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**Project Katara -**

**An automatic plant care solution**

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# Introduction

Project Katara is an automated plant monitoring and care system designed to address the challenges of plant maintenance in busy lifestyles. Whether it’s watering your plants, ensuring they receive adequate light, or monitoring soil conditions, the system provides an electronic solution. The goal of this project was to develop a device that simplifies plant care, even during extended absences, by combining hardware, software, and connectivity.

The project began as a proof of concept to explore how microcontrollers, sensors, and mosfets could automate plant care. Over two years, it evolved into a fully integrated system with custom-designed PCBs, real-time monitoring capabilities, and an intuitive web interface.

With features like automated watering, customizable light spectrums via Neopixel LEDs, and a plant-specific data interface accessible through a website, the system aims to meet the needs of modern plant enthusiasts. While functional, the project also posed several challenges, including electrical design refinements, thermal management, and user interface optimization. This application note documents the journey, detailing each step of the design process, component selection, challenges faced, and the solutions implemented.

# Proof of concept

## Objectives

A green circuit board with black and white components

Description automatically generatedThe primary goal of the initial design was to validate the feasibility of automating plant care using off-the-shelf components. This included controlling a water motor, monitoring soil moisture levels, and experimenting with light adjustments for plant growth. The focus was on creating a low-cost, modular system that could serve as a foundation for more advanced iterations.

## Design overview

The proof-of-concept system began with a simple relay module connected to an ESP32 development board. This initial setup tested the feasibility of controlling a water motor, laying the groundwork for more complex implementations. Once this basic concept was validated, the project quickly progressed to designing a custom PCB to enhance functionality and integration.

The first PCB iteration retained the ESP32 as a development module and introduced MOSFETs to replace the relay for motor control. The system consisted of:

Figure : First PCB prototype

* **Water Motor Control:** A MOSFET-driven circuit to manage a 12V water pump.
* **Soil Moisture Monitoring:** Basic capacitive soil moisture sensors for data collection.
* **Lighting:** Neopixel LED strips to provide a customizable light spectrum for plant growth.
* **Power Supply:** External adapters to provide 5V and 12V required by different components.

While the custom PCB marked a significant step forward, it also highlighted critical design flaws, particularly related to power distribution and MOSFET implementation.

## Key challenges

1. **MOSFET Troubles:** One of the major challenges faced in this entire project, was the use of mosfets. In general, it is easy to use mosfets, but quite a challenge to work exactly the way you designed for, modern day electronic simulators still don’t get mosfets quite right. The mosfets used in this first iteration were not suited for high current, only being able to deliver a max of 100 mA. Next to this the gate pins of the mosfet were only being supplied by 3.3V. Which according to their datasheet should be sufficient to switch “on” the mosfet, yet in practice this was not the case.
2. **Short Circuits:** A major short circuit occurred due to the placement of the 12V DC plug, the 12V pin was switched with the ground pin which meant that, if power on, the entire board would fail. Luckily this mistake was spotted right before plugging in the adaptor and replacing it with wire bridges to correct the mistake.
3. **PCB Layout:** Limited experience in PCB design led to several avoidable mistakes, such as poor trace routing and inadequate clearance around high-current components. Almost all traces were the same width, and no special considerations were held into account for component placement. In general, this was a horrible PCB.

## Lessons learned

The proof-of-concept phase was a crucial learning experience, highlighting both the potential and the challenges of PCB design. In general, it was important to go through this first iteration to better understand that more knowledge of PCB and electrical design was needed before trying again.

# A green circuit board with white and black components Description automatically generatedFinal PCB

The final PCB that was settled on for this project ended up being a significant learning experience, introducing new knowledge and skills in the world of PCB design. It addressed several shortcomings of the initial proof-of-concept and incorporated numerous improvements to optimize the system’s performance and reliability. This section details the objectives, electrical design considerations, and challenges encountered during its development.

## Objectives and improvements

The primary objective of the final PCB design was to create a robust, integrated system that could manage all aspects of the automated plant care solution reliably and efficiently. Key improvements over the proof-of-concept included:

A diagram of a circuit

Description automatically generated**Enhanced MOSFET** **Control**: The inclusion of an MCP1406T-E MOSFET controller allowed for a 5V gate drive, solving the challenges faced in earlier iterations where a 3.3V gate voltage was insufficient to fully activate the MOSFETs.

**ESP32 Integration**: Transitioning from an ESP32 development board to an SMD-mounted ESP32 on the PCB reduced the overall footprint and improved system reliability. This required careful attention to boot mode configurations and programming circuits to ensure correct operation.

**Impedance Matching**: Special care was taken to design impedance-controlled traces for the USB-to-UART connection, ensuring reliable communication.

**Thermal Management**: Improvements were made to manage heat dissipation, particularly for the LDOs, which had previously caused the board to shut down under high loads.

**Current Return Paths**: Improved grounding strategies were implemented, ensuring that current return paths minimized noise and potential signal integrity issues.

**Differential Impedance Matching**: The design also considered differential impedance matching, a critical factor for high-speed signal integrity, especially in USB communication. This can be seen in the image below, this was a first deep dive into the world of impedance matching.

A red background with a red square with yellow and purple lines and a blue line

Description automatically generated with medium confidence

## Electrical overview

The final PCB integrates all the major components required to deliver the automated plant care solution. The power management system employs two LDOs to step down voltages, converting 12V to 5V and 5V to 3.3V. This configuration powers the microcontroller and sensors, with a specific focus on thermal design to prevent automatic shutdowns during high loads. The MOSFET circuitry, controlled by the MCP1406T-E driver, enables reliable motor and LED operation. The ESP32 microcontroller, integrated directly onto the PCB as an SMD component, acts as the brain of the system, handling automation and connectivity tasks. Additionally, the PCB includes inputs for multiple sensors to monitor environmental parameters such as soil moisture and temperature. For lighting control, connections for Neopixel LED strips are provided, enabling customizable light spectrums tailored to plant growth.

## Component selection

The selection of components played a critical role in overcoming challenges and ensuring the desired functionality of the system. The MCP1406T-E MOSFET driver was a key addition, addressing the earlier issues with insufficient gate voltage. It provided a reliable 5V gate drive, ensuring proper MOSFET operation. The ESP32, integrated as an SMD package, streamlined the design but required precise attention to programming and boot mode circuitry. Lastly, the LDO regulators were carefully chosen to deliver stable voltage outputs, despite presenting challenges related to heat dissipation. Looking back of course it might have been a better idea to use Nonlinear voltage regulators such as a Buck converter as this does not generate the amount of heat.

# Design challenges

The design of the final PCB was not without its challenges, and each issue provided valuable lessons. One of the initial problems encountered was with the boot mode configuration of the ESP32. Misplaced components in the boot circuitry prevented the microcontroller from booting correctly. This issue was resolved by connecting the 3.3V line to the enable pin, enabling proper operation. Heat dissipation was another significant challenge. The LDOs experienced considerable heating, especially when powering the LEDs, which eventually caused the board to shut down. This highlighted the importance of thermal design and the potential need for switching regulators or additional heat dissipation strategies in future iterations. Designing for controlled impedance in the USB-to-UART traces was also complex but necessary for reliable communication. This required extensive simulation and iterative design adjustments. Lastly, careful routing and placement of components to avoid noise and ensure efficient current return paths demanded significant effort and refinement.

Despite the significant improvements, some issues persisted in the final design. Misplaced resistors and capacitors in the boot mode configuration initially caused boot failures. Fortunately, these issues were quickly corrected with minimal redesign effort. The LDOs’ overheating problem remained a concern, particularly under heavy loads when the LEDs were left on for extended periods. Future designs should consider switching regulators or improved thermal management solutions to address this issue effectively.

# Testing and validation

Once the final PCB was fully assembled and most of the design fixes were implemented, rigorous testing and validation were conducted to ensure the system’s functionality. During this phase, the board was tested under various conditions, including extended periods of operation with all components active. While the PCB successfully powered the water motors, lit the Neopixel LEDs, and enabled the ESP32 to communicate with the internet for data transmission and reception, a recurring issue with heat dissipation was observed.

The LDOs, responsible for stepping down the voltage from 12V to 5V and from 5V to 3.3V, generated excessive heat when the board operated continuously for long periods. The temperature of the LDOs could rise above 125 degrees Celsius, triggering their automatic thermal shutdown. This behaviour was particularly evident when the LEDs were left on for extended durations. Although the board functioned as intended for moderate usage, the overheating issue remains a critical area for improvement in future iterations.

Despite this limitation, the final PCB achieved its intended functionality. The system reliably detected soil moisture levels, controlled Neopixel LEDs with precision, programmed the ESP32 without issues, and facilitated seamless internet connectivity for data exchange. The water motor integration was straightforward and performed efficiently, demonstrating the system’s capability to manage all plant care tasks effectively.

# Conclusion

The development of the final PCB for Project Katara represents a significant milestone in the project’s journey. Through iterative design, testing, and problem-solving, a robust and functional system was created that integrates multiple components seamlessly. The inclusion of the MCP1406T-E MOSFET controller and the transition to an SMD-mounted ESP32 were key achievements, addressing earlier challenges and enhancing system reliability.

While the project successfully achieved its primary goals, the heat dissipation issue with the LDOs highlights the importance of continued refinement and optimization in future designs. Addressing this limitation will be critical to ensure long-term reliability, especially under high-load conditions.

Overall, Project Katara demonstrates the potential of combining advanced PCB design with innovative automation to simplify plant care. The system’s ability to monitor environmental conditions, control lighting, power water motors, and connect to the internet showcases its versatility and effectiveness. This project serves as a foundation for future improvements and expansions, paving the way for more sophisticated and efficient plant care solutions.