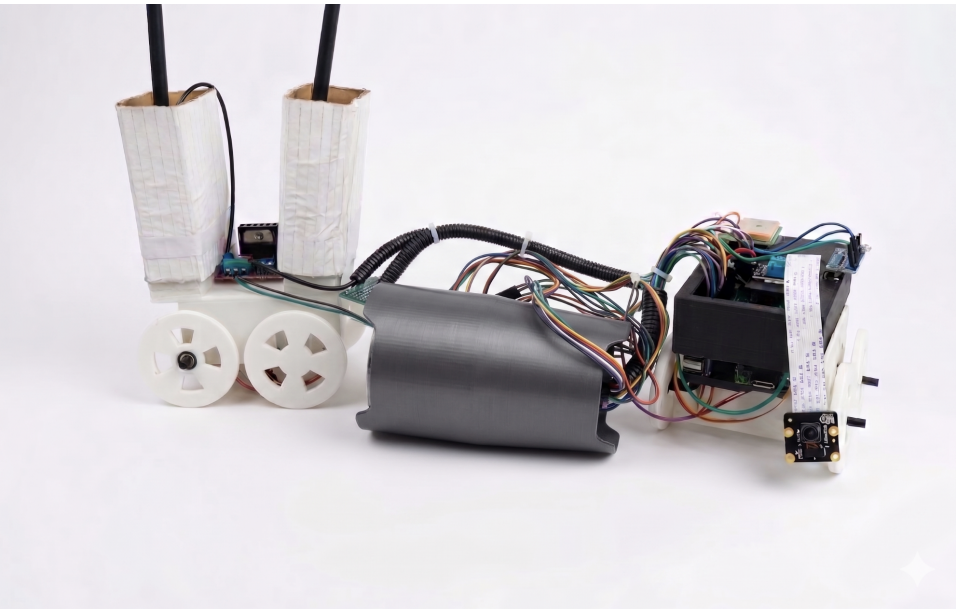
SPHAS

Smart Plant Health Analysis System

Final User Documentation



Project	SPHAS — Smart Plant Health Analysis System
Course	CSE 396 Computer Engineering Project
University	Gebze Technical University
Group	Group 1
Audience	End users with no technical background
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Contents

Project Team and Module Responsibilities

This document was produced by Group 1 of the CSE 396 Computer Engineering Project course at Gebze Technical University. The SPHAS system was designed and implemented as a joint effort, with each of the four system modules led by a dedicated pair of students. The table below summarises module ownership and cross-module support roles.

Module ID	Module	Description	Primary Students	Secondary Students
MOD-01	**M1: Sensor HAL**	Sensor integration, camera frame capture, and PWM-based pump control.	Ömer Faruk Demir Halil İbrahim Turan	Sümeyye Dalga Kerim Alp Özkan
MOD-02	**M2: AI Engine**	Lightweight CNN inference for plant species identification and disease detection.	Sümeyye Dalga Muhammed Korkmaz	Emre Kaan Şahin Umut Başaran
MOD-03	**M3: Data & Actuator**	Database management, threshold evaluation, and autonomous actuator decisions.	Umut Başaran Muhammed Emir Sivri	Halil İbrahim Turan Muhammed Korkmaz
MOD-04	**M4: Web Dashboard**	User interface, REST API visualisation, 3D digital twin, and manual controls.	Emre Kaan Şahin Kerim Alp Özkan	Ömer Faruk Demir Muhammed Emir Sivri

Note: Primary students were the main developers and reviewers of the assigned module. Secondary students provided cross-module integration support, testing, and code review. All team members contributed to system integration and the final demonstration.

1 Introduction

SPHAS (Smart Plant Health Analysis System) is a complete, integrated plant-care assistant built on a Raspberry Pi platform. It combines environmental sensing, camera-based AI plant-health diagnosis, autonomous irrigation and fertilisation control, and a real-time web dashboard — all in a single, cohesive system.

The system is designed for indoor and semi-outdoor potted plants. It continuously monitors the plant environment, triggers a camera analysis on demand, and helps the user take the right care action at the right time. No technical background is required to use the dashboard.

What SPHAS does

- Reads temperature, humidity, soil moisture, and light level from dedicated sensors every second and displays the values live on the dashboard.
- Streams a live camera feed from the Raspberry Pi camera module. A single button press triggers the AI to capture and analyse a fresh plant image.
- Uses two separate INT8-quantised TensorFlow Lite (TFLite) neural network models — one for plant **species recognition** (14 plant types) and one for **disease detection** (38 disease classes) — to produce a health result with a confidence score.
- When the AI confidence is below 60%, a GrabCut segmentation algorithm is applied automatically to isolate the leaf from the background and improve accuracy.
- Applies a rule-based **Decision Engine** that evaluates every incoming sensor reading and AI result. The engine can autonomously trigger the water pump or the fertiliser pump, generate alerts, and defer watering if rain is forecast.
- Integrates **OpenWeatherMap** to check current and 3-hour rain forecasts before any autonomous watering decision, preventing unnecessary irrigation.
- When a disease is detected, the system looks up a built-in treatment database covering more than 20 disease classes and displays the recommended product, active ingredient, dosage, and application method directly on the dashboard.
- Displays a **3D Digital Twin** — a three-dimensional visual model of the plant and device — so the user can see the device state at a glance.
- Supports **up to 16 devices** simultaneously; each device is monitored independently with a 5-second polling cycle over WebSocket.
- Allows the user to **export all recorded sensor data** as a CSV file at any time for personal records or project review.
- Provides **manual override buttons** for watering, fertilising, and mechanical tilt adjustment when the user prefers to act directly.

Who this document is for

This document is written for end users who interact with SPHAS through the web dashboard and who set up or maintain the physical device. No programming or electronics knowledge is required to follow the instructions in this document.

Important user note

> **Warning:** SPHAS is an assistance system. It helps you monitor plants and make better care decisions, but it should not be used as a substitute for professional agricultural diagnosis. If a plant is seriously damaged or of high value, verify the recommendation with a plant-care expert.

2 System Overview

How SPHAS works — high-level flow

The system is built from four loosely coupled modules that communicate with each other through well-defined interfaces. From the user's perspective, the flow is:

1. The **hardware layer (M1)** continuously reads all sensors and streams camera frames. It sends sensor readings to the backend every second.
2. The **AI engine (M2)** waits for a camera trigger. When the user presses **Capture** on the dashboard, the camera takes a photo and the AI analyses it within a few seconds.
3. The **backend (M3)** receives sensor data and AI results, stores them in a local database, evaluates decision rules, and serves a REST API.
4. The **web dashboard (M4)** polls the backend every 5 seconds, pushes live updates to the browser over WebSocket, and lets the user send commands back to the hardware.

Supported plant species

The AI models were trained on the PlantVillage dataset and recognise the following 14 plant species:

Apple	**Blueberry**	**Cherry**
Corn	**Grape**	**Orange**
Peach	**Pepper**	**Potato**
Raspberry	**Soybean**	**Squash**
Strawberry	**Tomato**	

> **Note:** If your plant is not in this list, the system will still report the closest match and a confidence percentage. A low confidence value (below 40%) is a signal that the species may not be recognised correctly. In that case, use the analysis results as a general guide only.

Detectable disease classes

The disease model can identify 38 disease classes across these species, covering conditions such as bacterial spot, early and late blight, powdery mildew, black rot, mosaic virus, spider mites, leaf mold, and more. Healthy leaves are also detected and labelled as **Healthy**.

3 Package Contents and Hardware Parts

The standard SPHAS package includes the following components. The exact parts may vary depending on the prototype or final production version provided by the project team.

Item	Purpose	User action required
SPHAS main device (Raspberry Pi unit)	Runs all software modules and connects all hardware.	Place near the plant on a stable, dry surface.
Raspberry Pi camera module	Captures plant images for AI health analysis.	Position it so one or more leaves are clearly visible.

Item	Purpose	User action required
DHT11 temperature and humidity sensor	Measures the air temperature and humidity around the plant.	Keep it exposed to open air; do not cover or seal it.
ADS1115 ADC board	Converts analogue signals from the soil and light sensors to digital values.	Internal component; no direct user action needed.
Soil moisture probe	Measures how wet or dry the soil is.	Insert gently into the soil near the root zone.
Light sensor (LDR, two channels)	Measures the ambient light level around the plant.	Do not cover or shade the sensor.
NEO-6M GPS module	Provides the location of the device for weather integration.	Internal component; no user action normally needed.
MG90S servo motor	Controls the automatic insertion and retraction of the soil probe.	Ensure the servo arm has free movement; do not block it.
28BYJ-48 stepper motor(s)	Adjusts the tilt angle of the device mechanism.	Use the Rotate/Tilt buttons on the dashboard to adjust.
Peristaltic water pump and tube	Dispenses water when triggered by the system or manually.	Place the outlet tube on the soil. Keep the intake tube in clean water.
Peristaltic fertiliser pump and tube	Dispenses liquid fertiliser when triggered.	Use only suitable liquid fertiliser.
Power adapter / approved power source	Powers the entire SPHAS device.	Connect to a stable mains outlet; use the correct adapter.
Dashboard access address	The local network address used to open the control panel.	Open from any browser on the same network as the device.

4 Hardware Setup — Step by Step

Follow the steps below in order. **Do not connect power until all sensors and tubes are placed safely.**

Step 1 — Choose a safe placement location

- Place the plant and the SPHAS device on a stable, dry, flat surface.
- Keep the device away from direct water splash or high humidity.
- Make sure the pump tubes can reach the plant pot without bending sharply.
- Ensure the camera area is clear and the plant leaves are unobstructed.
- Keep at least 20 cm of space around the device for airflow and access.

Step 2 — Insert the soil moisture probe

1. Choose a spot near the plant root zone, away from the pot wall.
2. Insert the probe gently into the soil until the metal sensing area is fully covered.
3. Do not force the probe through hard or dry soil; loosen the soil first if needed.

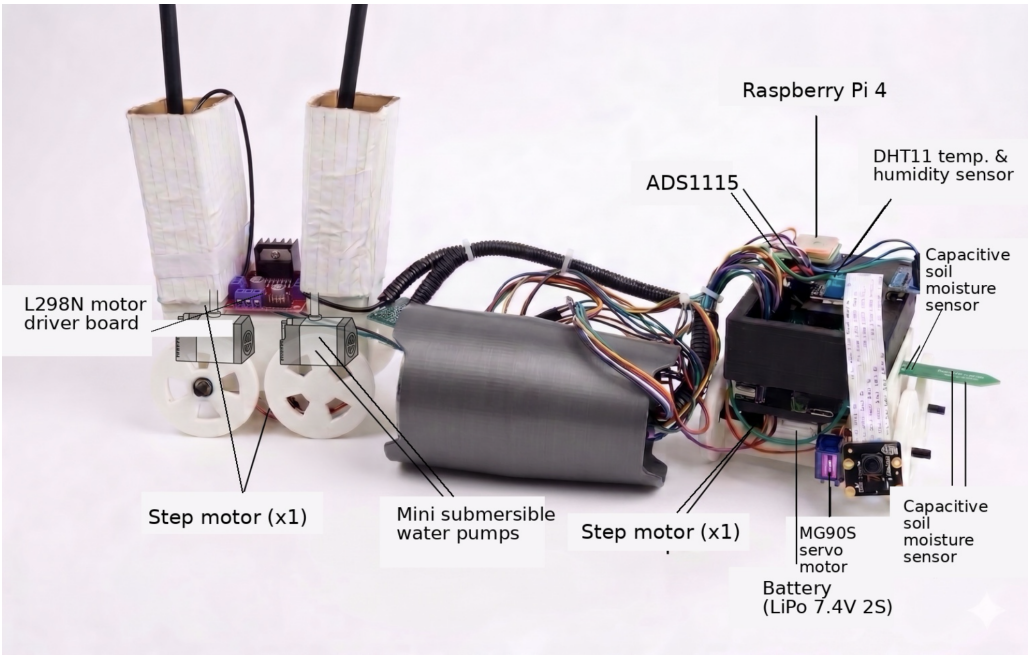


Figure 1: Figure 1 — Prototype wiring reference diagram.

4. Ensure the cable is not pulled tight or pressed under the pot.
5. Leave enough slack in the cable so the servo can retract and re-insert the probe automatically during a soil-dip sequence.

> **Tip:** The system includes a **servo-driven soil dip** function. When the Soil Dip button is pressed on the dashboard, the servo automatically lowers and raises the probe. Ensure the servo arm has room to move before using this feature.

Step 3 — Position the camera

6. Point the camera toward the leaves.
7. Avoid placing a bright light source directly behind the plant, as strong backlight reduces analysis accuracy.
8. Aim to have at least one full leaf visible and, if possible, both a healthy-looking area and any suspicious area in the same frame.
9. Use the dashboard camera preview to adjust the angle after connecting power.

Step 4 — Prepare the water and fertiliser pump tubes

10. Place the **water outlet tube** on the soil surface, close to the plant base but not directly on the stem.
11. Place the **water intake tube** into a container of clean water.
12. If fertilising is enabled, place the **fertiliser outlet tube** on the soil and the **fertiliser intake tube** in a container of suitable liquid fertiliser.
13. Check that no tube end can fall out or become blocked during operation.
14. Keep the water and fertiliser containers lower than the device, or on the same level, to help the pump prime correctly.

> **Caution:** Do not run either pump without the intake tube submerged in liquid. Running a dry pump can damage it. The maximum single-dose volume is **200 mL** per pump command, enforced by the system.

Step 5 — Connect power and wait for startup

15. Connect the approved power adapter to the SPHAS device.
16. Wait approximately **one minute** for the system to start all modules.
17. Open the dashboard in a browser (see Section 5). When the device appears in the Devices list and the status shows **Connected**, the system is ready.
18. If the device does not appear after two minutes, check the power connection and make sure the browser and device are on the same local network.

Step 6 — Network connection

The SPHAS dashboard runs on the local network. To access it:

- Open a browser on a phone, tablet, or computer connected to the **same Wi-Fi or wired network** as the SPHAS device.
- Enter the dashboard address provided by the project team. In a prototype setup this is typically a local IP address (for example `http://192.168.x.x:3000`) or a local hostname.
- The dashboard does not require an internet connection to function. Internet is used only for the optional weather integration feature.

5 Web Dashboard — Overview and Navigation

The SPHAS web dashboard is the main user interface. It brings together all system information and controls in one page. No installation is required; the dashboard runs directly in any modern web browser.

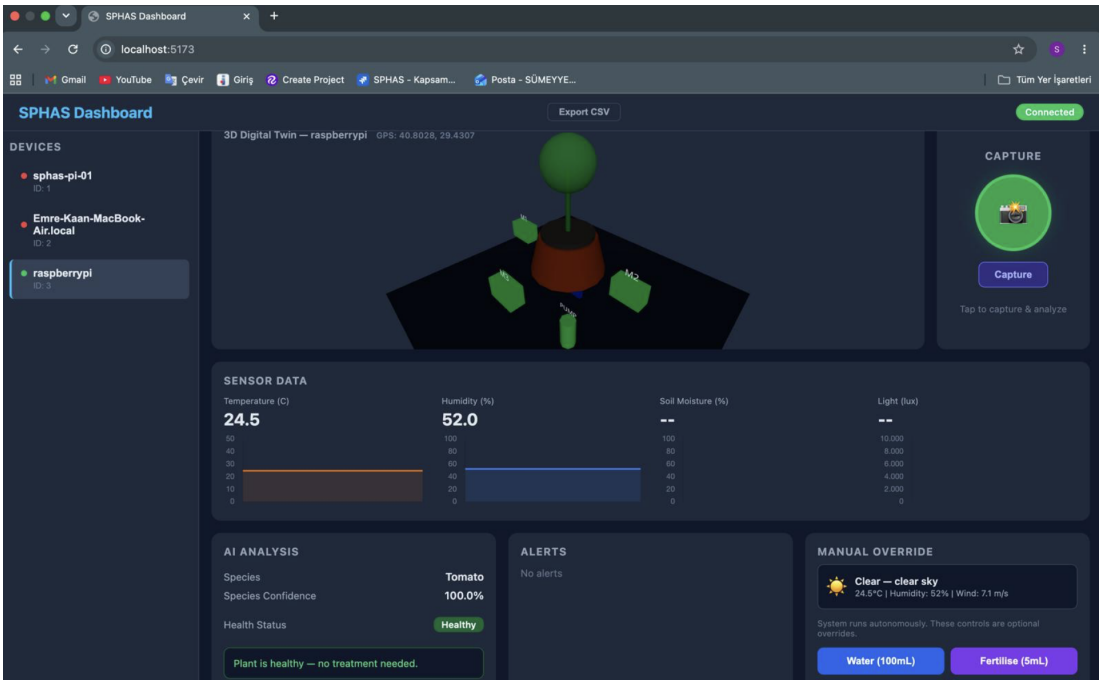


Figure 2: Figure 2 — SPHAS dashboard with device list, live camera, sensor readings, AI analysis panel, alerts, manual override controls, and threshold settings.

5.1 Opening the dashboard

1. Open a web browser (Chrome, Edge, Firefox, or Safari recommended).

2. Enter the dashboard address provided with the device or demo setup.
3. Wait for the page to load. The connection status indicator appears at the top.
4. Select your device from the **Devices** panel on the left side.

5.2 Dashboard layout — area by area

Dashboard area	What the user sees	What it is used for
Devices panel	A list of all registered SPHAS devices with names and status icons.	Choose which device to monitor and control. Supports up to 16 devices.
Connection status	Connected, Offline, or Warning label at the top of the page.	Quickly confirm whether the selected device is reachable.
3D Digital Twin	An interactive three-dimensional model of the plant and the SPHAS device.	Understand the current device orientation and plant state at a glance.
Live Camera	A camera preview area with **Start** and **Capture** buttons.	View the plant through the device camera; trigger a new AI analysis image.
Sensor Data	Numeric tiles showing temperature (°C), humidity (%), soil moisture (%), and light level (lux) with live-updating values and small trend graphs.	Monitor the plant environment continuously.
Weather	Current weather condition, temperature, and rain forecast icon from the device's GPS location.	Understand why the system may have deferred an automatic watering event.
AI Analysis	Plant species name, health status (Healthy / Disease name), confidence percentages for species and disease, and a treatment recommendation panel when a disease is detected.	Understand the AI result and any recommended treatment.
Treatment Recommendation	Product name, active ingredient, dosage, application method, and severity level — shown automatically when a disease is detected.	Know what action to take when a disease is found.
Alerts	A list of the five most recent system alerts with messages and severity levels.	See what currently needs attention.
Manual Override	Buttons for Water, Fertilise, Rotate (Tilt Up / Down), and Soil Dip.	Operate the device manually when needed, overriding the automatic schedule.

Dashboard area	What the user sees	What it is used for
Threshold Settings	Editable fields for soil moisture minimum (%), temperature min/max (°C), light minimum (lux), fertilisation interval (days), and pump volumes (mL).	Customise the care profile for the selected plant species.
Data History / Export	A button to download all recorded sensor data as a CSV file.	Keep a personal record or export data for project review.

5.3 Main buttons and their functions

Button / Control	What it does	When to use it
Start (camera)	Starts the live camera preview stream from the device.	Use when you want to see the plant through the camera.
Capture	Takes a new still image and sends it to the AI for analysis. Triggers species identification and disease detection.	Use whenever you want a fresh health check of the plant.
Water	Sends an immediate watering command to the pump (manual override). The default volume is 100 mL; this can be changed in Threshold Settings.	Use when you want to water the plant directly regardless of sensor values.
Fertilise	Sends an immediate fertilisation command (default 5 mL).	Use with caution and only with the correct liquid fertiliser loaded.
Tilt Up / Tilt Down	Commands the stepper motor to adjust the device tilt angle.	Use to reposition the camera or probe angle as needed.
Soil Dip	Commands the servo to lower the soil probe into the soil and then raise it again.	Use to take a fresh soil moisture measurement if the probe was raised.
Save (thresholds)	Saves the edited threshold values for the selected species.	Use after editing any care-profile values to apply the changes.
Export CSV	Downloads all stored sensor history as a comma-separated values file.	Use for reports, long-term tracking, or project submissions.

6 Autonomous Features and Decision Logic

SPHAS can act autonomously without the user pressing any button. This section explains when and why the system takes automatic actions.

6.1 Automatic watering

The Decision Engine evaluates soil moisture continuously. If the soil moisture percentage falls below the configured minimum threshold for the detected plant species, the system will:

1. Check the **pump lockout timer**. If the water pump has been activated in the last **6 hours** (by the system or manually), the pump will not run again during that period. This prevents over-watering.
2. Check the **weather forecast**. If it is currently raining or if rain is expected within the next 3 hours at the device's GPS location (using OpenWeatherMap data), watering is deferred. An alert is generated to inform the user.
3. If neither condition blocks the action, the **water pump is activated** automatically for the configured volume. An alert is generated and displayed on the dashboard.

> **Note:** The default minimum soil moisture threshold is **30%**. This can be changed per species in the Threshold Settings panel. The maximum single watering volume is **200 mL**, enforced by the hardware layer.

6.2 Automatic fertilisation

Fertilisation is time-based, not moisture-based. When the configured fertilisation interval (default: **14 days**) has elapsed since the last fertilisation event, and the 6-hour lockout is not active, the fertiliser pump runs automatically for the configured volume (default: **5 mL**).

6.3 Alert types

The system generates alerts automatically for the following conditions:

Alert type	Trigger condition	Recommended user action
Low Moisture	Soil moisture has dropped below the configured minimum. Watering may have been triggered automatically.	Check the water container. Confirm that the pump tube outlet is on the soil.
High Temperature	Air temperature has exceeded the species maximum threshold.	Move the plant to a cooler location or improve ventilation.
Low Light	Light level has fallen below the species minimum threshold.	Move the plant to a brighter location or add supplemental lighting.
Fertilise Due	The fertilisation interval has elapsed and fertiliser has been dispensed.	Confirm that the fertiliser tube is correctly placed.
Disease Detected	The AI model found a possible disease on the leaf image.	Read the treatment recommendation panel. Take a clearer photo to confirm.
Sensor Fail	M1 has flagged a sensor reading as invalid (read error or connection issue).	Check sensor connections and placement. Restart the device if needed.

Alert type	Trigger condition	Recommended user action
Module Offline	The M1 (hardware) or M2 (AI) module has not sent a heartbeat for more than the expected interval.	Restart the device. Check the system power supply.

6.4 Treatment recommendations

When the AI detects a disease, the system automatically looks up the disease in a built-in treatment database and shows the recommended treatment on the dashboard. The database covers over 20 disease classes. The recommendation includes:

- **Treatment type** — fungicide, bactericide, insecticide, or fertiliser.
- **Product name** — a specific, commercially available product.
- **Active ingredient** — the chemical or biological agent in the product.
- **Dosage** — concentration in grams or millilitres per litre of water.
- **Application method** — how and where to apply (e.g., foliar spray, soil drench).
- **Frequency** — how often to repeat the treatment.
- **Severity level** — low, medium, or high urgency.
- **Additional notes** — special precautions or cultural practices.

> **Warning:** Treatment recommendations in SPHAS are based on general agricultural guidance and the PlantVillage dataset. Always read the product label before applying any chemical treatment. Some products may not be available in all countries. Consult a local agronomist or plant-care expert for professional advice.

7 Threshold Settings — Care Profiles

Each plant species can have its own care profile stored in the system. The thresholds control when automatic actions are taken and what volumes are used.

Setting	Default value	What it controls
Soil moisture minimum (%)	30%	If soil moisture drops below this, the system considers watering.
Temperature minimum (°C)	10 °C	Informational lower bound. An alert may be generated below this value.
Temperature maximum (°C)	35 °C	If temperature exceeds this, a High Temperature alert is generated.
Light minimum (lux)	500 lux	If light falls below this, a Low Light alert is generated.
Fertilisation interval (days)	14 days	How often the fertiliser pump runs automatically.
Water volume (mL)	100 mL	Volume delivered per automatic or manual watering event. Max 200 mL.

Setting	Default value	What it controls
Fertiliser volume (mL)	5 mL	Volume delivered per automatic or manual fertilisation event. Max 200 mL.

How to change threshold settings

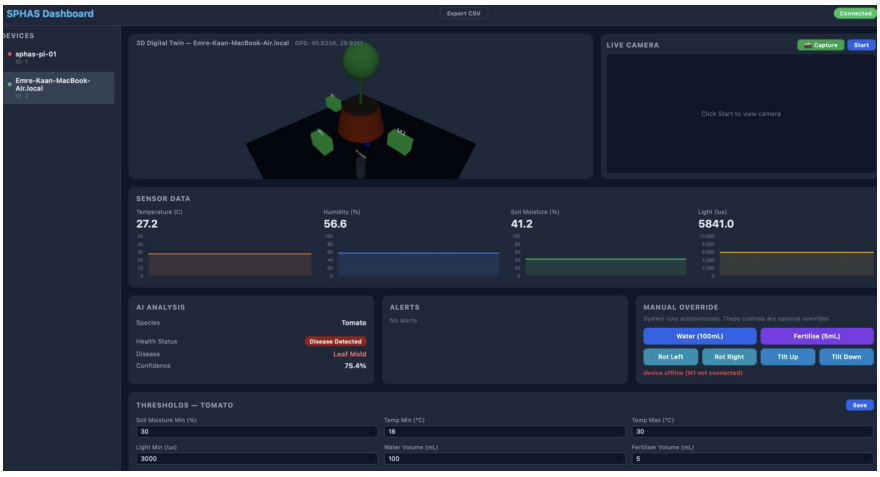
1. Select the device in the Devices panel.
2. Scroll to the **Threshold Settings** section of the dashboard.
3. Edit the field you want to change.
4. Press **Save**. The new values take effect immediately for the next decision cycle.

> **Tip:** Different plant species have different ideal care ranges. For example, tomatoes may need more frequent watering than strawberries. Adjust the thresholds when you change the plant species or when seasonal conditions change.

8 Daily Usage Scenarios

Scenario 1 — Morning plant health check

1. Open the SPHAS dashboard in your browser.
2. Select the device from the Devices panel.
3. Confirm the connection status shows **Connected**.
4. Read the Sensor Data tiles: soil moisture, temperature, humidity, and light.
5. Check the **AI Analysis** panel for the current health status. If the status shows a disease name, read the Treatment Recommendation panel below it.
6. Check the **Alerts** panel. If any alerts are listed, read the message carefully before pressing any manual control.
7. If the weather panel shows rain, note that the system may have skipped an automatic watering cycle. This is expected behaviour.



Scenario 2 — Requesting a new plant image for analysis

8. Open the dashboard and select the device.
9. Press **Start** in the Live Camera area to begin the video preview.

10. Check that the leaves are visible. If not, adjust the camera or move the plant slightly so leaves are in frame.
11. Press **Capture**. The system takes a still image and sends it to the AI engine.
12. Wait approximately 5 seconds for the result to appear in the AI Analysis panel.
13. Review the species result, disease result, confidence scores, and any treatment recommendation that appears.

> **Note:** If the AI confidence for species or disease is below 40%, try taking another image in better lighting conditions or move the camera closer to the leaves. The system automatically applies GrabCut segmentation when confidence is below 60% to try to improve the result.

Scenario 3 — Manual watering

14. Check the soil moisture value in Sensor Data first.
15. Read any active alerts. If the system says watering is not needed, consider whether you have a specific reason to water manually.
16. Confirm the water intake tube is submerged in water and the outlet tube is on the soil.
17. Press **Water** in the Manual Override section.
18. Observe the plant pot for a few seconds to confirm water is delivered correctly.
19. Do not press Water again immediately. The 6-hour pump lockout prevents the system from automatically over-watering, but manual overrides bypass this lockout entirely. Monitor the water volume delivered carefully when pressing the button multiple times.

> **Warning:** The maximum volume per watering command is **200 mL**. Do not attempt to override this limit. Over-watering can damage plant roots.

Scenario 4 — Adjusting the device tilt or soil probe

19. If the camera angle is not ideal, press **Tilt Up** or **Tilt Down** in the Manual Override section. The stepper motor will adjust the mechanism angle incrementally (each press rotates the motor 15 degrees).
20. If you want to manually trigger a soil moisture reading with the probe retracted, press **Soil Dip**. The servo will automatically lower the probe, wait three seconds, and raise it again. The new reading will appear in the Sensor Data panel within a few seconds.

Scenario 5 — Exporting plant data

21. Open the dashboard and select the device you want to export data from.
22. Press **Export CSV**. The browser will download a file named `sphas_export.csv`.
23. Open the file in a spreadsheet application (such as Microsoft Excel, Google Sheets, or LibreOffice Calc).
24. The file contains columns for timestamp, temperature, humidity, soil moisture, light level, and GPS coordinates.
25. Review the data for long-term trends or use it for project reports.

Scenario 6 — Adding or switching a device

26. When a new SPHAS device starts, it registers itself with the dashboard backend automatically. It will appear in the Devices panel within a few seconds.
27. To monitor a different device, select it from the Devices panel. The dashboard updates all panels to show the data for the newly selected device.
28. If a device shows as Offline, check the device power and network connection. The system marks a device as offline after **60 seconds** without a response.

9 Status Indicators and Alert Meanings

9.1 Connection and device status

Indicator	State shown	Meaning	What to do
Connection status	**Connected**	The device is reachable and sending data.	No action needed.
Connection status	**Offline**	The device has not responded for more than 60 seconds.	Check power, network, and cables. Refresh the dashboard.
Connection status	**Warning**	One or more sensors reported an invalid reading.	Check sensor connections.
Device list icon	Green dot	Device is online and healthy.	No action needed.
Device list icon	Red dot	Device is offline.	Check the device and network.
Device list icon	Yellow dot	Device is online but has sensor warnings.	Check sensor readings and placement.

9.2 Hardware status indicators

Hardware indicator	State	Meaning	What to do
Power LED	Solid green	Device has power.	No action needed.
Power LED	Off	Device has no power.	Check the adapter, cable, and outlet.
Network LED	Solid blue or Connected label	Device is connected to the local network.	No action needed.
Network LED	Blinking / Offline label	Device is starting up or network is not ready.	Wait one minute, then refresh.
Sensor warning	Yellow indicator on dashboard	A sensor value is missing or flagged invalid.	Check sensor placement and connections.
Alert indicator	Red warning on dashboard	The plant needs attention or a disease has been detected.	Open the Alerts panel and read the message.
Pump active	Active indicator on dashboard	A pump is currently running.	Watch the tube outlet and do not move the device.

9.3 Common dashboard messages

Message or problem	Possible reason	Solution
Device offline	Device is not reachable or has not responded for 60 seconds.	Check power. Confirm browser and device are on the same network. Refresh.
Camera does not start	Camera module busy, disconnected, or stream not ready.	Wait a few seconds, press Start again. Check the camera cable.
No sensor data	The hardware layer is not sending readings.	Check sensor placement and restart the device if values do not return.
Soil moisture always very low	Probe not inserted correctly or soil is extremely dry.	Re-insert the probe and check the soil manually. Use the Soil Dip button.
Soil moisture always very high	Probe tip is too wet, too deep, or touching the water container.	Remove, dry gently, and reinsert at the correct depth.
Disease detected	AI found a possible disease pattern in the image.	Read the treatment recommendation. Take a clearer photo to confirm.
Watering skipped — rain forecast	OpenWeatherMap shows current or upcoming rain at the device GPS location.	Expected behaviour. No action needed unless you want to water manually.
Manual control disabled	Device is offline or a lockout is active.	Wait for Connected status to appear, then try again.
Export failed	Browser blocked the download or no data is in the database yet.	Allow downloads in browser settings and try again. Ensure the device has been running long enough to record data.
Low confidence result	Image quality was poor, lighting was bad, or the species is not in the trained set.	Take a new image in better lighting. Move the camera closer to the leaves.
Species not recognised	The plant type is not among the 14 supported species.	The system will report the closest match. Use results as a general guide.

10 Frequently Asked Questions

Can SPHAS water my plant automatically without my involvement?
Yes. When the soil moisture drops below the configured minimum threshold and neither the 6-hour pump lockout nor the rain-skip condition is active, the water pump runs automatically. You should still check the water container level and tube placement regularly.

How does the weather integration work?
The system uses the GPS module to obtain the device's location coordinates. These coordinates are sent to OpenWeatherMap to fetch the current weather and a 3-hour rain forecast.

If rain is currently falling or is predicted within the next 3 hours, the autonomous watering decision is deferred and an alert is shown. Internet access is required for this feature.

What happens if there is no internet connection?
The system continues to work normally for all local functions: sensor monitoring, AI analysis, autonomous watering (without the weather check), and the dashboard. Only the weather integration feature is unavailable without internet.

Can I use any fertiliser with the fertiliser pump?
Use only **liquid fertiliser** that is suitable for the plant species and safe for small peristaltic pump systems. Do not use thick, viscous, solid, crystallised, or highly concentrated liquids that may block or damage the tube and pump head.

Does a "disease detected" result mean the plant is definitely diseased?
No. The result is a probability-based prediction from a machine-learning model. Poor lighting, a blurry image, an unusual leaf angle, or a species not in the training data can reduce accuracy. If the result seems wrong, press Capture again with the plant in better lighting. A higher confidence score indicates a more reliable result.

What does the confidence percentage mean?
Confidence is how certain the AI model is about its result, expressed as a percentage. 100% confidence means the model is fully certain (which rarely happens). Values below 40% indicate a low-reliability result. The system applies GrabCut segmentation automatically when confidence is below 60% to try to improve it.

Why did the system skip watering even though soil moisture is low?
The most common reasons are: (1) the 6-hour pump lockout is active from a recent watering event, or (2) the weather service reported current rain or a rain forecast. Both conditions are shown as alert messages on the dashboard.

What is the 3D Digital Twin?
The 3D Digital Twin is a real-time three-dimensional visualisation of the SPHAS device and the plant, rendered using React Three Fiber (WebGL). It updates to reflect the current device state. It is a visual aid to help users understand the device orientation and plant status without reading raw numbers.

Can I monitor more than one plant or device at the same time?
Yes. The dashboard supports up to 16 registered devices simultaneously. Select any registered device from the Devices panel to see its data. Each device runs independently.

Can I use the system outdoors?
The project scope is **indoor and semi-outdoor potted plants**. Keep the electronics protected from direct rain, water spray, and extreme temperatures. The IP rating of the prototype is not certified for outdoor weatherproofing.

What should I do if the water pump runs but no water comes out?
Check whether: (1) the water container is empty, (2) the intake tube has fallen out of the container, (3) a tube is bent sharply, or (4) the outlet tube is blocked. Also confirm that the intake tube end is below the water surface so the pump can prime correctly.

How do I know the stepper motor has moved?
After pressing Tilt Up or Tilt Down, you should see (or hear) the motor move. The 3D Digital Twin model also updates its tilt angle. Each press rotates the stepper approximately 15 degrees.

11 Safety, Care, and Maintenance

Electrical safety

- Use only the approved power adapter or power source supplied or specified for the device.
- Do not open the device enclosure while it is powered.
- Keep all liquid containers lower than or safely separated from the electronics enclosure wherever possible.
- Disconnect power before moving the device or repositioning any tube or sensor.
- Do not use the device if any cable is damaged, frayed, or has exposed wiring.
- In case of any liquid spill near the electronics, disconnect power immediately and allow the unit to dry fully before reconnecting.

Water and fertiliser safety

- Use clean, fresh water for watering. Avoid water with high mineral content (very hard water) as it may leave deposits in the pump tubes over time.
- Do not run either pump without the intake tube correctly placed in the liquid container. Dry running can damage the pump.
- Clean tube ends regularly (weekly if possible) to prevent algae or mineral build-up.
- Do not use aggressive chemicals, herbicides, or unfiltered pond water in the pump system.
- If fertiliser spills occur, clean the spilled material immediately and keep it away from electronic components.

Camera and sensor care

- Wipe the camera lens gently with a soft, dry cloth if dust or moisture accumulates. Do not use solvents.
- Avoid exposing the soil moisture probe tip to very acidic or alkaline solutions, as this may damage the sensing surface over time.
- Do not bend or kink the sensor cables sharply.

Regular maintenance checklist

Frequency	Task	Why it matters
Daily	Open the dashboard and check all Sensor Data values and Alerts.	Early warnings are useful only if reviewed promptly.
Daily	Check the water container level.	The pump cannot water if the container is empty.
Every 2–3 days	Visually confirm that the plant leaves are visible in the camera preview.	Leaves may have grown or shifted; reposition if needed.

Frequency	Task	Why it matters
Weekly	Check tube outlet and intake positions.	Loose tubes may water outside the pot or draw from an empty container.
Weekly	Wipe the camera lens gently with a soft, dry cloth.	Dust and droplets reduce image quality and AI accuracy.
Weekly	Check the soil moisture probe position and re-insert if it has shifted.	Incorrect placement causes unreliable moisture readings.
Monthly	Review and adjust threshold settings for the current season or plant age.	Plant water needs change with growth stage and ambient conditions.
Monthly	Flush the pump tubes with clean water to prevent blockage.	Mineral deposits and algae can restrict flow over time.
As needed	Export CSV data and archive the file.	Useful for project records, long-term observation, and troubleshooting.
As needed	Refill the fertiliser container with fresh liquid fertiliser.	Old or degraded fertiliser may lose effectiveness.

12 Disease Reference Table

The following table lists the main detectable diseases and their severity levels as recognised by the SPHAS AI models. This is a summary; detailed treatment information is shown automatically on the dashboard when a disease is detected.

Disease / Condition	Species	Severity	Treatment type
Apple Scab	Apple	Medium	Fungicide (Captan)
Black Rot	Apple / Grape	High	Fungicide (Mancozeb / Myclobutanil)
Cedar Apple Rust	Apple	Medium	Fungicide (Myclobutanil)
Powdery Mildew	Cherry / Squash	Low	Fungicide (Sulfur / Potassium Bicarbonate)
Cercospora Leaf Spot	Corn	Medium	Fungicide (Azoxystrobin)
Common Rust	Corn	Low	Fungicide (Propiconazole)
Northern Leaf Blight	Corn	High	Fungicide (Mancozeb + Azoxystrobin)
Esca (Black Measles)	Grape	High	Biocontrol (Trichoderma) — preventive only
Leaf Blight	Grape	Medium	Fungicide (Copper Oxychloride)
Huanglongbing	Orange	High	Insecticide (Imidacloprid) + nutrition — no cure

Disease / Condition	Species	Severity	Treatment type
Bacterial Spot	Peach / Pepper / Tomato	Medium	Bactericide (Copper Hydroxide)
Early Blight	Potato / Tomato	Medium	Fungicide (Chlorothalonil / Mancozeb)
Late Blight	Potato / Tomato	High	Fungicide (Metalaxyl-M + Mancozeb) — urgent
Leaf Scorch	Strawberry	Low	Fungicide (Captan / Copper)
Leaf Mold	Tomato	Low	Fungicide (Chlorothalonil / Copper Oxychloride)
Septoria Leaf Spot	Tomato	Medium	Fungicide (Mancozeb / Chlorothalonil)
Spider Mites	Tomato	Medium	Miticide / Neem Oil (Abamectin)
Target Spot	Tomato	Medium	Fungicide (Azoxystrobin + Difenoconazole)
Tomato Mosaic Virus	Tomato	High	No chemical cure — remove infected plants
Tomato Yellow Leaf Curl Virus	Tomato	High	Insecticide (Imidacloprid for whitefly) — no cure
Healthy	All species	—	No treatment needed

Caution: Diseases marked **High** severity should be acted upon promptly. Diseases listed as "no cure" require isolation or removal of the infected plant to prevent spread to other plants.

13 Glossary for Non-Technical Users

Term	Simple meaning
Dashboard	The web page where you monitor and control the SPHAS system.
Sensor	A small electronic part that measures something, such as temperature or soil wetness.
Soil moisture	A percentage showing how wet the soil is. 0% means completely dry; 100% means saturated.
Threshold	A limit value set in the system. If a sensor reading crosses this limit, the system may generate an alert or take an automatic action.
AI / Artificial Intelligence	Software that uses mathematical models trained on thousands of plant images to recognise species and detect diseases from a photo.
TFLite model	A compressed AI model file that runs on the Raspberry Pi device without needing a powerful server.
Confidence	A percentage showing how certain the AI model is about its result. Higher is more reliable.

Term	Simple meaning
GrabCut	An image processing technique that automatically separates the plant leaf from the background in a photo to help the AI focus on the leaf.
3D Digital Twin	A three-dimensional visual model of the SPHAS device and plant shown on the dashboard, updated in real time.
Manual override	A button that lets the user trigger a pump or motor directly, bypassing the automatic schedule.
Peristaltic pump	A type of small pump that moves liquid by squeezing a flexible tube. Used for water and fertiliser delivery.
IPC (Inter-Process Communication)	The internal communication channel between software modules inside the SPHAS device. Not visible to the user.
WebSocket	A communication protocol that allows the dashboard to receive live updates from the device without requiring the user to refresh the page.
REST API	A way for software modules to communicate over a network using standard web requests. Not visible to the user.
CSV	A simple file format (Comma-Separated Values) that can be opened in any spreadsheet program to view recorded data.
Offline	The dashboard cannot currently reach the device. The device may be powered off or disconnected from the network.
Lockout (6-hour pump lockout)	A built-in safety rule that prevents the water or fertiliser pump from running again within 6 hours of the last activation, to protect the plant from over-watering.
Heartbeat	A regular status signal that each module sends to confirm it is running correctly. If the heartbeat stops, the system generates a Module Offline alert.
GPS	A satellite-based positioning system. The SPHAS device uses a GPS module to obtain its geographic coordinates, which are used for the weather integration feature.
OpenWeatherMap	An online weather data service. SPHAS queries this service using the device's GPS coordinates to check rain conditions before making watering decisions.

14 Support Checklist

Before reporting a problem or requesting support, collect the following information. This helps the project team identify and resolve the issue faster.

- Device name as shown in the Devices panel.
- Connection status shown at the top of the dashboard (Connected / Offline / Warning).
- Screenshot of the dashboard at the time of the problem.
- Approximate date and time when the issue occurred.
- A description of what action was taken before the problem appeared.

- Whether the device was recently moved, restarted, or disconnected.
- Whether any liquid spill occurred near the device.
- The most recent alert messages shown in the Alerts panel.
- A CSV export file if the problem is related to sensor data or pump behaviour.

Project Links Support

https://kerim111.github.io/GROUP1/

https://youtu.be/OEOXxKMZTmY

Access our project repository and video demonstration directly using these links.

15 Technical Specifications Summary

The following table provides a concise technical summary for users who want to understand the key system parameters.

Parameter	Value
Platform	Raspberry Pi (Linux-based, single-board computer)
AI species recognition model	INT8 quantised TFLite model, input 96×96 pixels, 14 output classes
AI disease detection model	INT8 quantised TFLite model, input 224×224 pixels, 38 output classes
Supported plant species	Apple, Blueberry, Cherry, Corn, Grape, Orange, Peach, Pepper, Potato, Raspberry, Soybean, Squash, Strawberry, Tomato (14 total)
Supported disease classes	38 disease classes across all supported species
GrabCut threshold	Applied automatically when species or disease confidence is below 60%
Sensors	DHT11 (temperature + humidity), ADS1115 ADC with soil moisture probe and dual LDR light sensors, NEO-6M GPS
Sensor polling interval	Approximately 1 second (hardware layer default)
Actuators	Two peristaltic pumps (water, fertiliser), MG90S servo (soil dip), 28BYJ-48 stepper motor(s) (tilt control)
Pump safety limit	Maximum 200 mL per command; 6-hour lockout between activations
Default water volume	100 mL per watering event
Default fertiliser volume	5 mL per fertilisation event
Default fertilisation interval	14 days
Camera	Raspberry Pi camera module, MJPEG stream on port 8080
Dashboard technology	React + Three.js + WebSocket, served on port 3000

Parameter	Value
Backend API	Python Flask REST API, port 5000
Dashboard polling interval	5 seconds (M4 polls M3 backend automatically)
Device offline threshold	60 seconds without response
Maximum simultaneous devices	16
Data storage	SQLite database on the Raspberry Pi
Weather integration	OpenWeatherMap current weather + 3-hour forecast; requires internet access
Data export	CSV format, downloadable from the dashboard at any time
Stepper motor step per command	Approximately 15 degrees per Tilt Up / Tilt Down button press
Servo soil dip duration	Approximately 3 seconds lowered, then raised automatically

16 Conclusion

SPHAS combines continuous environmental sensing, AI-based plant diagnosis, weather-aware autonomous irrigation, and a real-time web dashboard into a single integrated platform. The result is a system that significantly reduces the effort and guesswork involved in everyday plant care.

The key strengths of SPHAS as experienced by the user are:

- **Continuous monitoring.** Sensor data is collected every second and displayed live with no user action required.
- **AI-assisted diagnosis.** A single button press delivers a species and disease result within seconds, with a built-in treatment recommendation when a disease is found.
- **Intelligent automation.** The Decision Engine handles watering and fertilisation autonomously, respecting pump lockouts and live weather forecasts to prevent over-irrigation.
- **Full user control.** Every automatic action generates a dashboard alert; manual override buttons ensure the user is always in control.

Limitations

The AI models cover 14 plant species; plants outside this set receive a closest-match result. Weather-based deferral requires internet access. The prototype enclosure is designed for indoor and semi-outdoor use only, and AI results below 40 % confidence should be verified by a specialist.

Looking ahead

The modular architecture of SPHAS — with M1, M2, M3, and M4 communicating through well-defined interfaces — allows each layer to be upgraded independently. Future work may extend the species library, add mobile notifications, and introduce a weatherproofed outdoor enclosure.

> **Tip:** Review threshold settings when introducing a new plant species, check the dashboard daily, and keep the camera lens clean. These three habits cover the majority of routine care needs.