Design and Implementation of a Garden Control System

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2 Introduction

This project explores the design and implementation of a simple greenhouse monitoring and control system based around an ESP32-s3 micro-controller, utilising various sensors for measuring environmental conditionals such as soil moisture and nutrient (NPK) levels, while controlling pumps, irrigating plants and logging historical data. This project is a broke students means of exploring supervisory control and data acquisition (SCADA) systems.

3 Background

While the main component of this project is the control board, some brief research was conducted to understand the influence of sensed nitrogen, phosphorus and potassium levels on plant growth.

Plant Nutrients:

The Earth is a beautiful and dynamic environment, millions of unnoticed processes could consume a lifetime in their study, categorised by matter dominant in their environments, the four biospheres of Earth are summarised below:

- **Hydrosphere:** Categorised by gaseous, liquid and solid water on Earth.
- **Biosphere:** Including all of animals, plants and microorganisms of Earth.
- **Lithosphere:** Made up of all of hard/solid land mass on the Earths surface, to the semi-solid molten rocks found in volcanic regions.
- **Atmosphere:** In my opinion, the most significant of each. Determines the constant exchange of a slice of the electromagnetic magnetic spectrum of photons and radiowaves from cosmic sources to our surface. Made up mostly of nitrogen, oxygen, carbon dioxide and argon (78%,21%,1%,0.039%, 0.93%), the rest made up from trace gases.

however as an electrical engineering student, time is limited, therefore a very brief systems point of view is provided here to aid the understanding of what exactly the control variable are. A brief note on the reading of Chemistry of the Environment by Thomas G. Spiro and William N. Stigliani be thrown here.

Biochemical Energy:
All of biology depends on oxidation and reduction processes. The primary source of energy in the biosphere is the energy stored in reduced carbon compounds, generated through photosynthesis. Such reduced compounds are the main components of the biosphere (principally CH_2O, carbohydrates). When there is adequate oxygen, energy is released via oxidation of carbohydrate molecules to carbon dioxide and water:

$$(CH_2O) + O_2 = CO_2 + H_2O$$

Nitrogen, Phosphorus and Potassium: The Limiting Nutrients:
These nutrients, as depicted in Figure [1], determine the health of most plants, although particular species have different optimal NPK profiles.

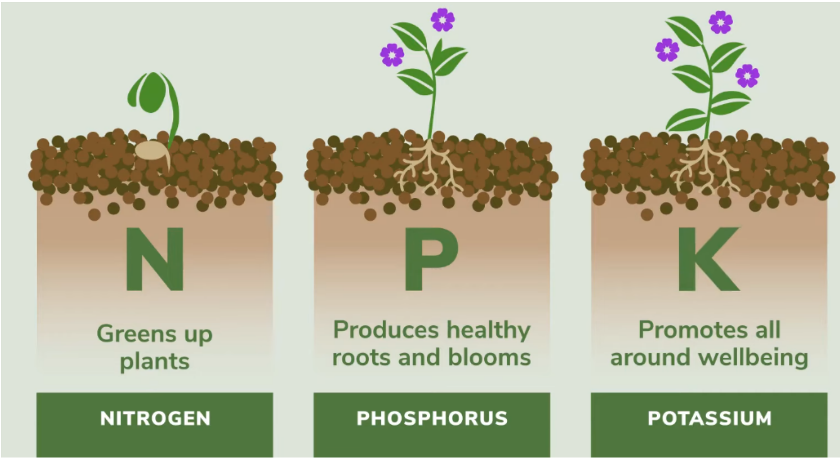

Figure 1: Nitrogen, Phosphorus and Potassium

Future projects will explore the use of controlled fertilisation methods to directly influence NPK profiles of the plants, however this project will simply use ON/OFF control based sampled moisture levels of the soil.

4 Control Board:

As stated previously, the control board is based on a ESP32-s3 microcontroller devkit [1]. The board controls up to four TPS22810 dedicated high-side IC's (for general use, this board only controls a single 12V pump), which are capable of switching 18V, 2A maximum continuous current. Each of these switches has thermal shutdown, and UVLO protection. The board also features JST connectors, each connected to a channel of the ADS1115 [3] for external sensor interfacing. Input power is easily monitored via an ACS712 [4] Hall-effect current sensor. The PCB design is shown in Figure [2]

Dimensions:

- **Width:** 90mm
- **Length:** 65mm

4.1 Sensor Calibration

The main sensor of the project is a capacitive moisture sensor available from CORE electronics [5]. A total of three sensors were tested in completely dry conditions versus completely submerged. A basic linear relationship was established to approximate the moisture of the plants within the greenhouse.

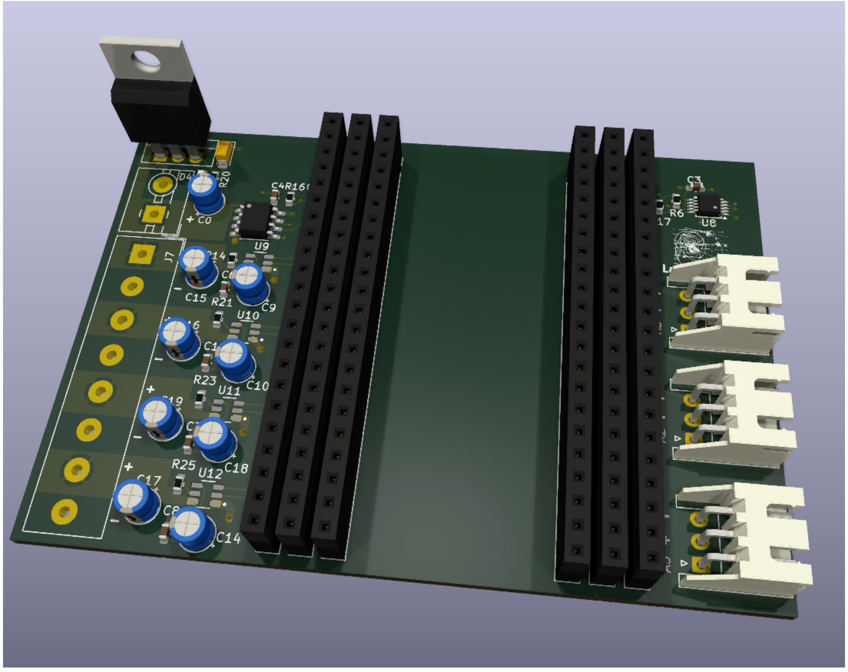

Figure 2: Greenhouse Control PCB

$$V_{immersed} = 0.9\text{V}$$
$$V_{dry} = 2.4\text{V}$$

From these measurements:

$$M_{\%} = 1 - \frac{V_{read} - V_{immersed}}{V_{dry} - V_{immersed}} \times 100$$

The sensor outputs an analogue voltage proportional to the soil moisture content. This voltage is digitised using the onboard ADS1115 16-bit Analog-to-Digital Converter (ADC), which communicates with the microcontroller via the I^2C protocol. The high resolution of the ADS1115 allows for precise measurement of small voltage variations, which is crucial for consistent monitoring across varying soil conditions.

The secondary NPK sensor is currently implemented on an additional ESP32 node to ensure it can be transported for measurement of plant nutrients throughout the garden. For reference, the circuit schematic is shown in Figure [3]

ADC Sampling

Each sensor is sampled periodically in a round-robin fashion. The raw digital value is then converted back to voltage using the following relation:

$$V_{read} = \frac{ADC_{raw} \cdot V_{ref}}{2^{15}}$$

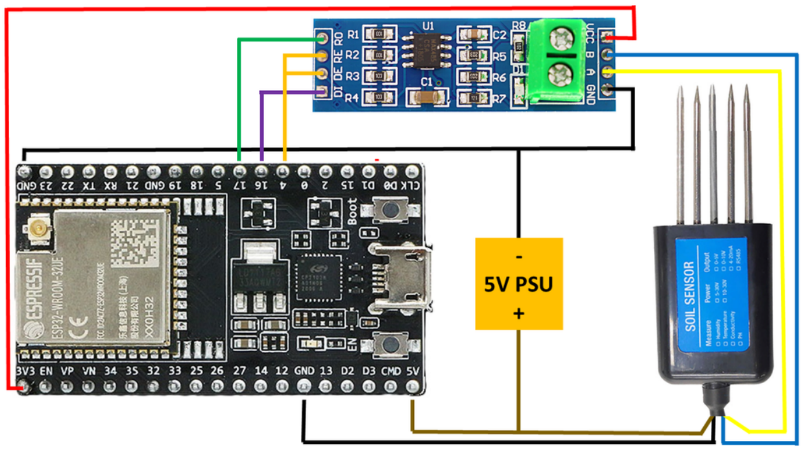

Figure 3: Pinout for NPK Sensor node.

where $V_{ref} = 3.3\,\mathrm{V}$ is the ADC reference voltage, and ADC_{raw} is the signed 16-bit value read from the ADS1115.

The moisture percentage $M_{\%}$ is then computed as previously defined:

$$M_{\%} = 1 - \frac{V_{read} - V_{immersed}}{V_{dry} - V_{immersed}} \times 100$$

This value is constrained between 0% and 100%.

Pump Control Logic

If the average moisture percentage $\bar{M}_{\%}$ across all three sensors drops below a defined threshold of 10%, the system activates an irrigation pump via a GPIO-controlled dedicated high-side switch IC. This ensures that plants are only watered when a critical dryness level is reached. This can be varied dependent on the target plants.

The pump remains active for a fixed duration (e.g., 5 seconds) before the system re-evaluates the moisture condition. This cycle ensures efficient water usage while maintaining healthy soil moisture levels.

4.2 Getting Started

The esp32-s3 devkit is easily found on Ali-Express for approximately $5 AUD (depending on the seller), while designed PCB shield BOM and KiCad files can be found in the GitHub repository Greenhouse-Controller Hardware at . The firmware is located in a different repository, named Greenhouse-Controller. Currently it is in version 1.

4.3 User Interface:

In order to access data readings from the system, simply set up receiver and garden node within the source code with your WiFi SSID and password. It is assumed that the user has sufficient experience with ESP-idf to do so. Once the software has been flashed, the serial monitor should print received data as shown in Figure [4]

```
Conductivity:  = 181.00 uS/cm
pH:  = 5.9
Nitrogen:  = 0.00 mg/L
Phosphorus:  = 38.00 mg/L
Potassium:  = 29.00 mg/L
Salinity:  = 89.00 g/L
TDS:  = 81.00 mg/L
Moisture:  = 23.2 %
Temperature:  = 17.7 deg.C
Conductivity:  = 157.00 uS/cm
pH:  = 5.9
Nitrogen:  = 0.00 mg/L
Phosphorus:  = 32.00 mg/L
Potassium:  = 24.00 mg/L
Salinity:  = 85.00 g/L
TDS:  = 77.00 mg/L
Moisture:  = 21.6 %
Temperature:  = 17.6 deg.C
Conductivity:  = 154.00 uS/cm
```

Figure 4: Data Received from Garden Node

5 Testing and Results

In order to validate the buck converter working, a list of tests have been devised and are to be evaluated once the hardware is assembled and the software is flashed.

Physical Requirements

ID	Description	Verification
PHY-001	Device shall operate from 12 V DC input.	Test
PHY-002	MCU Power $<$ 500mW	Measurement

Functional Requirements

ID	Description	Verification
FUN-001	Packet loss should be no greater than 10%.	Test
FUN-002	Remote monitoring.	Demonstration

Performance Requirements

ID	Description	Verification
PER-001	Each pump trigger should increase average moisture by 50%	Test

5.1 Test Setup

- Bench power supply simulating solar panel
- 12V AGM battery load
- Oscilloscope to monitor switching waveform

5.2 Results Summary

Test	Expected	Observed
Input Voltage Range	11.8V< V_{in} <12.7V	12.5V
Max Input Current	5A	3A (submerged pump)
Moisture Level Increase	50%	82.5%
Packets Received (n=10)	9	10

6 Future Work

Currently within development is an MPPT that will be used to charge the Lead-Acid battery powering the project. Further work includes implementing a UI where users can directly monitor their garden statistics over time, and control moisture levels remotely.

7 Conclusion

This project demonstrates a simple and effective greenhouse automation project which can be used in small apartments and large properties alike. The simple hardware and effective monitoring allows students and hobbyists to build on the project, without having to pay excessive amounts to buy a SCADA kit.

BOM

Component	Cost
Ozito 12V submersible pump	$34 AUD
19mm Polypipe	$10 AUD
Hose Clamp	$2 AUD
ESP32-s3	$5AUD
ADS1115	$ 1.5AUD
TPS22810	$0.7AUD/unit
PCBs (5)	$22 AUD
Total	$75.5 AUD

References

[1] ESP32-S3-WROOM-1 Datasheet Version 1.5

[2] Texas Instruments TPS22810, 2,7-18V, 79mΩ, On Resistance Load Switch with Thermal Protection

[3] Texas Instruments, ADS111x Ultra-Small, Low-power I^2C-compatible 860SPS, 16-bit ADCs with Internal Reference, Oscillator, and Programmable Comparator.

[4] Allegro ACS712, Fully Integrated, Hall Effect-Based Linear Current Sensor with 2.1 kVRMS Voltage Isolation and a Low-Resistance Current Conductor

[5] Core Electronics: Capacitive Moisture sensor https://core-electronics.com.au/capacitive-soil-moisture-sensor-v20.html