ECE198 Design Document

Plant Monitoring System Using STM32 Microcontrollers

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Needs Assessment

Client/Customer definition

Customer Challenge

- Inconsistent Soil Moisture: Many plant owners struggle with maintaining the optimal moisture level for each plant and determining when each plant should be watered. Incorrect watering can lead to issues such as root rot, wilting, or drought stress, ultimately affecting plant health and growth [1].
- Temperature Variability: Temperature is a vital environmental factor that influences plant metabolism and growth cycles. Indoor plants are particularly susceptible to indoor air temperature fluctuations, which can change the temperature of the soil and may lead to stunted growth, or even death of the plant [2].
- Resource Management: Effective gardening requires significant time and effort, especially in monitoring and adjusting environmental conditions manually. Gardeners with limited time may find it challenging to consistently check and adjust environmental parameters, leading to neglected plants [3].
- Light-weight aid: Many plant owners enjoy the process of devising solutions and changing environmental conditions for different types of plants [17], yet find it laborious to take measurements and often lack tools to do so [16].

Target Market

Demographic: Urban homeowners from ages 25-45

- Consists of individuals who recently purchased their homes and are looking to enhance living spaces
- Look to grow plants for aesthetic, health, or food production purposes
- May have young families and look to create a healthy environment at home
- Familiar with technology and specifically smart home devices, open to using technology to streamline their daily routine

Geographic: Suburban areas of North America

- Homes in this area have more space: gardens, patios, balconies
- Backyards and large living space allows for both indoor and outdoor gardening
- Often face fluctuating weather conditions, making it difficult and time-consuming to maintain consistent plant care [4]

Economic: Middle-income bracket

- Earn enough disposable income to invest in hobbies and lifestyle improvements such as gardening
- Seek solutions that can help them maintain their garden hobby while investing little effort

Competitive landscape

Smart Irrigation Systems – Rachio Smart Sprinkler Controller [14]

Challenges Addressed

- Uses weather data to and sensors to automatically water plants
- Tracks temperature and soil moisture
- Addresses issue of inconsistent soil moisture

Shortcomings

- Do not offer real-time feedback on individual plant conditions – users do not have a way to view measured sensor values
- Primarily designed for outdoor use
    - Costly for homeowners looking to monitor small indoor gardens
    - Does not accurately track indoor temperature
- Require integration with other smart home devices, adding complexity and additional costs
- [14] On the company's website, Rachio sells individual sensor management systems which range from 99USD - 300USD, whereas the bundle product costs 500USD for both soil moisture and temperature sensors.

Indoor Smart Planters – Click & Grow Garden [15]

Challenges Addressed

- Manages resources using automated watering systems, built-in grow lights, and sensors monitoring temperature and soil moisture
- Allows gardeners to maintain plant health with minimal effort

Shortcomings

- Not suitable for outdoor use where plants are grown in traditional soil beds
- Built-in features like automatic lighting do not cater to those who enjoy the creative aspect of customizing their plant care routines
- Costly: products start from 300USD and reach up to 1300USD

Gardening Mobile Apps – PlantSnap [18]

Challenges Addressed

- Provide plant care tips
- Resource management: users should adjust environmental conditions only when prompted to do so
- Aids users in developing creative care routines for plants

Shortcomings

- Do not report soil conditions to user – user must measure soil conditions themselves, which is time-consuming
- Advice given is very generalized since plant condition is not known to the app, potentially leading to poor resource management

Requirement Specification

<u>Functional requirements</u>

1. **Wireless Communication Distance**
    - Requirement: Maintain mutual connection between sensor (microcontroller 1) and user interface (microcontroller 2) over a range of 15 meters at baud rate 38400
    - Permitted Range: 5m ≤ distance ≤ 25m
    - Measurement: Test signal transmission success rates at different distances
    - Reference: [5] HC-05 Bluetooth modules support ranges of up to 30m
      [6] In Ontario, the median above-grade living area of a single-detached house is 1,520 square feet. Square dimensions of 11.9m*11.9m, with a diagonal distance of 16.8m. To adjust to rectangular floor plans, the maximum transmission range is set to 25m.
2. **Temperature Measurement Accuracy**
    - Requirement: Measure the average temperature of the soil with an accuracy of ±1˚C
    - Permitted Range: 10˚C ≤ Temperature reading ≤ 50˚C
    - Measurement: ˚C
    - Reference: [8] Most houseplants grow best in a soil temperature between 15-24°C
3. **Moisture Measurement Accuracy**
    - Requirement: the microcontroller must measure humidity of soil within 5%VWC (Volumetric Water Content)
    - Permitted Range: 21% ≤ water moisture ≤ 80%
    - Measurement: VWC (volumetric water content)
    - Reference: [10] Most houseplants grow optimally with water moisture of 21% to 80%

<u>Technical requirements</u>

1. **Thermocouple Range & Error Range**
    - Requirement: accurately measure temperature between 10˚C and 50˚C with accuracy of ±1˚C
    - Permitted Range: 10˚C ≤ temperature ≤ 50˚C
    - Measurement: ˚C
    - Reference: [7] Standard thermocouples get within approximately 1% of the actual temperature at the measuring junction, which is about 0.5˚C at temperature reading of 50˚C
2. **Soil Moisture Sensor Range & Error Range**
    - Requirement: the microcontroller must measure humidity of soil within 5%VWC
    - Measurement: [measure the RH (relative humidity) of dry air and water to find the readings of 0%RH and 100%RH, and map other RH in between the readings.
    - Reference: [9] operating range of SKU:SEN0193 is between 10˚C and 60˚C, can read exact RH values
3. **Wireless Data Packet Size**
    - Requirement: Packet Size should not exceed 64 bytes, transmission success rate above 98%
    - Permitted Range: packet size ≤ 64 bytes
    - Measurement: inspect and calculate packet size in firmware code

- Reference: [11] hc-05 Bluetooth maximum packet size range from 1kb to 3kb depending on the distance

4. **Screen Size**
   - Requirement: LCD screens must display 32 characters with character font size of at least 24 (~8.5mm)
   - Permitted Range: character size $\geq$ 8.5mm
   - Measurement: character size (mm)
   - Reference: [12] The recommended font size for comfortable reading from 10 feet away is 72, 1m is 3.3 feet and thus the recommended font size is 24.

<u>Safety requirements</u>

1. **Environmental Resistance:**
   - Requirement: Microcontroller must be encased in a water-resistant casing to protect against accidental water spills and high moisture levels (IPX4 rating).
   - Permitted Range: Must meet IPX4 water resistance standards.
   - Measurement: Test by exposing item to an oscillating spray for a minimum of 10 minutes, as per IPX4 guidelines
   - Reference: [13] IEC 60529:2013 Defines ingress protection ratings for Enclosures.
2. **Energy Consumption:**
   - Requirement: the system will not consume, transfer, or discharge more than 30W of energy
   - Permitted Range: power $\leq$ 30W
   - Measurement: use a voltmeter to measure voltage and current to calculate power consumption
   - Measurement Units: W
   - References: Project rubric
3. **Energy Storage:**
   - Requirement: The system will not store more than 500 mW of energy at any point in time
   - Permitted Range: power stored $\leq$ 500 mW
   - Measurement: use equations for any necessary energy storage components (inductor, capacitor, etc) to calculate energy stored
   - Measurement Units: mW
   - References: Project rubric

Analysis
Design

Technical Analysis
<u>Power equation</u>

- To test our energy consumption, power will be calculated using the equation: P=IV [19]
- Where:
  - P = power
  - V = the difference in voltage between the cathode and anode of the power supply
  - I = current
- **Implementation**
  - After wiring is completed, we will attach a voltmeter to the Voltage and ground and measure the difference in Voltage and current, then we will verify, using the above equation, that our system satisfies the safety requirements

<u>Energy Stored in Capacitors equation</u>

- To calculate the energy stored in our system at any given time, we will need to calculate the Energy stored in capacitors using the equation: E=1/2CV^2
  - E = stored energy in Joules
  - C = capacitance in Farad
  - V = voltage across the capacitor
- **Implementation**
  - To measure the energy stored in our system, we will measure each capacitor used in the microcontroller and ones that we use in our circuitry. We will measure the voltage difference across the capacitor, and we will research specific capacitance for each capacitor, then we will assess our energy levels in comparison to the safety requirements.

<u>RH to VWC conversion equation</u>

To measure we will be converting the readings from RH to VWC, which includes a multi-step equation: [20]

1. Calculating soil water potential: $\psi = \frac{RT}{V_m}\ln(\mathrm{RH})$
   - ψ = soil water potential
   - R = universal gas constant
   - V_m = molar volume of water
   - RH = relative humidity
2. Van Genuchten’s (1980) model to calculate VWC $\theta = \theta_r + \frac{\theta_s - \theta_r}{[1 + (\alpha|\psi|)^n]^{1-1/n}}$
   - θ = VWC
   - θ_s = saturated water content for given soil type
   - θ_r = residual water content for given soil type

        - α: soil-specific constant for how easily soil pores begin to drain
        - n: soil specific constant
        - ψ = soil water potential
        - Refer to [21] for soil-specific constants
- **Implementation**
    - To prototype, we will purchase a specific type of soil, then we will research the soil-specific constants, and write a driver which converts the voltage measured into RH, then use the above equation to display soil humidity in VWC

Costs

Manufacturing Costs

Implementation Costs

Risks

Energy analysis

Risk analysis

Testing & Validation

Test plan

Citations

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