Independently Controlled Irrigation System for Agriculture Plots

Introduction

Problem:

Maintaining optimal environmental conditions for plant growth is essential for farmers, particularly those in rural farming lands where limited water supplies and lack of resources hinder productivity. Currently, both novice and experienced farmers/gardeners share a similar problem - different plant species require varying levels of soil moisture and ensuring each plant receives an ideal amount of water can be very time-consuming and error-prone. In modern day, most gardening enthusiasts manually cater their resources to each plant and this has proven to result in low-efficiency and lots of errors like under watering/overwatering plants. The concerns with modern-day irrigation plans is evident as underwatering/ overwatering plants cause significant issues like stunted plant growth and even plant death. Experiments highlighted by TreeNewal state that 80% of tree/plant problems can be attributed to the soil environment. According to the National Library of Medicine, 80-95% of the fresh biomass in plants is made up of water, highlighting the vital role water plays in a plant’s growth, development, and metabolism. ScienceDirect further emphasizes that inconsistent watering and drought results in consequences like high salinity levels, heat stress, and attack of pathogens. This challenge becomes significantly more profound for farmers that have to monitor the specific water needs for different plant species.

The need for a precise, efficient, automatic irrigation solution is evident. Numerous countries across the world depend on the plant/crop yield of irrigated lands for resources like food. Clearly, inefficiencies and errors in the modern day manual irrigation have severe consequences as citizens of various countries are dependent on the plant’s health and yield. According to the Food and Agriculture Organization (FAO), countries like India and Mexico depend on irrigated land for 55% of their agricultural output. As we can see, proper irrigation and watering systems are the key to high productivity in crop/plant outputs. The FAO also further highlights the need for a new automated watering system as currently, countries are spending a high amount of resources and money but are still not getting the results they want. For example, despite the high investments in the agriculture industry and improved irrigation, as much as 60% of the water diverted and pumped for irrigation is wasted. Smart, automated systems that can provide tailored irrigation for varying plant species are the next step in ensuring successful plant growth and assisting in combating real world crises like water scarcity.

References:

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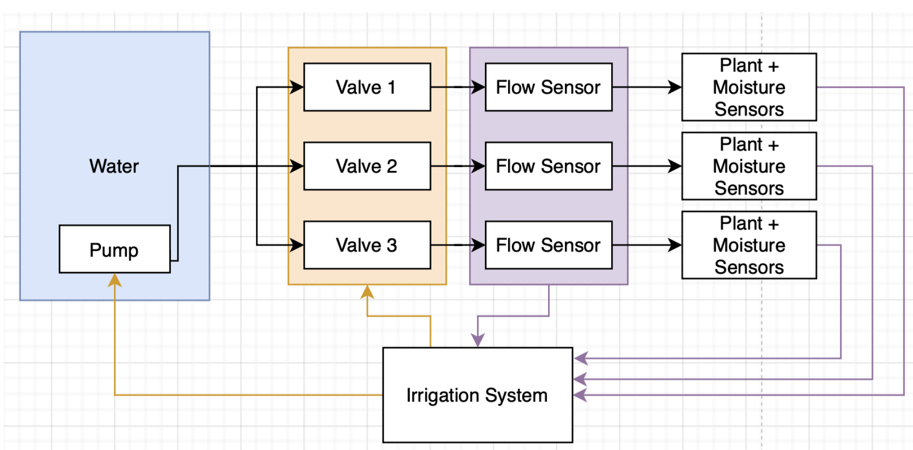
Solution:

Our solution aims to combat the inefficiencies and inconsistencies of modern-day irrigation approaches by creating a smart,automated watering system designed to cater to the needs of varying plant species. At the heart of this solution is a central water supply that is connected to each of the plants through its own valve. To prevent overwatering/underwatering, the most common issues when manually watering plants, each valve dispenses water based on real-time soil moisture data. This approach ensures that each plant receives the optimal amount of water and the correct times, and combats the issues in water waste and manual labor. By utilizing real-time data and automating the irrigation, we can eliminate the inevitable errors that come with human labor and significantly improve plant health/growth.

Our solution is split into 2 components, the irrigation system and the sensing system. The sensing system collects real-time data from the soil-moisture sensors to inform the irrigation system when and how much water each plant needs. Additionally, at the core, our solution includes a central microcontroller that will process the data from the soil sensors and can relay the information so the water valves provide the optimal amount of water to ensure precise and efficient crop growth. Our sensors will be distributed evenly across the soil in the plant environment and will be wirelessly transmitted to the control system via Bluetooth Low Energy. Our new irrigation solution will utilize Bluetooth Low Energy to transmit data as in rural area/farm lands WI-FI availability is minimal. In order to assist farmers that look to improve crop yield, we have taken account of the lack of available resources in the rural countryside. The control system processes data from the sensors and activates the irrigation system. The irrigation system includes pumps that use Pulse Width Modulation to regulate flow rate through the valves. Flow sensors will be integrated to deliver key information regarding water volume and flow rate to ensure the correct amount of water is delivered. We will include a user interface with React so users are enabled to adjust irrigation settings, track water usage in real-time, and customize watering schedules to their liking. This automated watering solution will ensure plants receive the perfect care without much human intervention, making it an ideal solution for managing diverse plant environments.

Visual Aid:

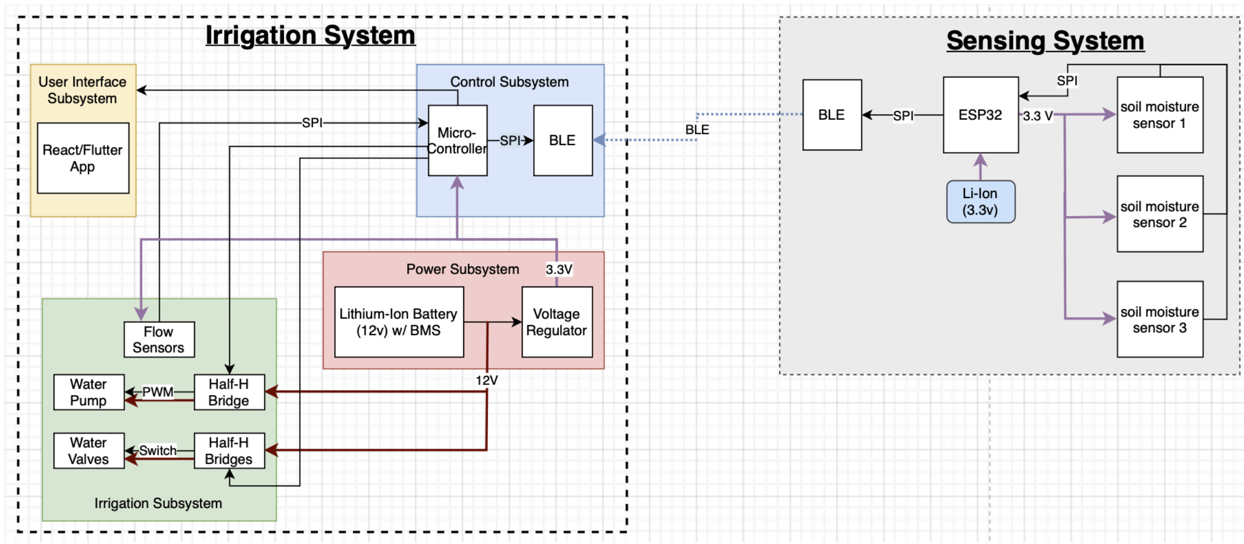


High-Level Requirements List:

1) **Precise Water Delivery :** Upon recognizing low moisture levels in the soil, the system must activate the correct valve and deliver the optimal amount of water required. The flow sensor must indicate and verify that the water released is within +/- 5% of the requirement indicated by the current moisture level.
2) **Real-Time System Response :** A key feature of our solution is that human error is eliminated and the system is automated in real-time. For our solution to be viable, we must ensure that the water delivery occurs with a fast response time to maintain optimal moisture levels. The system must process data from the sensors and adjust water flow within the valves within 25 minutes of receiving the new data.
3) **Accurate Moisture Detection :** At the foundation of our solution, we must first ensure that our sensors are able to accurately detect the moisture levels in the soil in order to begin the automatic watering system. The system must measure and transmit soil moisture data from three independent sensors with an accuracy of +/- 5% compared to the actual soil moisture levels. Then, the sensors must trigger a response to the control unit within 5 minutes if the moisture levels reach below a predefined threshold.

Design

Block Diagram:



Subsystem Overview:

Our project has two main systems: the irrigation system and the sensing system.

IRRIGATION SYSTEM

The irrigation system is the core of our project and includes subsystems that control the amount of water released, and when it is released. It also sends data to our user interface.

1. **Control Subsystem**

The control subsystem acts as the central processing unit of the irrigation system, coordinating all other subsystems to ensure efficient and precise operation. It includes a microcontroller that processes inputs and outputs according to the program logic defined for irrigation. This subsystem uses the SPI (Serial Peripheral Interface) protocol to communicate with the user interface subsystem, ensuring that user commands and configurations are accurately received and executed. It also uses BLE (Bluetooth Low Energy) for wireless communication with remote sensor modules, receiving real-time soil moisture data. The control subsystem interprets these data points to manage the activation and deactivation of the water valves and pumps through the irrigation subsystem, thus maintaining optimal soil moisture levels across the garden.

The control subsystem must efficiently handle data via SPI and BLE protocols to ensure real-time communication and operation control. This subsystem requires a microcontroller capable of processing multiple data streams concurrently to manage the real-time data received from the soil moisture sensors via BLE and the commands from the user interface via SPI. The requirements for the control subsystem include:

- The microcontroller must support SPI communication at a frequency of at least 1 MHz to ensure timely updates and responsive control adjustments.
- BLE communication must maintain a stable connection with a minimum range of 10 meters to ensure consistent data reception from the distributed sensors in the garden.
- The subsystem must process and relay commands to the irrigation subsystem within 100 milliseconds to ensure timely activation and deactivation of irrigation mechanisms.

A potential risk within the control subsystem is the latency in BLE communication which might delay the reception of moisture data, affecting the system's responsiveness. To mitigate this risk, the feasibility of BLE's performance can be analyzed through simulation of the communication protocol under various environmental conditions and distances, ensuring that the system can operate effectively with a maximum tolerable delay of 50 milliseconds before water distribution is affected.

2. User Interface Subsystem

The user interface subsystem provides an interactive platform for users to monitor and control the irrigation system. This subsystem is built with a React or Flutter application, enabling a robust and responsive user experience across various devices. The application communicates with the control subsystem via SPI, allowing users to set preferences, view real-time data, and receive alerts about the irrigation process. Through this interface, users can customize watering schedules based on specific plant needs, view historical data to track water usage and soil moisture levels, and adjust settings to optimize water conservation and plant health.

The user interface subsystem is critical for user interaction and control over the irrigation system. This subsystem requires a stable and intuitive application that can run on multiple platforms (iOS, Android, Web). The specific requirements include:

- The user interface must update in real-time, reflecting system changes and sensor data within 2 seconds of receiving new data from the control subsystem via SPI.

3. Irrigation Subsystem

The irrigation subsystem is directly responsible for the physical delivery of water to the plants. It consists of a network of water pumps and valves controlled by the microcontroller in the control subsystem. The pumps use PWM (Pulse Width Modulation) signals to regulate the flow rate, while the valves, operated by switches, control the distribution of water to different sections of the garden. Flow sensors integrated within this subsystem provide feedback on water volume and flow rate, ensuring that each section receives the precise amount of water as instructed by the control subsystem. This feedback loop enables the system to adjust the water delivery dynamically, preventing overwatering or underwatering.

The irrigation subsystem directly impacts the water delivery and distribution efficiency. The requirements for this subsystem include:

- Water pumps must operate within a voltage range of 10V to 12V and provide flow rates from 0.5 to 2 liters per minute.
- Valves must open and close in less than 2 seconds upon receiving a command via PWM to allow timely distribution of water.
- Flow sensors must have an accuracy of ±5% to correctly report water delivery metrics back to the control subsystem for real-time adjustments.

The failure of valves to operate within the required response time is a critical risk. The feasibility of this component can be assessed through time-series analysis of valve actuation under different electrical loads and temperatures to ensure reliability, aiming to maintain operational tolerance within 1 second.

4. **Power Subsystem**

The power subsystem ensures that all components of the irrigation system have a reliable and stable power supply. It centers around a lithium-ion battery equipped with a Battery Management System (BMS), which helps in monitoring the battery's health and manages charging and discharging to extend battery life. The subsystem also includes a voltage regulator that steps down the 12V battery output to a stable 3.3V needed by the microcontroller and other low-voltage electronics. This setup supports the system's autonomy and allows it to operate in remote areas without direct access to electrical grids. The design is aimed at ensuring that power is efficiently distributed across the subsystems, minimizing energy waste and enhancing overall sustainability.

The power subsystem must supply a stable and sufficient power supply to all other subsystems. The requirements include:

- The lithium-ion battery must provide a continuous output of 12V with a capability to supply at least 500mA to the rest of the system.
- The voltage regulator must provide a stable output of 3.3V with a tolerance of ±0.1V to ensure sensitive components like the microcontroller and sensors operate within safe electrical thresholds.

A key risk is the voltage regulator failing to maintain the required voltage level, potentially damaging sensitive components. To address this, a simulation of the regulator's performance across a range of input voltages from the battery can be conducted. The goal would be to demonstrate that the regulator can consistently maintain output within specified tolerances under varying load conditions.

SENSING SYSTEM

1. **Sensor Subsystem**

The sensor subsystem is centered around a capacitive soil moisture sensor connected to an ESP32 microcontroller. The sensor detects soil moisture by measuring changes in the soil's dielectric constant, which varies with the water content. This data is output as an analog voltage, proportional to the moisture levels. The wiring involves connecting the sensor's VCC pin to the ESP32's 3.3V power supply and the GND pin to ground. The sensor’s analog output is connected to an analog input pin, such as GPIO36, on the ESP32. The microcontroller reads these analog signals, scales them using its ADC (Analog-to-Digital Conversion), and interprets the soil moisture level accordingly.

2. **Power Subsystem**

The power subsystem utilizes a 3.3V lithium battery (e.g., a 18650 Li-ion battery) to supply power to both the ESP32 microcontroller and the soil moisture sensor. The battery is connected to the ESP32 through its VIN or 3.3V input pin, benefiting from the ESP32's built-in power management. In case the battery outputs a higher voltage, a voltage regulator is included to maintain a steady 3.3V supply. The soil moisture sensor shares this power supply with the ESP32, receiving power through its VCC pin. This ensures that both components are powered consistently throughout the operation.

3. **Control Subsystem**

The control subsystem is managed by the ESP32, which serves as the main control unit. It reads analog soil moisture data from the sensor and transmits the processed information to a central hub using Bluetooth Low Energy (BLE). The ESP32 operates as a BLE peripheral device, sending data either via advertisement packets or through GATT-based communication every 30 minutes. For scenarios involving multiple sensors, SPI communication may be employed for more complex data handling. The system is timed by the ESP32’s internal clock, ensuring data transmission is spaced evenly. Additionally, TDMA scheduling can be implemented to avoid interference by ensuring that each sensor transmits data in its own designated time slot.

TOLERANCE ANALYSIS

Irrigation System:
The control subsystem relies on SPI and BLE for communication, with SPI requiring a frequency tolerance of ±5% to avoid data corruption, and BLE needing a signal range tolerance of ±10% for stable communication within 10 meters. The system’s command relay must occur within 100 milliseconds, with a tolerance of ±10 milliseconds to prevent water distribution delays. The user interface must reflect real-time data within 2 seconds, with a tolerance of ±500 milliseconds to maintain responsiveness. The irrigation subsystem’s pumps must maintain a flow rate of 0.5 to 2

liters per minute with a ±10% tolerance, while valves should open within 2 seconds, tolerating a ±0.5-second delay to ensure efficient water delivery. Flow sensors need ±5% accuracy to prevent over- or under-watering. Power-wise, the 12V battery must supply at least 500mA with a ±5% voltage variation, while the voltage regulator needs to stabilize the output to 3.3V within a ±0.1V tolerance for reliable component operation.

Sensing System:
The sensor subsystem, centered on a capacitive soil moisture sensor, must maintain an accuracy tolerance of ±5% to ensure reliable moisture detection despite variations in soil composition or temperature. The ESP32's ADC precision requires a ±2% tolerance in converting analog signals for correct moisture level interpretation. The power subsystem's 3.3V lithium battery must provide stable voltage with a ±5% tolerance, while the voltage regulator must output 3.3V with a ±0.1V tolerance to protect sensitive electronics. The control subsystem's BLE communication should transmit moisture data every 30 minutes with a tolerance of ±10 seconds for minor transmission delays, and TDMA scheduling must allow for ±5ms drift to avoid sensor interference. These tolerances ensure accurate data collection and timely communication, supporting efficient irrigation decisions.

ETHICS AND SAFETY

Our optimized irrigation system should take into consideration the principles contained in the IEEE Code of Ethics including data confidentiality. The sensor system collects moisture levels as well as the amount of water consumed within a given period and this information may be sensitive and private to each farmer/gardener. We intend to use Bluetooth Low Energy (BLE) to transmit information ensuring safety of the communication and users will be sure that their data is classified. Furthermore, we want our solution to be available not only to gardeners looking to improve their plant growth but also for farmers looking to improve their crop yield in rural areas. This adheres to the principles of IEEE non discrimination and provision of equal opportunity. Lastly, considering the environmental impact of our solution, IEEE's principle is to comply with ethical design and sustainable development practices. Our solution inherently looks to reduce water waste and contribute to the sustainable development of agriculture. We will ensure that the components used in our solution are energy-efficient and environmentally safe.

According to the IEEE Code of Ethics, our design must hold paramount the safety, health, and welfare of the public. If there are faults in our irrigation system, crops may get damaged and lead to economic losses for farmers and gardeners. To abide by the IEEE Code of Ethics, we will install alert systems that will instantly notify users if a sensor or valve malfunctions in order to prevent over/under watering. Additionally, in our 3 Requirements to ensure our solution is successful, we have included tests to ensure the fail-safe precise nature of our solution. Finally, another concern may be the electrical safety of our project as we use microcontrollers and lithium-ion batteries. To avoid hazards like short circuits and water damage, we will ensure our project meets industry standards and certifications for electrical safety. We will make sure our solution is water resistant by including proper casing and isolation for components that may be exposed to moisture.