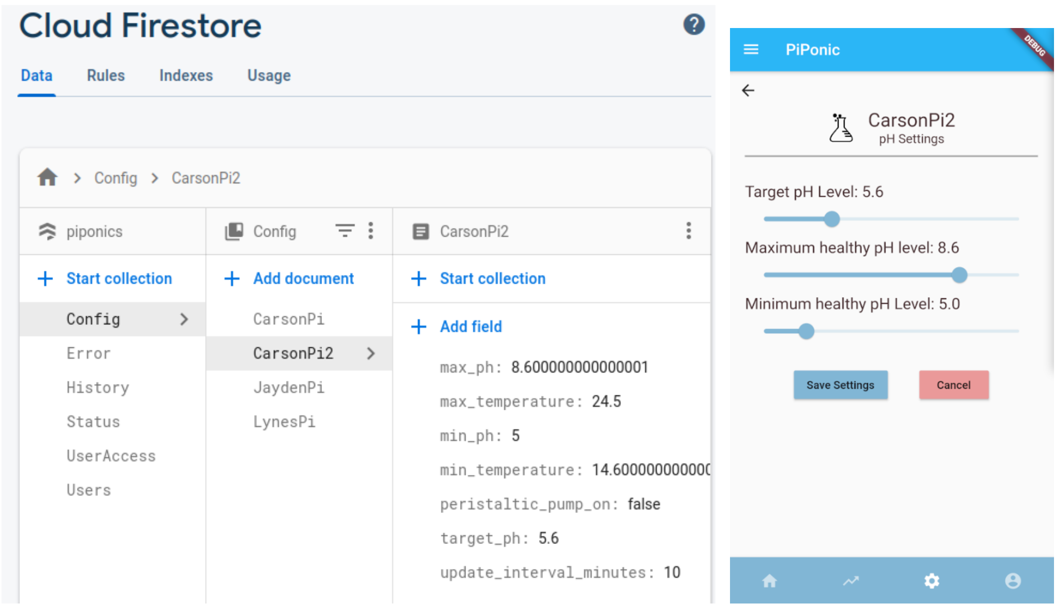

Figure 11: Screenshots taken during test ST_3

When ran, the above test **PASSED**.

ST_4: Software application recieves notifications if sensor readings are outside of a normal range.

Purpose

This test checks whether notifications/alerts are sent to users if sensor measurements from their aqua/hydroponic systems are outside of a normal range. For instance, if the pH is detected to be very acidic (i.e pH = 4), then the user should be alerted with a warning that the pH is too low.

Procedure

1. Spill water on the water leakage sensor. If no push notification recieved by the mobile application, test FAILED.
2. Set the minimum pH to 5. Place the pH probe in pH = 4 solution. If no pH too low notification recieved by the mobile application, test FAILED.
3. Remove backup batteries from the sensing and control system. If no battery low notification recieved by the mobile application, test FAILED.
4. Remove the water level sensor from water. If no water level low notification, test FAILED.
5. Set the minimum water temperature to 10 C. Place the temperature sensor in ice water. If no water temperature low notification, test FAILED.
6. If no failures detected above, test PASSED.

Result

Please see below for a sample image of notifications being received by the mobile application.

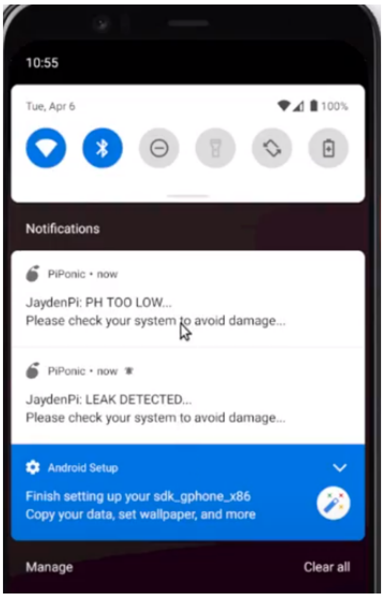

Figure 12: App notification screenshot taken during test ST_4

This test **PASSED** when ran.

ST_5: Software application can be used to calibrate the pH sensor

Purpose

This test verifies that the pH sensor can be calibrated from the mobile application.

Procedure

1. Open the mobile application and select the settings gear icon on the bottom tab
2. Select the pH calibration setting
3. Follow the instructions on the mobile application page.
4. Place the pH probe in a solution with known pH and ensure the value read on the mobile application matches.

Result

Below in Figure 13, you can see the pH calibration page. We used two solutions to calibrate the pH sensor, with pH = 4 and pH = 7.

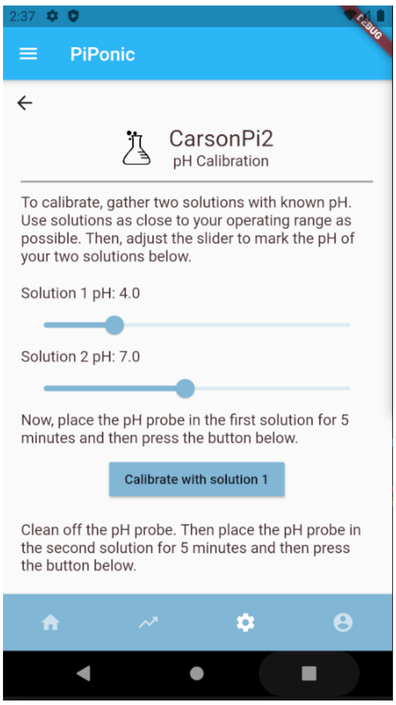

Figure 13: pH calibration page during test ST_5

Afterward, we placed the pH probe in a solution with pH = 7, and found that the pH reading was accurate. Therefore, this test **PASSED**.

ST_6: Software application has an appropriate login system

Purpose

To verify that users can create their own accounts and login in properly.

Procedure

1. Open the mobile application.
2. Try to login using a random email and password. This should not allow you to login. Otherwise, test FAILED.
3. Create a new account using an email and password.
4. Try to login to the system, but misspell your username. If the app crashes, or allows access to your account, test FAILED.
5. Login to the system using your email and password. If you are not able to login to your account using email and password, then test FAILED.
6. Test PASSED if no failures detected above.

Result

Below in Figure 14, you can see the login pages that were tested using the above procedure.

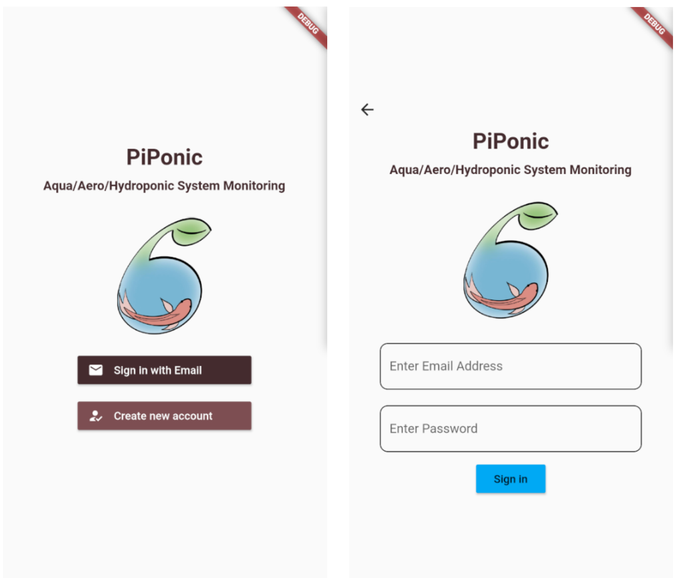

Figure 14: Login pages during test ST_6

All the tests for ST_6 **PASSED**.

3 Validation

This section states validation tests and their corresponding results for our project. The purpose of this section is to ensure that our design meets the needs of our users, who are aquaponics and hydroponic growers.

Our validation tests consist of questions asked to users, who provide feedback about the design. Our design has been used by our client over the past two months at his home hydroponics system. The feedback provided in this section will be from his comments. In future, similar questions can be asked to new users too.

Table 4 below provides an overview of our validation tests and their corresponding results.

Table 4: Validation Test Overview.

Test	**Req(s)**	**Purpose**	**Key User Feedback**
V_1	F_1	Viewing system variables	• Add configurable time periods between sensor measurements for each sensor.
V_1	F_2	Analyzing system variable trends	• Time-averaging data points in sensor measurement charts. This helps the user visualize trends more clearly.
V_3	F_3	Recieving system alerts	• Verify that notifications are recieved by phones even when the app is not running. • pH and water temperature notifications can be changed to daily notifications instead of immediate notifications.
V_4	F_4	Recalibrating sensors	PENDING
V_5	NF_3	Installation and setup procedures	• Create a short video explaining how to install the system
V_6	All	General feedback	• Adjust the pH only if multiple measurements detect that the pH is low

Please note that this section assumes the reader is familar with the design of our project as outlined in the attached *Design* document.

V_1: Viewing system variables

Purpose

System variables like water pH, level, temperature and more must be displayed to growers in a clear manner.

Results

In Table 5, we provided validation questions to help us understand whether our design meets our user's needs. Note that for each question, we asked our client to mention any difficulties he had with our system, or if he had any suggestions for improvements.

Table 5: Questions to validate user experience of viewing system variables.

	Question	User Feedback
Q_1	Were you able to create an account and login?	Yes
Q_2	Were you able to locate all sensor measurements with the app?	Yes
Q_3	Were the sensor measurements easy to interpret and understand?	Yes
Q_4	Were warning messages displayed by the app easy to interpret and understand?	Yes
Q_5	Do you have any recommendations about how we might improve how sensor readings are displayed?	Read interval should be controllable by sensor. Eg: - spill sensor needs updates frequently. Water level sensor may not show low reading for a long time - it only will go low for a short part of the fill/drain cycle.

Analysis

The key recommendation from our client is to add configurable time periods between sensor measurements for each sensor. This allows some sensors (like the water leakage sensor) to be read faster than slower changing variables (like water pH). This improvement can be made in the next iteration of the design.

V_2: Analyzing System Variable Trends

Purpose

The user should be able to effectively analyse trends within their aquaponic/hydroponic system. This means that a user should be able to analyze variables including water pH, level, battery level over time using our design. Currently, this is implemented by showing time charts of the various system variables we monitor.

Results

Please see Table 6 for the questions we asked our client and his feedback about analyzing system trends.

Table 6: Questions to validate user experience when analyzing system trends.

	Question	User Feedback
Q_1	Were you able to locate where to view system trends within the app?	Yes
Q_2	Were you able to view system trends within the timeframe that you like?	Yes
Q_3	Were charts displayed of system variables easy to understand and navigate?	Yes
Q_4	Do you have any recommendations about how we might improve how system trends are displayed?	The graphs are sufficient for short period trends. Looks like data points could be averaged out to improve the looks of the charts.

Analysis

As seen above, one area of improvement is to improve the look of the charts. Currently, many data points can appear clustered together if sensor measurements are taken at a fast rate. See Figure 15 below for an example of this phenomenon.

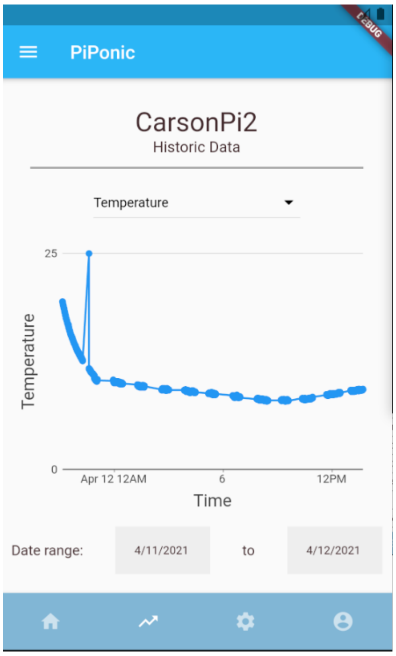

Figure 15: “Charts Page” with clustered temperature readings.

This can be improved as our client suggests by time-averaging data points in the charts.

V_3: Recieving system alerts

Purpose

The user should be able to recieve alerts if there are any issues detected with their aquaponic or hydroponic system. Currently push notifications are send to users phones if there are any issues detected. This section seeks to validate this functionality.

Results

Please see Table 7 for the questions we asked our client and his feedback about recieving system alerts.

Table 7: Questions to validate user experience when recieving system alerts.

	Question	**User Feedback**
Q_1	Were you able to configure your system's normal operating range for water temperature and pH?	Yes
Q_2	Were you able to understand warning and alert messages?	Yes
Q_3	Were you able to recieve a notification if your system was outside of its healthy operating range?	Yes - I am receiving notifications. It may be that I only get notifications when the app is running on my phone?
Q_4	Do you have any recommendations about how we might improve how alerts are sent and displayed?	Some alerts are more important than others. Leak - very important and needs to go out immediately. Water temp - pH level, could be handled as a summary once per day.

Analysis

There are two points of improvement that can be made here, as our client suggests:

1. Verify that notifications are recieved by phones even when the app is not running.
2. pH and water temperature notifications can be changed to daily notifications instead of immediate notifications.

The first point has previously verified in simulation. However, it should be tested with different phones including the client's to detect any issues.

V_4: Recalibrating sensors

Purpose

After reading the user manual, the user must be able to calibrate the each of the sensors to ensure their readings are accurate.

Results

Please see Table 8 for the questions we asked our client and his feedback about recieving system alerts.

Table 8: Questions to validate user experience when recalibrating sensors

	Question	**User Feedback**
Q_1	Were you able to successfully calibrate the pH sensor?	PENDING
Q_2	Are there sensors that you could not calibrate but would like to?	PENDING
Q_3	Was the calibration process clear and easy to follow for all sensors?	It appears okay. I did not go through the steps.
Q_4	Do you have any recommendations about how we might improve how sensors are calibrated?	I like how the pH level calibration is set up.

Analysis

This section needs to be repeated once our client has tested the calibration procedure. However, our client gave positive feedback about the calibration procedure as shown on the app.

V_5: Installation and setup procedures

Purpose

Users need to install our sensing and control system onto their hydroponic or aquaponics system. This section seeks to assess how straightforward it is for users to install our system.

Results

Please see Table 9 for the questions we asked our client and his feedback about recieving system alerts.

Table 9: Questions to validate user experience when recalibrating sensors

	Question	**User Feedback**
Q_1	Was it clear how to install all sensors and control devices onto your hydro/aquaponic system?	I was familiar with it already. Without that familiarity I may need some more instructions.
Q_2	Do you have any recommendations about how we might improve how our system can be installed?	A short instructional video - possibly with URL in form of a barcode.

Analysis

Our client was involved in the testing process throughout the development of our design. Therefore, this test should be repeated for new users.

Nevertheless, the recommendation of creating a short video explaining how to install the system would be helpful and can be done as a future step.

V_6: General feedback

Purpose

This section seeks to gather any other feedback that users may have that is not included in the above sections.

Results

Please see Table 10 for the questions we asked our client and his feedback about recieving system alerts.

Table 10: General user experience questions.

	Question	**User Feedback**
Q_1	Do you have any recommendations about how we might improve how our system in general?	I notice that the pump is coming on as soon as the pH level registers low. I would make adjustments slowly - when reading goes low, start a counter. Only if reading is confirmed by several readings, make an adjustment. Once adjustment is made, wait the same interval to make further adjustment. This process should override the apps interval settings for the pH sensor.

Analysis

The key piece of feedback here is to adjust the pH only if multiple measurements detect that the pH is low. This could improve the reliability of our control system despite fluctuating pH levels.