Design Document

Soil Irrigation System

By

Aashi Chaubey

Nidhi Subrahmanya

Srija Chitturi

ECE-198

University of Waterloo

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Customers

Introduction

Our target customers for this project are individuals diagnosed with Dementia, Alzehimers, or other cognitive impairments who are passionate about gardening but unfortunately cannot due to memory challenges. To further tighten our customer base, we are specifically focusing on those living in Canada with Young-onset Dementia, Dementia that affects those between ages 40-65. According to a study by Alzeimer's Society of Canada, there are an estimated 28,000 Canadians suffering from Young-onset dementia [1], and these patients will be our customers. They often forget to water their plants or may overwater them, leading to the plants' deterioration.

This scenario is common among those with memory-related conditions. In a 2022 survey conducted with Dementia Adventure, 70% of respondents with dementia garden less or stopped gardening altogether after their diagnosis [2]. Gardening, a once-enjoyed hobby, becomes difficult and hard to manage for them. Therefore, we believe that with our project, we will help improve the lives of those with dementia, as they'll be able to continue with their previous hobbies without sacrificing them, and gardening has been shown to increase mental health.

Customer Definition/Challenges

Age Demographic

★ Unlike typical dementia, which primarily affects older adults, Young-onset dementia impacts people in the prime of their lives. This age group still holds responsibilities such as jobs, families, and social obligations. This disorder unfortunately disrupts their ability to manage many daily tasks. With so many daily tasks adding up, it's easy for these people to get overwhelmed, so reducing their task load would be a huge advantage for them.

★ Young-onset Dementia is relatively less common (with around 28,000 Canadians affected), meaning there are fewer resources, support groups, and systems specifically designed for this demographic. Many programs and interventions target older adults with dementia, so this group may feel underserved or overlooked by current support networks and services. The struggle to be diagnosed with dementia at such a young age is hard, and it can really impact someone hard emotionally and mentally. So, we aim to help ground these people.

Disorder Demographic: Struggle with Technology

★ For individuals with Young-onset Dementia, one of the significant challenges is interacting with technology. As their cognitive abilities decline, they may struggle with complex systems, remembering steps, or navigating unfamiliar interfaces. So, we aim to combat this struggle by keeping the system easy to use and automated.

Geographic Location

★ Canada has a very widespread population, meaning there are fewer healthcare facilities in more rural areas. Therapeutic programs are often in urban areas and people with dementia in rural areas may find it difficult to access these services. Our services must be accessible by everyone, no matter how far from an urban center they are.

★ (Specific to Gardening) Canada's weather fluctuates a lot. Areas with harsher winters or unpredictable weather patterns can make outdoor gardening more difficult. In colder months, many Canadians turn to indoor gardening, where the risk of overwatering or underwatering is high. And this is especially harder for people dealing with memory issues. We need a system that accounts for the weather fluctuations of Canada.

Economic

★ Some may have limited income due to their health status, relying on disability benefits or pension plans, which can affect their ability to afford high-cost technological solutions

Table 1 Components of the economic burden of dementia from 2020 to 2050 under current trends

Cost Component		2020	2030	2040	2050
Direct Costs	Emergency Dept.	$40	$70	$90	$100
	Hospitalizations	$6,440	$10,620	$15,270	$18,020
	Home care	$310	$510	$610	$630
	Long-term care	$6,990	$11,680	$17,760	$21,800
	Out of pocket	$1,360	$2,250	$3,230	$3,810
Productivity	Caregivers	$21,830	$35,990	$52,360	$60,730
	Dementia	$3,160	$4,130	$4,510	$5,190
Total		**$40,130**	**$65,230**	**$93,830**	**$110,280**

Figure 1: Table of Total Estimated Costs for Dementia Patients

Source: Adapted from [3]

★ According to the Canadian Centre for Economic Analysis, an average of $65,000 is spent per person with dementia[3]. Especially with the cost for caregivers and hospital fees so high, it's important we lessen the economic burden on our customers, so we must aim to make our products affordable.

Competitive Landscape

Three existing social, economic, or technological systems that address any or all of the defined challenges are identified. Explanation is given of how each of these systems addresses the defined challenges. Shortcomings of each of these systems with respect to the defined challenges are also explained. A minimum of one citation/reference is required for each system. Sources must be verifiable by the TA. If necessary, snapshots of relevant passages may be submitted. 5/3/1 points are allocated for 3/2/1 systems satisfactorily identified and detailed.

1. Horticulture Therapy:

Horticulture therapy is used to promote higher intellectual power, boost social interactions, improve emotional stability, and physical functions. It's the use of simple gardening activities to help the body mentally and physically. A 2024 study that lasted 5-weeks showed that those who had cognitive impairment demonstrated improvement in their cognitive, physical, and social functioning[4].

They address the following challenges: lack of social interactions, unavailability for all levels, mental stress, and lack of guidance.

1. These programs are designed to accommodate varying levels of ability, ensuring that participants can engage in gardening without feeling overwhelmed. Structured tasks help reduce confusion and provide clear instructions, making it easier for individuals with memory challenges to participate.
2. These programs often involve group activities, fostering social interaction and a sense of community among participants. Engaging with others who share a passion for gardening can enhance emotional well-being, reduce feelings of isolation, and provide a support network for individuals with dementia and their caregivers.
3. Participating in gardening activities can help maintain motor skills, enhance cognitive function, and provide sensory stimulation. Regular engagement in these activities can slow cognitive decline and improve overall mental health, offering therapeutic benefits beyond just the act of gardening. This was proven by the study, as it was shown that participants developed a better intellectual, social, emotional and physical wellbeing, even stating that a patient with previous knowledge assumed the role of co-facilitator and improved their self-determination[4].

An example of one of these horticulture programs is the Canadian Horticultural Therapy Association. This is a non-profit/social-profit organization, volunteer driven organization[5].

This organization runs many events for members, and runs a conference every year for non-members to come and learn. They encourage people of all ages, and have several activities, including, book-clubs, regional gatherings, webinars, and film-nights[5].

The limitations of these associations include: availability, cost, program quality, and physical presence.

1. There are several geographical limitations with this. These programs are not available all of Canada, especially in regions like Thunder Bay and more up North. For example, CHTA events, like the gatherings and conferences, take place in urban areas, making it harder for people in rural areas to access these.
2. Since CHTA is a non-profit organization, it relies on members to fund itself. For example, a student has to pay around $55 CAD annually to become a member, and the prices are increased for adults[5]. Members gain access to exclusive events, resources, and educational materials, but these perks may not be accessible to those who cannot afford the membership fees, limiting their ability to engage with the full range of programs. This price might be a barrier to many individuals, as it's a subscription basis too.
3. The quality and structure of therapeutic horticulture programs can vary depending on the facilitator's experience, funding availability, and regional support. In some areas, there may be limited access to highly trained horticultural therapists who specialize in working with individuals with cognitive impairments. The CHTA specifically relies on volunteers, so patients may not get the best treatment possible.
4. For many individuals with dementia, attending in-person horticultural therapy programs can be a challenge due to mobility issues or difficulties with transportation. And, in many cases, people with Young-onset Dementia may need to be accompanied by a caregiver to attend these programs, which most of the time is not plausible.

2. Locator Device

Locator devices provide a real-time tracking solution that enhances the safety of individuals with Young-Onset Dementia. They allow caregivers to monitor movements, reducing the risk of wandering and getting lost. For individuals who still enjoy outdoor activities like walking or gardening, these devices offer a balance between freedom and security.

How it addresses the defined challenges:

- ★ Independence with Safety: Individuals with dementia often struggle with the fear of getting lost, which can limit their ability to engage in activities like going for walks or gardening. Locator devices mitigate this issue by allowing individuals to roam freely while providing caregivers with the peace of mind that their location is being monitored. This balance helps maintain their independence without compromising safety.
- ★ Emotional Well-being: Engaging in outdoor activities like gardening provides emotional relief and cognitive stimulation, helping individuals maintain a sense of accomplishment. By ensuring safety during these activities, locator devices enable them to continue engaging in meaningful tasks, which can reduce emotional strain and frustration.

Shortcomings:

- ★ Technology Gaps: While locator devices are useful, they are not foolproof. GPS coverage can be inconsistent, particularly in rural or densely built areas, leading to potential lapses in tracking.
- ★ Cost Barriers: The high cost of these devices may place them out of reach for individuals relying on limited income, such as disability benefits or pensions. This financial barrier restricts access to an otherwise valuable tool.
- ★ Privacy Concerns: Constant tracking can raise issues of autonomy and privacy. Some individuals may feel uncomfortable with the idea of being monitored at all times, which could affect their willingness to use such technology [6]

3. MemRabel

System: Memory prompting calendar for seniors and people with deteriorating memory.
How it addresses the challenges mentioned: Assistive reminder devices help individuals with cognitive impairments by sending reminders for daily tasks. It is capable of setting daily time reminders to plan a person's daily routine using voice, picture & video reminder messages.

Shortcoming: While effective for reminders, these systems still require initial customization and some ongoing interaction, which may be difficult for individuals with dementia. Additionally, they rely on the user remembering to check or respond to the reminders.[7]

Requirement Specifications

A restatement of the requirements from the Project Proposal. Each requirement has a description, acceptable range, and units of measurement. One point deduction for each missing requirement or not specified appropriately

Requirement #1: Moisture Detection

1. Soil Moisture Detection
    - The sensor must detect soil moisture levels in the range of 0-100% (volumetric water content)
    - Trigger level to turn on the water pump: <30%soil moisture
2. Moisture Sensor Sensitivity
    - Resistive sensors must be accurate to ±5% for soil moisture readings
3. Waterproofing
    - All electronic components near water must be rated IP67 or higher to ensure waterproofing

Requirement #2: Water Pump Activation

1. Water Pump Activation
    - Water pump must switch on when the moisture level falls below 30%, and off when it exceeds 70%
    - The pump should respond within 10 seconds of detecting moisture below the threshold and should water for x amount of time determined by Darcy’s law based on the soil type
2. Waterproofing
    - All electronic components near water must be rated IP67 or higher to ensure waterproofing

Requirement #3: LED Status Indicators

1. LED Status Indicators
    - ★ The green LED must light up when the water pump is on
    - ★ The white LED must light up continuously for a maximum 24 hours until the plant has been watered by a human. If the 24 hours are exceeded, the water pump will automatically turn on and the white LED will turn off
    - ★ The red LED must light up when the water pump is off
    - ★ The LED status changes must occur within 10 seconds of a pump state change

Requirement #4: Power Supply

1. Power Supply
    - ★ The system operates on a 5V or 3.3V DC supply, depending on our sensor and microcontroller requirements
    - ★ The current consumption for the whole system must be under 150mA during operation [8]
2. Current Limiting
    - ★ The system must include a fuse or current limiter to protect against short circuits, with a limit of 150mA

Requirement #5: Energy Within System Must be Less than 500mJ

1. Energy Specification
    a. The soil irrigation system's energy consumption must be less than 500 millijoules (mJ) per operation cycle. This energy budget covers the entire cycle, including soil moisture detection, activation of water dispensing mechanisms, and any feedback or control signals processed by the system.

Design

The irrigation system will monitor soil moisture levels using two STM-32 microcontrollers and sensors to control the water pump to ensure optimal watering based on soil moisture content and environmental factors. The system will have sensors, controllers, and status indicators to automate irrigation.

Microcontroller #1 will continuously monitor the soil moisture levels via the soil moisture sensor. Once the moisture levels falls below its predefined threshold, the microcontroller will send a signal to controller #2 to turn off a white LED continuously for a maximum limit of 24 hours. This white LED signals that the plant needs watering.

If the plant is watered within the 24-hour period and the soil moisture level rises to the acceptable threshold, Microcontroller #1 will send a signal to Microcontroller #2 to:

- ★ Turn off the white LED
- ★ Turn on the green LED, indicating that the plant has been sufficiently watered

However, if the soil moisture level does not reach the required threshold within 24 hours, Microcontroller #1 will signal Microcontroller #2 to:

- ★ Turn off the white LED
- ★ Turn on the red LED to indicate that the water pump has been activated

Once the correct soil moisture level is reached, Microcontroller #1 will signal Microcontroller #2 to:

- ★ Turn off the red LED
- ★ Turn on the green LED, indicating that the irrigation is complete and the soil has the correct moisture level.

Key Components

- ★ Two STM32 Microcontrollers
    - **First Microcontroller:** The first STM32 microcontroller is responsible for reading soil moisture sensor data and determining if the moisture level is below a specified threshold. Based on this data, it signals the second microcontroller to activate the water pump if needed.
    - Specifications
        - Type: STM32F401RE
        - Input/Output Ports: Connects with the soil moisture sensor and communicates with the second microcontroller
        - Power Requirement: 3.3V DC
    - **Second Microcontroller:** The second STM32 microcontroller controls the operation of the water pump and LED indicators based on signals from the first microcontroller.
    - Specifications
        - Type: STM32F401RE
        - Input/Output Ports: Connects with the soil moisture sensor and communicates with the second microcontroller
        - Power Requirement: 3.3V DC
- ★ **Soil Moisture Sensor**
    - The soil moisture sensor measures the soil's moisture content and sends data to the first STM32 microcontroller. This data is used to determine whether the soil needs watering.
    - Specifications
        - Type: Resistive Soil Moisture Sensor
        - Output: Analog signal proportional to soil moisture level
        - Operating Voltage: 3.3V - 5V DC
        - Output Range: 0-3.3V
- ★ **Three LEDS**
    - **First LED**
        - Indicates when the system is powered on and ready for operation.

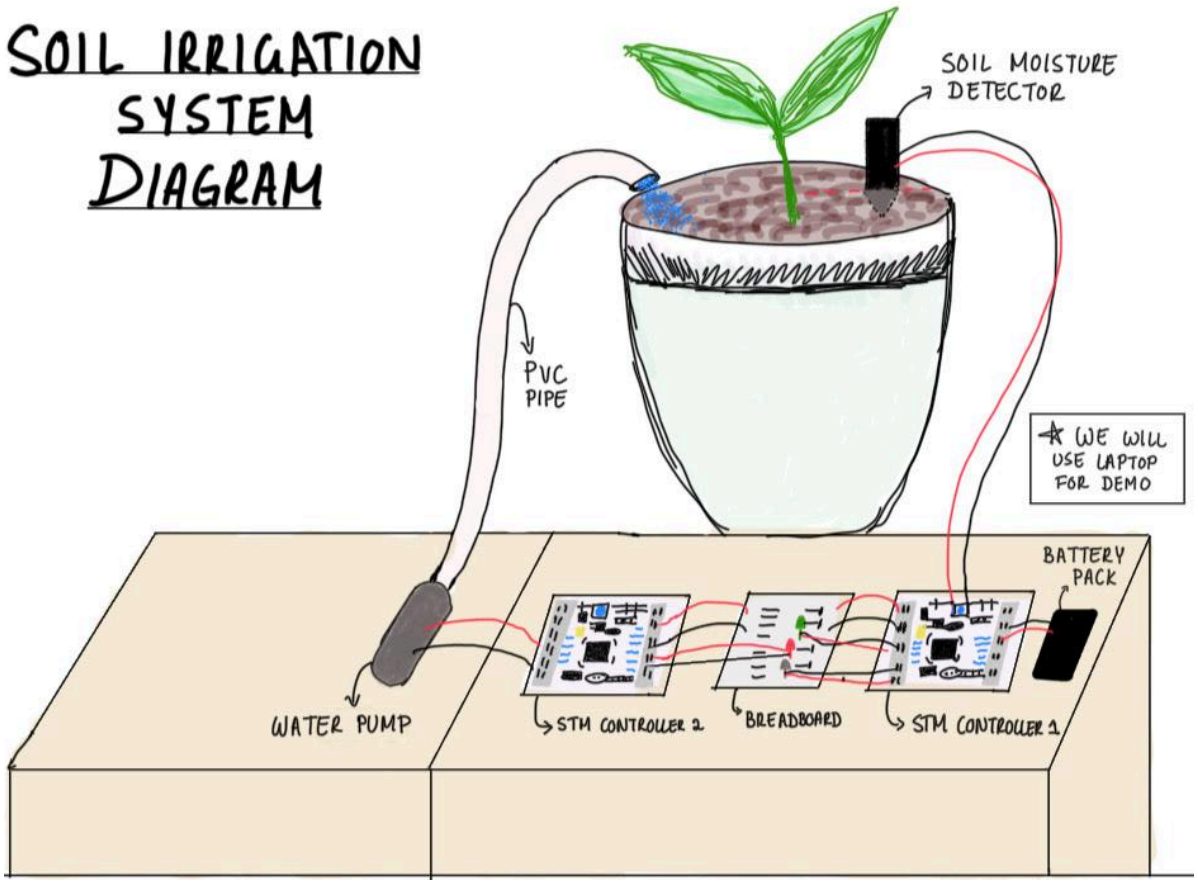
        - Specifications
            - Color: Green
            - Voltage Requirement: 3.3V DC
            - Current Requirement: ~20 mA
    - Second LED
        - Turns on when the soil moisture level is below the threshold, indicating that the plant should be watered.
        - Specifications
            - Color: Yellow
            - Voltage Requirement: 3.3V DC
            - Current Requirement: ~20 mA
    - Third LED
        - Indicates that the water pump is active.
        - Specifications
            - Color: Red
            - Voltage Requirement: 3.3V DC
            - Current Requirement: ~20 mA
- Water Pump
    - Supplies water to the soil when the first microcontroller indicates to the second controller to turn the water pump on.
    - Specification
        - Type: Submersible DC Pump
        - Flow Rate: Dependent on Darcy's Law
        - Run Time: Dependent on Flow Rate and Volume of Soil needed
        - Power Requirement: 5V DC
        - Activation: Controlled by the second STM32 microcontroller
- Power Source
    - Powers both STM32 microcontrollers and the water pump.
    - Specifications
        - **Type**: 6V DC Battery Pack

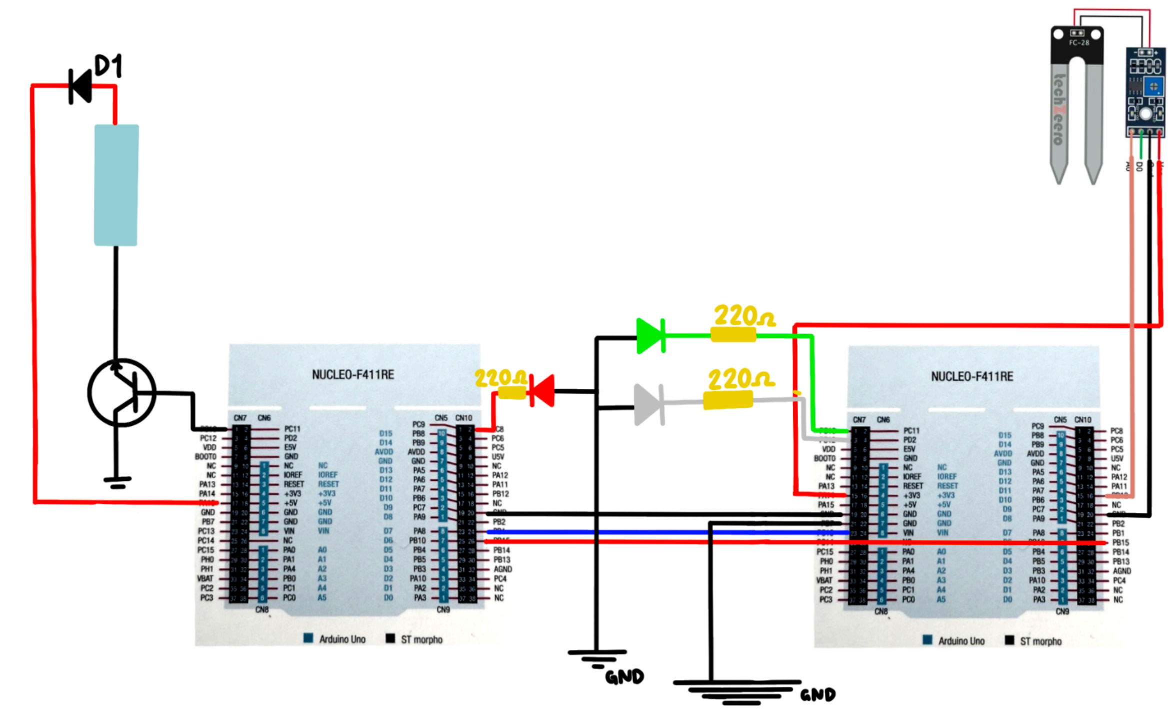
Steps

1. Requests User Input
    a. Using a front-end interface, app, or terminal, prompt the user to select:
        i. Soil Type: Choose from sandy soil, clay soil, or loamy soil. This choice will set the soil's permeability and use Darcy's Law to calculate the flow rate.
        ii. Pot Size: Choose from small, medium, large, or extra large. The pot size determines the soil volume, which is used to calculate the required flow time.
2. Calculate Water Flow Time
    a. We use Darcy's Law to calculate the water flow rate based on the soil's permeability and hydraulic gradient, which is determined by the selected soil type.
    b. Then this flow rate is used to determine the water flow time for the pot size specified by the user.
3. Determine Soil Moisture Level
    a. The Soil Moisture Sensor reads the moisture level of the soil and outputs a value between 0 and 1023 (Analog Output). [8]
4. Level Reading Interpretation
    a. The first microcontroller will read this value from the sensor. If the moisture reading is above 1/3 of 1023 (about 341), it indicates sufficient moisture, and the green LED is turned on(high voltage signal is sent to green LED).
    b. If the moisture reading is below 1/3 of 1023, it indicates that watering is needed. The green LED is turned off and the white LED is turned on to signal that the plant needs watering. The first microcontroller sends a signal to the second microcontroller to initiate watering if necessary.
5. Delay
    a. When the second STM32 receives this signal it implements a delay (of a few hours), allowing the user time to water the plant manually.
6. Watering Process

    a. Then the microcontroller will turn on the red LED, which means that the pump is activated. Then the water pump is turned on for the calculated flow time. Once the watering cycle completes, the pump and red LED turn off.
7. Repeat Monitoring
    a. Return to step 3 to continuously monitor the soil moisture and repeat the process.

System Layout & Circuit Diagram





Sample PseudoCode:

Pseudocode for Automatic Irrigation System

1. Define Variables

★ *soilMoistureValue*: to store the raw reading from the soil moisture sensor.

★ *percentage*: to store the soil moisture level as a percentage.

2. Setup Phase

★ Enable GPIO and ADC clocks to allow the STM32 to communicate with the sensor and control the pump.

★ Configure soil moisture sensor pin (analog input) to read moisture levels.

★ Configure pump control pin (digital output) to turn the pump on or off.

3. Main Loop

Read soil moisture value from the analog input (using ADC).

Convert the moisture value to a percentage using calibration values:

If the sensor reads a value near *dry soil*, set *percentage* to 0%.

If it reads a value near *wet soil*, set *percentage* to 100%.

Check soil moisture percentage:

If *percentage* is below 10%:

Turn the pump ON (set pump pin LOW if active low).

Display or log *Pump ON*:.

If *percentage* is above 80%:

Turn the pump OFF (set pump pin HIGH).

Display or log *Pump OFF*.

4. End Loop and Repeat

Alternate Solutions

Alternatives – Some other possible technical solutions were considered. Reasoning given for the solution selected. Reasoning is supported quantitatively by citations or technical analysis (below).

Design	Requirements
Capacitive Soil Moisture Sensor (instead of resistive sensor). Capacitive sensors measure soil moisture by detecting changes in the soil's dielectric property which doesn't require	Capacitive Soil Moisture Sensor: Must detect moisture levels within a range of 30-70% water content. Drip Irrigation Control: System should operate on a 5V DC to open/close the water flow. Microcontroller Requirements: Only one microcontroller would be required as the drop system would be activated based on threshold values on the sensor. Cons: Capacitive sensors can be more expensive than resistive

contact with the soil, preventing corrosion issues.	sensors and may require more specific calibration for accurate readings. [9]
Timer-Based Watering System with Environmental Sensors Instead of measuring soil moisture directly, this system uses a time-based watering schedule combined with environmental sensors (humidity, temperature, and sunlight) to adjust watering frequency.	Humidity, Temperature, and Sunlight Sensors: To monitor environmental factors and adjust watering times. Water Pump and Timer Module: The pump would be connected to a timer module programmed for specific watering cycles, adjusted based on environmental data. Microcontroller: Controls the timer and gathers environmental sensor data to adjust watering intervals Cons: This system does not account for real-time soil moisture, which could lead to overwatering or underwatering in certain conditions, especially during unexpected rainfall, sudden temperature changes, or if the user has already watered the plant. [10]
Irrigation using IoT-based Monitoring and control This advanced alternative uses IoT (internet of things) sensors (for soil moisture, humidity, and temperature) connected to an IoT platform for real-time monitoring and remote control. The platform can adjust	IoT-Compatible Sensors: Soil moisture, temperature, and humidity sensors connected to a cloud platform. Smart Controller: Receives data from sensors and uses machine learning algorithms to determine optimal watering patterns. Mobile App: Allows users to monitor and adjust settings remotely. Cons: Requires internet access and can be costly to set up and maintain, making it less feasible for smaller or low-budget projects. [11]

watering schedules and amounts automatically based on sensor data and environmental conditions.	

Why we chose our solution:
We chose a resistive soil moisture sensor with a drip irrigation system for its simplicity, low cost, and real-time soil moisture sensing capabilities. Unlike capacitive sensors, which can be more expensive and require calibration, resistive sensors are easy to implement and effectively measure moisture levels by detecting changes in soil resistance. This real-time feedback allows the system to adjust water flow directly, avoiding the over-or under watering issues that may occur in a timer-based system. Moreover, the Iot solution brought up issues like higher setup cost and complexity which may not suit our target audience's technological capacities and buying more, making the resistive sensor and drip system a more practical, cost-effective choice for small-scale irrigation.

Technical Analysis

Principles

Mathematical, Engineering, Scientific Principles

1. **Ohm's Law: V=I×R**

★ In the resistive soil moisture sensor, the resistance between the sensor leads changes as the soil moisture level changes. The voltage drop across the sensor can be measured and interpreted to determine the moisture level using Ohm's Law.

Principle: Ohm's Law states that voltage = current x resistance. Where resistance is inversely proportional to current. And voltage is proportional to resistance [12].

Application: The resistive soil moisture sensor has two probes that are inserted into the soil. The soil's moisture level impacts the electrical conductivity. If the soil is wet, then it conducts electricity better, as the current is higher, and the resistance is lower. If the soil is dry, then it conducts electricity poorly, and the resistance is higher. In this case, the system applies a known constant current. Using Ohm's Law, the voltage drop across the probe's can be measured, so lower voltage would indicate wet soil and high voltage would indicate dry soil. Ohm's Law can be used to interpret the sensor voltage readings, and the system can accurately control the water pump.

2. Darcy's Law

Principle: Darcy's Law describes the flow of fluid through a porous substance, stating that the flow rate is proportional to the hydraulic gradient and permeability of the medium. [13] It is expressed as $Q = -k \cdot A \cdot dH/dx$, where Q is the flow rate, k is the hydraulic conductivity, A is the cross-sectional area, and dH/dx is the hydraulic gradient [14].

Application: This concept can be applied to the water distribution system to understand how water seeps through soil when the pump is activated [15]. Based on the values provided from the calculation, it is possible to compare the water needs of different soil types and can help determine how long the water pump should run and how much water to deliver [16]. This prevents overwatering or underwatering, making the system more effective and efficient.

Contribution: Understanding how water moves through soil ensures that the system delivers the right amount of water based on soil moisture levels, preventing over or under-watering.

Application: Using Soil Type to Adjust Flow Rate and Run Time

Different soils affect the flow rate due to their unique k values:

- Sandy Soil: High k, so water flows quickly through it.
- Loamy Soil: Moderate k, balances water retention and drainage.
- Clay Soil: Low k, water moves slowly, increasing run time for effective irrigation.

To determine run time, we'll input soil type to set the appropriate k value in our calculations, then use the Darcy's Law formula to find flow rate and estimate run time based on water needs.

Example

Let's say we need 200 cm^3 of water to reach the desired moisture level.

1. Set Hydraulic Conductivity (k) Based on Soil Type

- Sandy Soil: $k \approx 0.1$ cm/s
- Loamy Soil: $k \approx 0.05$ cm/s
- Clay Soil: $k \approx 0.01$ cm/s [17]

2. Calculate Flow Rate () Using Darcy's Law

- Suppose the root zone area (A) is 100 cm^2, and we use a hydraulic gradient (dH/dx) of 1 cm/cm for simplicity.

For Loamy Soil:

$Q=k \cdot A \cdot dHdx=0.05 \cdot 100 \cdot 1=5$ cm^3/s [18]

3. Determine Run Time Based on Total Volume Needed

- Total water needed: 200 cm^3
- With Q=5 cm^3/s

Therefore Run Time=200 cm^3/5 cm^3/s=40 s for loamy soil. The same calculation can be applied to other soil types.

Sandy Soil

- Flow Rate (Q): 10 cm^3/s
- Run Time: 20 seconds

Loamy Soil

- Flow Rate (Q): 5 cm^3/s
- Run Time: 40 seconds

Clay Soil

3. Flow Rate (Q): 1 cm^3/s

4. Run Time: 200 seconds

3. Electrolytic Conductivity and Water Retention Capacity

Principle: The electrolytic conductivity of soil depends on the concentration of dissolved ions in soil water, which rises with soil moisture. When soil moisture increases, conductivity improves, allowing ions to move more freely between sensor probes, reducing measured resistance. This conductivity varies with soil type, as each type has different water retention capacities—for example, clay holds water longer while sand drains quickly.

The relationship between conductivity and ion concentration can be expressed by the formula: $\kappa = \sigma \cdot C$

where:

- κ is the electrolytic conductivity of the soil-water mixture, indicating how easily current flows through the soil .
- *σ sigmaσmolar conductivity*, property related to soil composition and ion types present in the water.
- C is the ion concentration in the soil, which rises as soil moisture increases, improving conductivity .

As soil moisture increases traction - C rises, enhancing the conductivity κ, which the sensor detects as lower resistance.

Application: Soil Moisture Sensing through Conductivity and Water Retention

1. Electrolytic Conductivity for Sensing: The resistive soil moisture sensor measures electrolytic conductivity to gauge moisture levels. When the soil is wet, a higher concentration of ions leads to lower resistance between sensor probes. This change is detected by the sensor, with higher moisture causing lower resistance and drier soil causing higher resistance .
2. Water Retention Adjustment: Different types of soil have varying water retention characteristics:

- Clay soils (high retention) retain ions for longer, resulting in lower resistance for extended periods after watering.
- Sandy soils (low retention) dry quickly, leading to higher resistance soon after watering

By configuring the system with the soil type, we can adjust the frequency of moisture checks and watering intervals, saving water and ensuring the plant roots are neither too dry nor oversaturated.

Example:

Sandy Soil

- Initial Condition: 300 Ω (wet).
- Check Interval: Every 30 minutes.
- Example: After 1.5 hours, resistance hits 1000 Ω, and the pump turns on.
- Summary: Waters every 1.5 hours due to faster drying and frequent checks.

Since our system needs to check soil moisture at least every 30 minutes, we decided to keep it on continuously. However, to optimize electricity usage, we will only activate the moisture check every 30 minutes.

Costs

Bill of Materials

Soil Irrigation System						
Manufacturer	Geographic Location	Item	Link	Units	Unit Cost	Total Cost
DUTTY	Made in China	Soil Hygrometer Detection Module, Soil	Soil Hygrometer Detection Module, Soil Moisture Sensor, 5PCS : Amazon.ca	1	$2.59	$12.99

		Moisture Sensor				
STMicroelectronics	Shipped from Switzerland	STM32-Nucleo-64	STM32-Nucleo-64	2	$20.31	$40.62
Würth Elektronik	Shipped from Germany	LED	LED RED DIFFUSED ROUND	3	$0.40	$1.20
POWXS	Manufactured in Canada	1.5 V Batteries	POWXS AA Lithium Batteries, 4 Pack 1.5V Lithium Iron Double A Batteries 3200mAh Super Capacity for Blink Camera, Video Doorbell, Flashlight, Toys, Remote Control【Non-Rechargeable】: Amazon.ca	4	$3.99	$15.99
Pimoroni Ltd	Manufactured in Canada	Water Pump	MINI SUBMERSIBLE WATER PUMP	1	$4.70	$4.70
GeekStory Store	Manufactured in Canada	3.3 Voltage Regulator	AMS1117-3.3 Voltage Regulator Step Down Power Supply Buck Module 4.2 V-10 V to 3.3V 800mA Geekstory (Pack of 10)	1	$11.13	$11.13
Aypzuke	Manufactured in	Breadboard Kit +	Breadboards Kit Include 1PCS 830	1	$19.99	$19.99

	Canada	Jumper Wires	Point 1PCS 400 Point Solderless Breadboards +65pcs Jumper Wires +140pcs Jumper Wires+1pcs Tweezer : Amazon.ca			
Proper Pour	Manufactured in Canada	PVC pipe	Proper Pour 10 Feet 3/8 inch ID 1/2 inch OD Clear Vinyl Tubing Food Grade Multipurpose Tube for Beer Line, Kegerator, Wine Making, Aquaponics, Air Hose : Amazon.ca	1	$14.99	$14.99
YAGEO	Shipped from Taiwan	220 Ohm Resistor	220 Ohm Resistor 5% 1/4W AXIAL	3	$0.16	$0.48
Central Semiconductor Corp	Shipped from United States	Bipolar NPN Transistor	Bipolar NPN Transistor	1	$0.75	$0.75
Diodes Incorporated	Shipped from United States	Diode	Diode: TRANS NPN 45V 0.1A SOT323	1	$0.17	$0.17
Total Cost					$84.17	$73.19

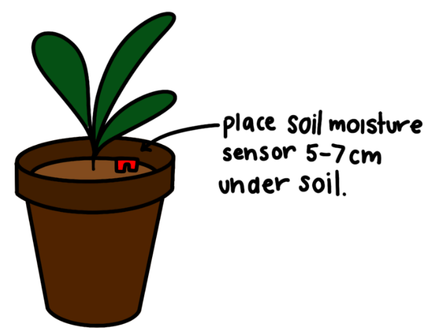
Installation Manual

What’s Inside:

- ★ Soil Moisture Sensor: Detects the moisture level in the soil. When the soil is dry, it signals the need for watering; when it's wet, no watering is needed.
- ★ Central Device: Acts as the brain of the system, deciding when your plants need water. It contains two STM microcontrollers and a breadboard internally, with three LED lights (green, white, and red) visible on the outside to show the system's status. It's connected to the soil moisture sensor.
- ★ Water Pump and Drip Irrigation: Delivers water to your plants only when needed. Includes a water pump and tubing to distribute water directly to the plant.
- ★ LED Indicators: Lights that provide visual signals about the system's status (low moisture, watering, or adequate moisture).

Steps:

1. Place Your Soil Moisture Sensor



Insert the soil moisture sensor probes about 5-7 cm deep into the soil near the root zone of your plant. This depth allows the sensor to measure moisture where the plant roots absorb water. Ensure the sensor is secure and stable in the soil.

2. Set Up the Water Pump and Irrigation System

Place the end of the tubing connected to the water pump near the base of the plant's soil to ensure water reaches the roots when the pump is on. Fill the water pump with water.

3. Power Your Water Buddy

Insert 4 AA batteries to supply power to the Water Buddy system. Your Water Buddy is installed and ready to use!

User Guide

Welcome to Your Water Buddy!

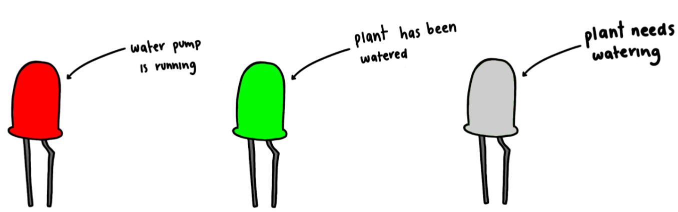
Overview:

Your Water Buddy is an automatic watering system that helps keep your plants healthy and hydrated. It senses when the soil around your plant is dry and flashes a light to let you know it needs water. If you forget to water it, don't worry—within a day, Water Buddy will water the plant itself to keep it thriving!

1. Understanding the LED Signals

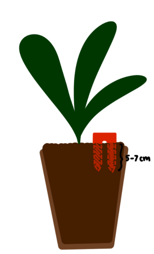
Your Water Buddy uses three LED indicators to let you know your plant's status:

- ★ Green LED: This means the soil has enough moisture, so no watering is needed at this time. Your plant is healthy and happy!
- ★ Flashing White LED: The soil is getting dry, and the Water Buddy is preparing to water. If you want to water it manually, you can do so now until the white light stops flashing and the green LED turns on. This is your friendly reminder to water your plant.
- ★ Red LED: The Water Buddy is actively watering the plant with the pump on, delivering water directly to the roots. No action is needed on your part—your Water Buddy is handling it!



Tips for Optimal Use

- ★ Sensor Placement: Make sure the moisture sensor is positioned properly at the root level, as this ensures it gives accurate readings for your plant's needs (refer to Installation Manual)



★ Water Source: Remember to refill the water pump every week! Keep the water container filled, especially if you're relying on Water Buddy's automatic watering function. This way, the pump always has water available.
★ Power: Check the batteries or power source regularly to ensure the system runs smoothly.

Troubleshooting

★ LED Lights not turning on: Ensure all 4 batteries are fully charged.
★ Continuous Watering: If the red light stays on, double-check the sensor placement or try repositioning it to make sure it's at the right depth.
★ Pump Not Running: Confirm that all connections are secure, and make sure the pump has a stable water supply in its container.

With your Water Buddy, caring for plants has never been easier. Now you can enjoy healthy, thriving plants without the stress of daily watering. Let Water Buddy handle the rest! 🌱

Risks

Energy Analysis

Objective: Confirm that the smart irrigation controller system meets design requirements for power and energy, ensuring it does not exceed the specified 500 mJ (0.5 J) energy limit and 30 W power cap. This analysis includes a breakdown of energy storage, energy use, and compliance with baseline standards.

Reference Standards and Evidence of Appropriateness

1. Reference Standard for Power Levels:
    - The design uses a baseline power consumption standard based on average current draw for typical battery-operated systems within the target voltage range.
    - *Standard*: 1.5V alkaline batteries in series provide stable power levels suitable for low-energy electronics. [19]
2. Sufficient Evidence for Standard Appropriateness:

- The use of four 1.5V batteries (6V in total) aligns with common industry standards for microcontroller-driven circuits. The design is specifically built to avoid requiring a higher-power AC adapter, enabling low-energy, portable use without significant energy storage.
- *Visual Evidence*: A picture of the battery configuration, wiring, and connections would substantiate compliance with battery safety and suitability standards. [19]

Component Analysis and Energy Storage Consideration

1. Significant Energy Storage Identification:
   - The controller operates solely with four 1.5V batteries in a series connection. No capacitors or large inductors are incorporated that might otherwise act as temporary energy storage components, limiting significant energy retention.
   - *Scientific Reasoning*: The system's power source (alkaline batteries) lacks the capacity to store excess energy beyond the specified operational usage. Geometrically and materially, the circuit layout is designed without additional storage components, ensuring compliance with the 500 mJ cap.
2. Energy Storage Quantification:
   - Electrical: With the batteries and microcontroller circuit, the system is calculated to operate within a maximum energy of 500 mJ over a runtime of up to 1.67 seconds.
   - Chemical: Alkaline batteries store chemical energy, but in this configuration, they release energy at a rate that directly supports low-power device operation, minimizing risk of overload. [21]
   - Mechanical: No mechanical components (e.g., springs, motors) are present that would contribute additional kinetic or potential energy.
3. Maximum Energy Stored in System:
   - Formula Used: $E=V\times I\times t$
   - With a current draw of 50 mA, voltage of 6V, and energy limit of 500 mJ, the maximum operational time achievable is:

$$t=E/P=0.5J/0.3W\approx 1.67 \text{ seconds}$$

Risk Analysis

The smart irrigation controller is designed to operate within specific parameters to assist users with cognitive impairments. This risk analysis considers potential hazards, unintended use, malfunctions, and their possible impacts on safety and the environment.

1. Risks from Intended Use

- Battery Leakage:
    - Risk: Over time, batteries can degrade and leak hazardous chemicals if not replaced periodically.
    - Consequence: Leakage could harm the environment by contaminating soil and groundwater. For users, it could cause skin irritation or respiratory issues if exposed to fumes.
    - Mitigation: Ensure that the device includes a clear indicator or periodic maintenance instructions for battery replacement. [22]
- Short Circuit:
    - Risk: If water seeps into the battery compartment or circuitry, a short circuit could occur.
    - Consequence: This could lead to the overheating of components, possibly creating a fire hazard.
    - Mitigation: Encasing the circuitry in a water-resistant shell and placing a warning label to keep the device dry can reduce this risk.

2. Risks from Incorrect Usage

- Overuse of Batteries:
    - Risk: Users may attempt to use the device with depleted batteries without realizing the reduced capacity for consistent power.
    - Consequence: Batteries drained to extreme levels are more prone to leakage or rupture. This poses both environmental and user safety risks.

    - Mitigation: Provide user guidance on when to replace batteries and avoid overuse.
- Improper Installation:
    - Risk: Users may incorrectly assemble or connect the battery terminals, resulting in reverse polarity.
    - Consequence: This can cause immediate device malfunction and potentially damage the electronic components, shortening the device lifespan.
    - Mitigation: Design clear visual aids and markings on the device to guide correct battery installation. [23]

3. Risks from Misuse or Unintended Use

- Use in Wet Conditions:
    - Risk: If used in high humidity or direct water exposure (e.g., submerged), unintended moisture could affect electronic performance.
    - Consequence: Water exposure could short-circuit the device, posing a shock risk if handled immediately after. Environmental concerns include potential chemical leaching if batteries are damaged.
    - Mitigation: Include a warning to keep the device away from water and consider adding a moisture barrier or waterproof casing if feasible.
- Overloading the Circuit:
    - Risk: Using higher-voltage batteries than recommended could overload the circuit.
    - Consequence: This could cause immediate device overheating or electrical failure, risking both user safety and potential environmental hazards from burned components.
    - Mitigation: Specify appropriate battery types in the instructions and label the device to only use standard 1.5V batteries.

4. Potential Malfunctions

- Sensor Malfunction:
    - Risk: If the soil moisture sensor malfunctions, it may fail to trigger the irrigation system.

  - Consequence: Plants may not receive water as needed, leading to user frustration or plant damage.
  - Mitigation: Implement a basic calibration routine or fault indicator to alert users if the sensor is unresponsive.
- Power Supply Interruption:
  - Risk: If there's a loose connection or intermittent battery contact, power delivery could be disrupted.
  - Consequence: An interruption could cause device performance issues, leading to inconsistent watering or total device failure.
  - Mitigation: Secure battery connections within the compartment and use shock-absorbing materials to minimize connection issues. [24]

5. Safety and Environmental Consequences of Failure Mechanisms

- Short Circuits and Overheating:
  - Consequence: Potential fire hazard and risk of toxic fumes if any components are damaged by high heat.
  - Environmental Impact: Damaged or burned components might leach hazardous materials into the environment upon disposal.
  - Mitigation: Integrate thermal cutoffs or fuses if feasible to prevent damage from short circuits.
- Battery Leakage:
  - Consequence: Possible user exposure to chemicals and environmental contamination from battery acids.
  - Environmental Impact: Leakage could release harmful chemicals into soil or water if improperly disposed of.
  - Mitigation: Promote proper battery disposal methods in the instructions.
- Electrical Component Failure:
  - Consequence: Intermittent or unreliable device performance, potentially affecting plants and user safety.
  - Environmental Impact: Increased electronic waste if failures lead to premature disposal.

- Mitigation: Regular inspection and maintenance schedules provided in user instructions can help reduce waste.

Testing and Validation

Test 1: Verifying Power Supply

We need to verify that the power supply reaches throughout the circuit and is even to all the components, especially during the water pumping.

To test this we will connect our 6V power supply to both STM32 microcontrollers, LEDS, the moisture sensor, and water pump. We can use a multimeter connected between the power input and each component to check the power input and output of the multimeter. If the readings show power entering the component, then we know that the power is running through the circuit.

Test Inputs: Under normal conditions and also when the water pump is active(at maximum usage).

Quantifiable measurement: The measured voltage at each component remains at the expected level (e.g., 3.3V for microcontrollers). The measured current at each component remains under 150 mA.

Pass Standard:

- ★ Voltage at each component remains within ±5% of required levels.
- ★ No fluctuations in voltage or signs of power instability under peak load.
- ★ Power supply continues to provide stable output for three full system cycles without variance.

Test 2: Testing the Moisture Detection

We need to verify the detection of soil moisture levels and signal output to the microcontroller.

To test this we will connect the soil moisture sensor to the first STM32 microcontroller. We will place the sensor in various soil samples with controlled moisture levels. Then we will check the output readings on the STM32 microcontroller which should correspond to these moisture levels.

Environmental Parameters: The different soil types(sandy soil, clay soil, and loamy soil) and indoor humidity levels. Test each soil type in a 1-liter container for consistency.

Test Inputs: Manually alter the soil moisture in each soil type. First 0% moisture, then 50%, and then 100%.

Quantifiable Measurement: Measure sensor output voltage or digital signal on a scale from 0 to 1023. 0% moisture corresponds to 0, 50% moisture corresponds to ~510, 100% moisture corresponds to 1023. Resistive sensors must be accurate to ±5% for soil moisture readings.

Pass Standard:

- ★ For dry soil the sensor output should be < 341 (1/3 of 1023) and signal sent to indicate insufficient moisture
- ★ For moist soil the sensor output must be between 341 and 682 (1/3 to 2/3 of 1023) with no action taken
- ★ For saturated soil the sensor output should be > 682, signaling sufficient moisture
- ★ Same results for three trials for each soil type

Test 3: Checking for Water Pump Activation

We need to verify that the water pump activates only when soil moisture is below threshold and operates for the correct calculated flow time.

Do the calculations for the different soil types and find the theoretical flow time. Then use a timer to check if our water pump matches the theoretical flow times for each soil type.

Environmental Parameters: The different soil types(sandy soil, clay soil, and loamy soil) and indoor humidity levels

Test Inputs: Manually alter the soil moisture in each soil type. First 0% moisture, then 50%, and then 100%. Check flowtimes for each soil type: sandy soil, clay soil, and loamy soil.

Quantifiable Measurement Standard: Use a stopwatch to measure delay and flow time. Check if the right LEDS are activated for each soil moisture level.

Pass Standards:

★ Pump activates after the delay set for user watering time and operates for the pre-calculated flow time for each soil type
★ Pump turns off immediately after the calculated time has elapsed
★ Three trials for each soil type must yield consistent results

Test 4: Testing the LED Status Indicators

We need to verify that the LEDs accurately indicate system states: moisture level, pump activation, and warnings.

Connect Green, White, and Red LEDs to the first and second STM32 microcontrollers as specified. Check if the LEDS are activated at the right moisture levels, again, use controlled moisture levels of 0%, 50% and 100%.

Parameters: Set supply voltage to 3.3V for the LEDs.

Test Inputs: Test two cases, moist soil and dry soil. When there's moist soil the green LED should be on. And when there's dry soil the white LED should be one. And turn the water pump on to check if the red LED is working.

Quantifiable Measurement Standard: Observe LED status changes based on moisture levels and pump activation. Ensure LED status matches output readings from soil sensor.

Pass Standards:

- ★ Green LED lights when moisture is sufficient
- ★ White LED lights when moisture is below threshold
- ★ Red LED lights only when the pump is active and turns off when the pump stops
- ★ LEDs respond consistently across three repeated tests for each condition

Test 5: Checking Energy Consumption

We need to verify that the soil irrigation system's energy consumption does not exceed 500 millijoules (mJ) during the full operation cycle.

We can use the formula $E=V\times I\times t$, and place the multimeter in series with different components to find the different voltages and currents. We have to make sure our energy calculated at each component is less than 500mJ. Begin energy logging at the start of the cycle (when the sensor detects dry soil) and continue until the cycle completes (when the target moisture level is reached). Conduct the test for a minimum of three cycles to ensure consistency in energy usage.

Environmental Parameters: Maintain indoor humidity between 20-25 degrees celsius to keep soil from drying up.

Test Inputs: Set the system to start a cycle when soil moisture falls below a specified threshold (e.g., 30% relative moisture level). Start with a dry soil sample to trigger the moisture sensor, starting the irrigation cycle.

Quantifiable Measurable Standards: Compare energy usage at 100%, 50%, and 20% battery charge levels. Energy consumption should remain consistent within ±5% across different charge levels.

Pass Standards:

★ The system completes each irrigation cycle with an energy consumption of less than 500 mJ.

Citations

[1]
"Young-onset dementia growing in Canada. What's behind this rise? - National | Globalnews.ca," *Global News*. Available: https://globalnews.ca/news/10237254/young-onset-dementia-canada/
[2]
"Gardening and dementia," *Thrive*. Available: https://www.thrive.org.uk/get-gardening/gardening-and-dementia
[3]
Canadian Centre for Economic Analysis, "Dementia in Canada: Economic Burden: 2020 to 2050," 2023.
[4]
A. Lesnik and D. Spadafora, "Horticulture Therapy for Older Adults with Alzheimer Disease and Related Dementias (ADRD) - Report Series # 3," Sep. 2005.
[5]
"The Canadian Horticultural Association – Well With Nature," *Chta.ca*, 2024. Available: https://chta.ca/
[6]
"Shopping for assistive products," *Alzheimer Society of Canada*. Available: https://alzheimer.ca/en/help-support/dementia-resources/shopping-assistive-products
[7]
"MEMRABEL 2 DAILY CALENDAR ALARM REMINDER CLOCK," *Medpage-ltd.com*, 2020. Available: https://www.medpage-ltd.com/Memrabel-2-Dementia-Clock. [Accessed: Oct. 30, 2024]
[8]
"Learn Coding with Arduino IDE – Soil Moisture Sensor «osoyoo.com," *osoyoo.com*. Available: https://osoyoo.com/2017/12/28/arduino-lesson-soil-moisture-sensor/
[9]

L. García, L. Parra, J. M. Jimenez, J. Lloret, and P. Lorenz, "IoT-Based Smart Irrigation Systems: An Overview on the Recent Trends on Sensors and IoT Systems for Irrigation in Precision Agriculture," *Sensors*, vol. 20, no. 4, p. 1042, Feb. 2020, doi: https://doi.org/10.3390/s20041042

[10]

V. Sharma, "Soil moisture sensors for irrigation scheduling," *extension.umn.edu*, 2019. Available: https://extension.umn.edu/irrigation/soil-moisture-sensors-irrigation-scheduling

[11]

Senthil Vadivu Mani, Purushotham Reddy M, K. Rane, and N. B. Behare, "An IoT-Based System for Managing and Monitoring Smart Irrigation through Mobile Integration," *ResearchGate*, Jul. 05, 2023. Available: https://www.researchgate.net/ publication/372154590_An_I oT- Based_ System_for_Managing_and_Monitoring_Smart_Irrigation_through_Mobile_Integration

[12]

Fluke, "What is Ohm's Law?," *www.fluke.com*. Available: https://www.fluke.com/en-ca/learn/blog/electrical/what-is-ohms-law

[13]

"Darcy's law," *Columbia.edu*, 2019. Available: https://www.ldeo.columbia.edu/~martins/climate_water/lectures/darcy.html

[14]

S.-F. Lu, Z.-J. Han, L. Xu, T.-G. Lan, X. Wei, and T.-Y. Zhao, "On measuring methods and influencing factors of air permeability of soils: An overview and a preliminary database," *Geoderma (Amsterdam)*, vol. 435, pp. 116509–116509, Jul. 2023, doi: https://doi.org/10.1016/j.geoderma.2023.116509

[15]

Structx, "Hydraulic Conductivity and Permeability of Various Soil Types," *Structx.com*, 2014. Available: https://structx.com/Soil_Properties_007.html

[16]

Home, "Darcy," *Calculatoratoz.com*, 2016. Available: https://www.calculatoratoz.com/en/darcys-law-calculator/Calc-7960 . [Accessed: Oct. 30, 2024]

[17]

"8.5: Capacitor with a Dielectric," *Physics LibreTexts*, Nov. 2016. Available: https://phys.libretexts.org/Bookshelves/University_Physics/University_Physics_(OpenStax)/Uni versity_Physics_II_-_Thermodynamics_Electricity_and_Magnetism_(OpenStax)/08%3A_Capacitance/8.05%3A_Capacitor_with_a_Dielectric

[18]

"Soil Moisture Sensors, How Do They Work?," *Hackaday*, May 17, 2021. Available: https://hackaday.com/2021/05/17/soil-moisture-sensors-how-do-they-work/

[19]

"18.4: Capacitors and Dielectrics," *Physics LibreTexts*, Apr. 12, 2018. Available: https://phys.libretexts.org/Bookshelves/University_Physics/Physics_(Boundless)/18%3A_Electric_Potential_and_Electric_Field/18.4%3A_Capacitors_and_Dielectrics

[20]

"1.5 Volt Battery: The Ultimate Guide - Global Batteries," *Global Batteries - LifePO4 batteries for the highest safety, performance, and reliability standards.*, Sep. 23, 2024. Available: https://www.global-batteries.com/1-5-volt-battery-the-ultimate-guide/. [Accessed: Oct. 30, 2024]

[21]

K. Schmidt-Rohr, "How Batteries Store and Release Energy: Explaining Basic Electrochemistry," *Journal of Chemical Education*, vol. 95, no. 10, pp. 1801–1810, Aug. 2018, doi: https://doi.org/10.1021/acs.jchemed.8b00479. Available: https://pubs.acs.org/doi /10.1021/acs.jchemed.8b00479

[22]

B. Ryan, "The Worst Offenders: Understanding the Root Causes of Battery Leaks - Battery Skills," *Battery Skills*, Oct. 10, 2021. Available: https://www.batteryskills.com/what-causes-battery-leaks/. [Accessed: Oct. 30, 2024]

[23]

"How to Repair an Automotive Backwards Battery Connection," *2carpros.com*, Apr. 24, 2024. Available: https://www.2carpros.com/articles/resolving-reverse-battery-connection-in-cars-a-step-by-step-repair-guide. [Accessed: Oct. 30, 2024]

[24]

Magnus Sellén, “6 Symptoms of Loose Battery Cables,” *Mechanic Base*, Apr. 04, 2023. Available: https://mechanicbase.com/electric/loose-battery-cables-symptoms/. [Accessed: Oct. 30, 2024]

[25]

“UM1724 User manual,” 2020. Available: https://www.st.com/resource/en/user_manual/um1724-stm32-nucleo64-boards-mb1136-stmicroelectronics.pdf