ECE198 Design Document

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1. Needs Assessment

1.1 Client and Customer Definition

With global warming and rising global temperatures, the dry season for many parts of the world is exacerbating [4]. Dry seasons are depicted by long periods of decreased and uneven precipitation [3]. This leads to the soil's inability to facilitate the rotation of nutrients as soil movement is reduced as it hardens [3]. Many microorganisms may cease to function during these dry periods, and plants absorb less water, directly impacting their ability to take in nutrients, leaving them dried and withered [3]. Farmers, our targeted demographic, often face such conditions with little ability to properly assess the exact amount of water needed to compensate for the drought [3]. Specifically, a lack of necessary tools to properly determine the amount of water needed is especially detrimental as the farmers are left to the device of their own assumptions. Should the dryness of soil be properly assessed, the farmers would have significantly more reliable agricultural yields, thus allowing them to not only increase earnings, but also increase the reliability of their financial planning based therein.

In Ontario, there were around 49,600 farms in 2016 [7][8]. Between 2006 and 2016, there was an increase in drought and dry spells, as precipitation decreased over 50% in areas such as Ontario [1][7][8].

This also coincides closely with the growing season in Waterloo, where 1,300 farms reside [2]. Of those 1,300 farms, 31% are crop-based farms and therefore account for around 400 farms within the Waterloo region [2]. Hence, the customers for this project primarily will be the 400 farms in the Waterloo region affected by the droughts in the status quo, which comprises around 3,900 farmers [2][9], who:

1. Are financially restricted regarding purchasing and utilizing large/advanced agricultural machinery or systems – economic attribute.
2. Requires a specific minimum degree of moisturization in soil to ensure consistent yield – demographic attribute.
3. Geographic: Works primarily in the Waterloo region, the reasoning explained below.

1.2 Competitive Landscape

There are many ways farmers dealt with the challenge of decreased and unstable yield brought by drought in the status quo. First, many systems of methodologies in changing the approach to conventional farming are used by farmers to overcome such a challenge. For example, diversifying plant distribution proposes planting several different species of plants within a single area, which makes the overall system more resistant to changes in weather, such as dry spells [5][12][11]. This is an excellent solution as it effectively increases the dependability of the crops, but it has a high initial cost since farmers would have to grow new plants whilst also learning how to maintain them [12][11]. There is also the added complication of knowing what to plant since there is the inherent risk of certain plants outperforming others [12], which provides notable shortcomings to such a solution.

Another example of such a change in approach is the planting of early maturing crops, as they can decrease the possibility of reaching drought season [6]. This method has been developed and used in areas around Africa, hence showing that it is effective in addressing the challenge [6]. However, this solution has a significant shortcoming in the Waterloo region, where the drought season is becoming increasingly inconsistent with time, it is thus difficult to determine their arrival time and length. A second devised technological system that attempts to address this challenge is to genetically breed crops that are adaptive to severe weather, which obviously addresses the challenge mentioned above, but significant shortcomings are also seen as the long-term effects of such crops are disputed and concerns over plant diversity and the sustainability of such methods in the long run are raised [5][6][10].

However, a more common third approach is to abandon that crop cycle and plant fewer seeds at once to directly minimize the loss of a dry season [12][11]. As such, the challenge is addressed to an extent, however, the shortcoming is also obvious, as this method directly decreases the yield of plants [12][11]. Finally, although many technological systems already exist on the market that can monitor the moisture level of soil, hence helping farmers.

Finally, a technical approach exists on the market to directly measure the soil moisture in the soil. Such an approach tackles the challenge as it informs the farmer as to whether the soil is lacking water, and when the soil should be watered, thus directly solving the instability of yield brought by the dry spells. However, many products in the market either use a simple, inaccurate algorithm to determine the dryness of soil, or it is far too expensive and unaffordable to be implemented en masse in a field [37] [38]. Further, no product on the market has a communication module that can inform the user effectively when the soil needs to be watered, thus making the system ineffective and unable to completely tackle the challenge, providing significant drawbacks therein.

1.3 Solution and Requirement Specification

1.3.1 Requirement Specification

Out of the 8 specifications introduced in the proposal, 5 of the most critical ones were selected to be tested in the implementation demonstration. The tests assigned are seen in section 5, testing and validation.

Name	Description	Justification
Soil Humidity Measurement Range and Reaction	The product must be able to measure the humidity of the soil within the range of 0 to 0.55 wfv (water fraction by volume, or m^3m^{-3}). Our soil moisture measurer has a range of 0.0 to 1.0 wfv as a percentage, meaning a wfv of 0.35 would be recorded at 35%. An audible noise and change in LED colour should occur at a wfv of <35.	Full saturation of soil (i.e. all soil pore spaces filled with water) usually occurs between 0.35 to 0.55 wfv [13].
Alarm Sound Level	The product must be able to produce an audible noise akin to alarms, or around 80 dB, to inform the client of dry soil.	A typical alarm clock designed to raise awareness has a noise level of around 80 dB [14].
STM32 Communication	The product must be able to communicate between the two microcontrollers within a delay of less than 30 ms.	The lowest noticeable delay in electronic devices is 30 ms [15].

Operating Voltage	The operating voltage should be between 3.5 volts and 5 volts.	The moisture sensor probe can be powered with a DC supply or batteries in the range of 3.5 volts to 5 volts [17].
Measurement Accuracy	The product must be able to measure the moisture of the soil with an error of ±0.051 wfv.	The dataset collected from a lab-used soil moisture sensor generated a correlation of 0.95 and a RMS error of ±0.051 wfv [16].

The remaining three requirements are still included in this document, however, as per the rubric, will not be tested in the demonstration.

Signal Processing Unit Accuracy	The product must be able to measure the moisture of the soil with a correlation of above 0.95 and a root mean square error of ±0.051 wfv. The analog-to-digital converter must have a resolution of at least 18 bits.	The dataset collected from a lab-used soil moisture sensor generated a correlation of 0.95 and a RMS error of ±0.051 wfv [16]. 18 bits is considered the standard resolution by sensor manufacturers such as Bosch Sensortec [21].
Microcontroller Capacity	Operating frequency of 180 MHz, at least 512 KB of flash memory and 128 KB of RAM.	A standard STM32F4 series microcontroller has at least 180 MHz operating frequency, 512 KB flash memory, and 128 KB of RAM [18].

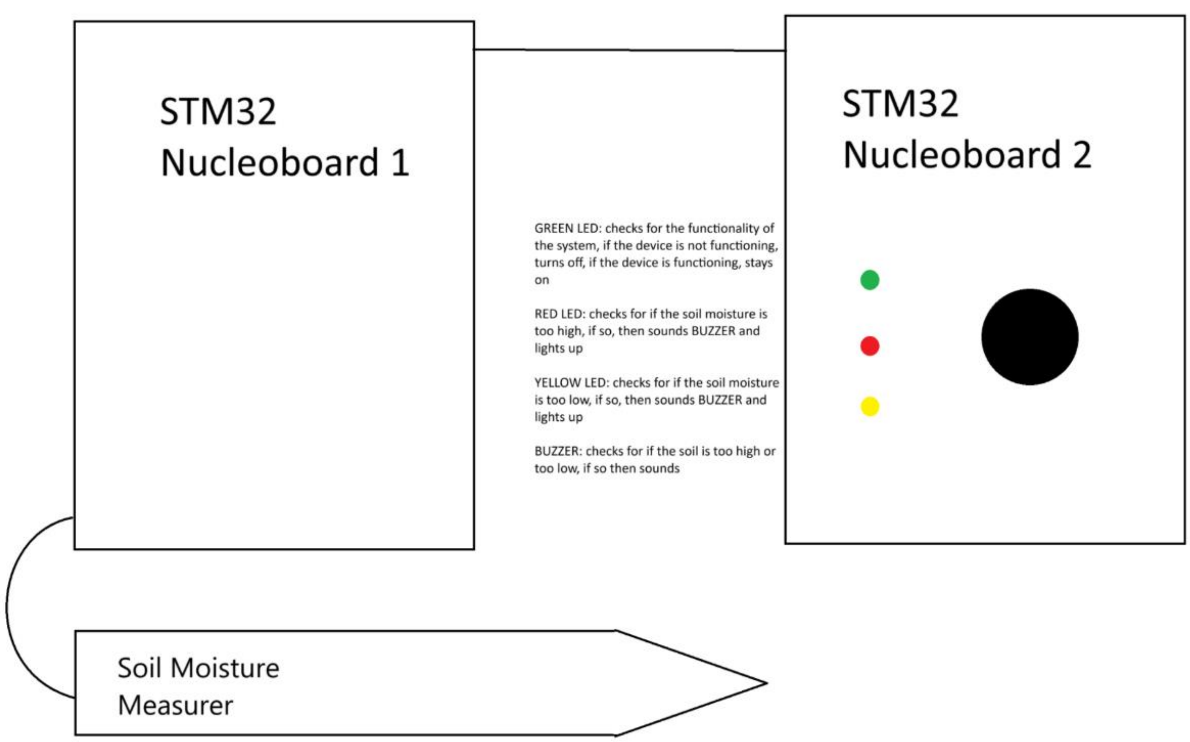
Enclosure (Waterproofing & protection against solid foreign objects)	The device must be at least IP 55 rated.	As the device is located near frequently watered soil and fields, it must be dust-protected and protected against water jets, which warrants a rating of IP 55 [19].

2. Analysis

2.1 Design

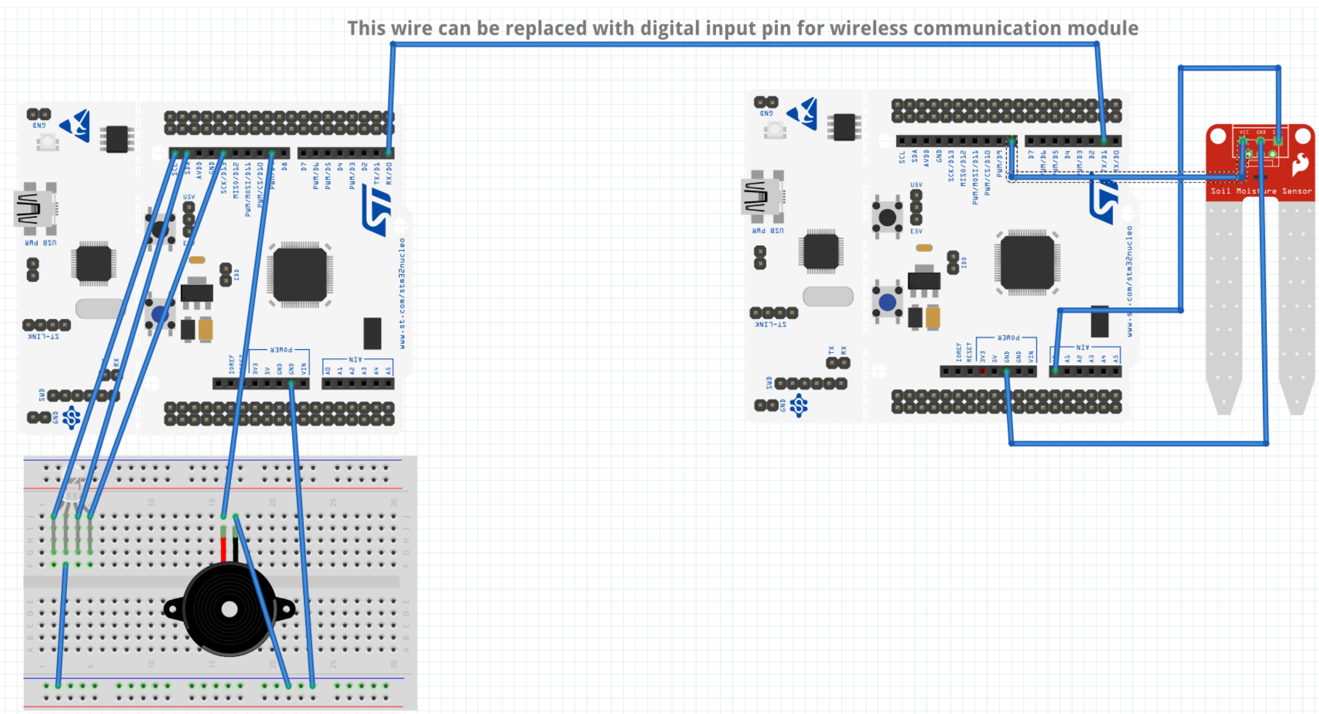
2.1.1 Product Design

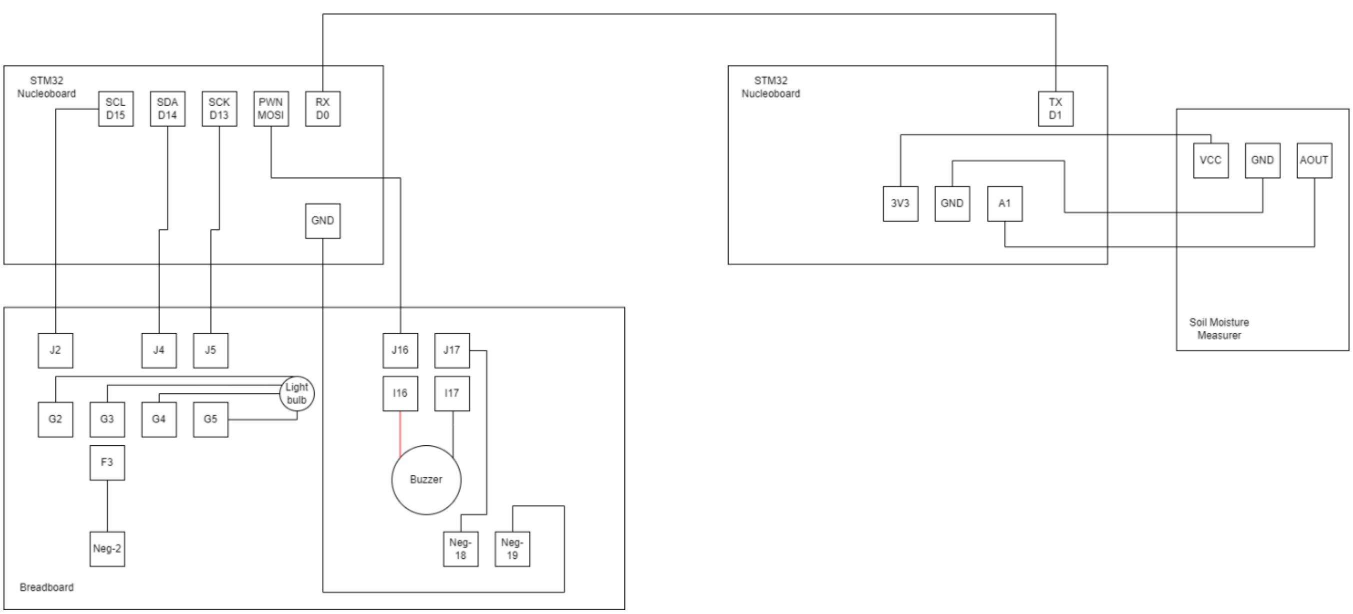
Below is a basic conceptual design and a simple description of this product. In essence, the first STM Nucleo board acts as a sensor module, as it connects with a soil humidity sensor, processes and packages the data for the second STM Nucleo board, which acts as a receiving module, and is connected to an LED light and a buzzer, thus communicating information to the user.



2.1.2 Electrical Design

Two diagrams are included, a detailed one for technical readers, and a general one for non-technical readers.





2.1.3 Software Design

Non-technical readers are advised to skip this section and move to 2.1.4.

The STM32CubeIDE

The STM32CubeIDE is the developing environment used for this product, as it interacts effectively with the STM32 Microcontroller used as the main processing unit. To operate and construct the product, installation of this IDE is necessary. Please refer to this official manual from STM [33].

All code below is put on top of the existing coding framework of the STM32CubeIDE – Simply insert the code into the regions marked by the comments or /**/ in the STM32CubeIDE.

Sensor Module

The code below allows the humidity in the dirt to be detected, averaged, and then sent to the receiving module with a packaged parity check. Note the accuracy of the ADC, the measuring accuracy and range of the sensor, the microcontroller capacity, and the operating voltage fulfill the requirements outlined above. This addresses the requirement for the soil humidity measurer requirement.

```c
/* USER CODE BEGIN 0 */
uint16_t readValue;
uint16_t valueSum {0};
uint16_t count {0};
/* USER CODE END 0 */

  /* USER CODE BEGIN 2 */
  HAL_ADC_Start(&hadc1); //This is preconfigured in the CubeIDE
  /* USER CODE END 2 */

 /* USER CODE BEGIN WHILE */
  while (1)
  {
    HAL_ADC_PollForConversion(&hadc1,1000); //Translates to decimal data from analog
    readValue = HAL_ADC_GetValue(&hadc1);
    count += 1; //Counts the number of data collected
    if (count < 3){
        valueSum += readValue;
        continue;
    }
    uint8_t parity = 0;
    uint16_t value_copy = valueSum; //Make an expendable copy of value
    while (value_copy){
        parity ^= (value_copy & 1);
        value_copy >>= 1;
    } //This algorithm makes parity 1 if there is an odd number of 1 bits, and 0 if an even number of 1 bits
    valueSum <<= 1;
    valueSum += parity; //This appends the parity bit to the end of the data
    HAL_UART_Transmit(&huart1, valueSum, sizeof(valueSum) - 1, HAL_MAX_DELAY); //UART is preconfigured in the CubeIDE


  }
    /* USER CODE END WHILE */
```

Receiving Module

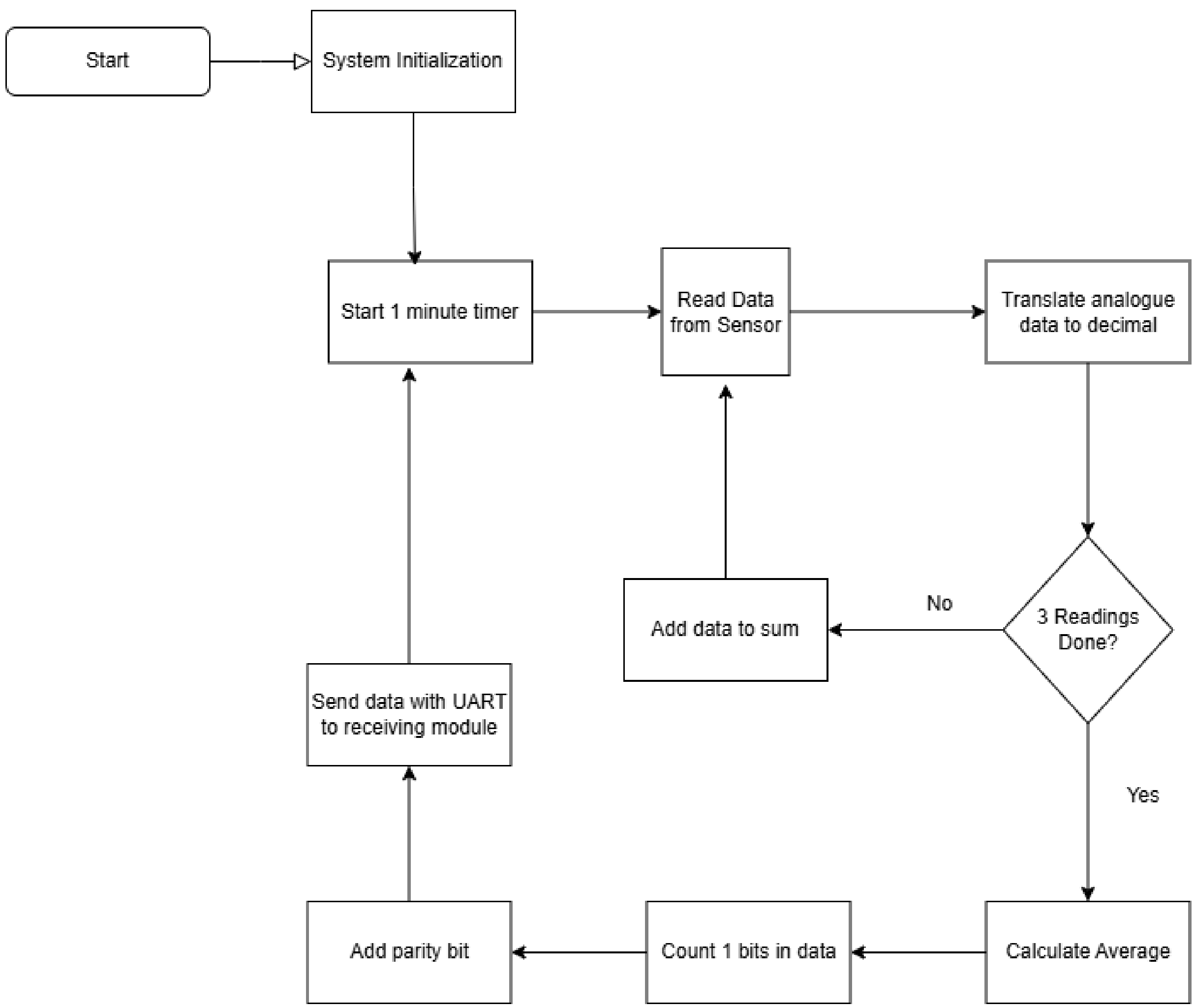
The code below allows us to receive the data from the sensor module, perform the parity check, send a warning if the check fails to the user, and warn the user if the soil humidity is too low should the check be successful. Note the alarm sound level and the microcontroller capacity are within the range of the requirements outlined above. These satisfactorily address the requirements mentioned above.

```
/* USER CODE BEGIN 0 */
uint16_t receiveValue;
uint16_t THRESHOLD {50};
/* USER CODE END 0 */
  /* USER CODE BEGIN 2 */
  HAL_ADC_Start(&hadc1); //This is preconfigured in the CubeIDE
  /* USER CODE END 2 */
 /* USER CODE BEGIN WHILE */
  while (1)
  {
    u16int_t count {0};
    HAL_UART_Receive(&huart1, rxData, sizeof(rxData) - 1, HAL_MAX_DELAY);
    uint16_t dataCopy = receiveValue;
    while (dataCopy){
      if (value_copy & 1){
        count++;
      }
      value_copy >>= 1; //This checks for the number of 1s in the data
    }
    if (count % 2 == 0){
      receiveValue >>= 1; //Removes the last bit
      if (receiveValue > THRESHOLD){
        HAL_GPIO_WritePin(GPIOB, GPIO_PIN_9, GPIO_PIN_SET); //Turn on LED
        HAL_Delay(1000)
        HAL_GPIO_WritePin(GPIOB, GPIO_PIN_9, GPIO_PIN_RESET);
      }
      else{
      HAL_TIM_PWM_Start(&htim3, TIM_CHANNEL_1); //This is preconfigured in IDE
      HAL_GPIO_WritePin(GPIOB, GPIO_PIN_10, GPIO_PIN_SET); //Turn on LED
      HAL_Delay(1000);                          // Beep for 1 second
      HAL_TIM_PWM_Stop(&htim3, TIM_CHANNEL_1);
      HAL_GPIO_WritePin(GPIOB, GPIO_PIN_10, GPIO_PIN_RESET);
      }
    }
    else { //Parity check failed
      HAL_TIM_PWM_Start(&htim3, TIM_CHANNEL_1); //This is preconfigured in IDE
      HAL_GPIO_WritePin(GPIOB, GPIO_PIN_8, GPIO_PIN_SET); //Turn on LED
      HAL_Delay(1000);                          // Beep for 1 second
      HAL_TIM_PWM_Stop(&htim3, TIM_CHANNEL_1);
      HAL_GPIO_WritePin(GPIOB, GPIO_PIN_8, GPIO_PIN_RESET);
    }
  }
    /* USER CODE END WHILE */
```

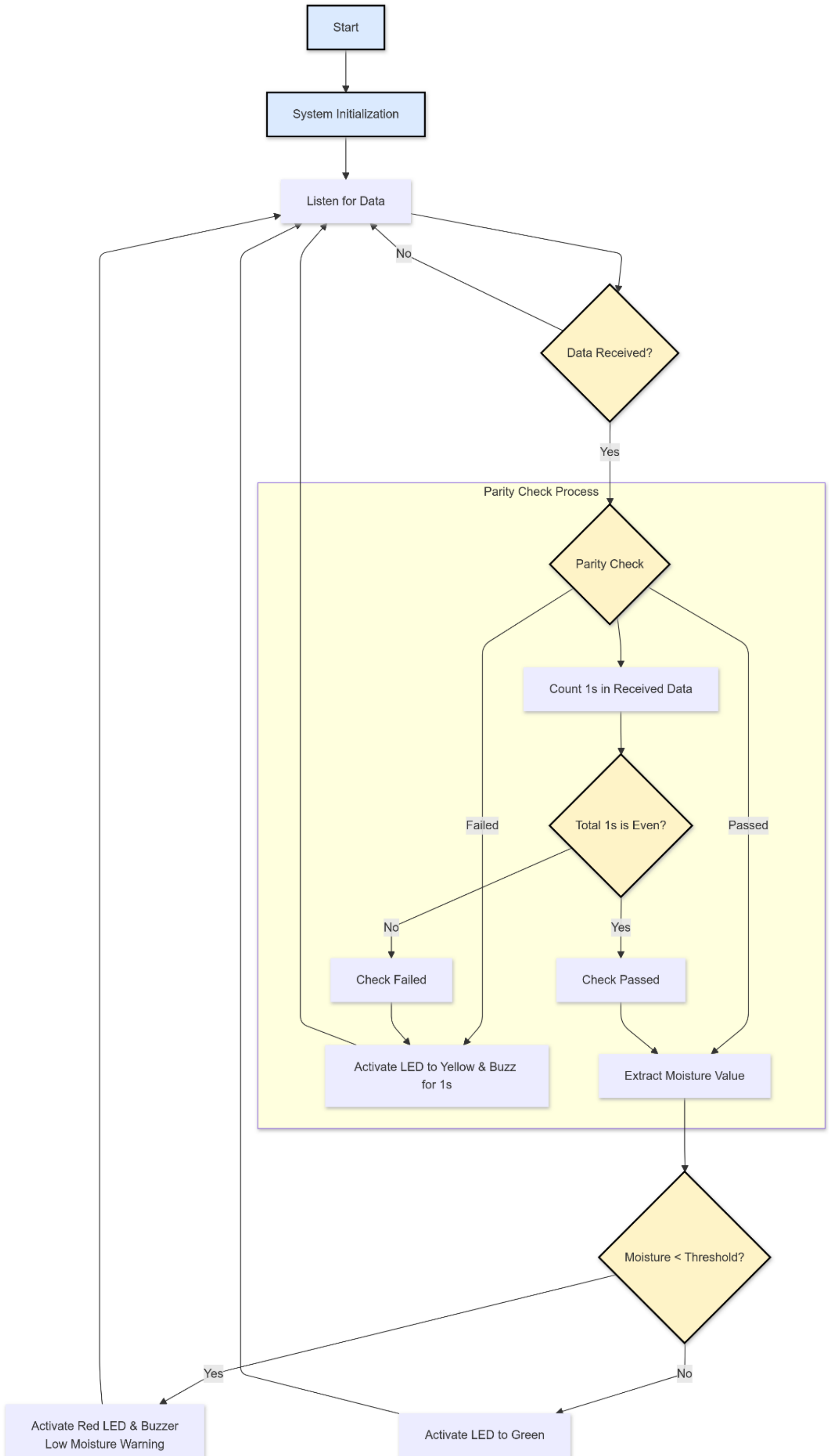
2.1.4 Operation Flowcharts

Below are two operation flowcharts for the two STM 32s, detailing how their software was designed to operate for non-technical readers. Note that all information included in section 2.1.3 is effectively included here with a more friendly manner of presentation. These satisfactorily address the requirements mentioned above.

Sensor Module



Receiving Module



2.1.5 Alternatives Considered

1. Infrared Communication

Infrared communication was initially considered as one of the possible methods for connecting the soil moisture sensor module to the alarm module. This method is cost-effective, easy to implement, and consumes relatively low power. However, it is significantly limited in terms of communication range. For reference, TV remotes using infrared typically have a range of around 10 meters [35]. Moreover, in the complex environment of farms, infrared communication can easily be blocked by obstacles. Additionally, if multiple soil moisture sensors are deployed, infrared communication can lead to interference between devices. Due to these limitations, infrared communication is not well-suited for use in such complex agricultural environments.

2. SMS Notification

Using SMS to send soil moisture information was initially considered as a potential solution. SMS can function wherever there is mobile signal coverage, allowing for a nearly unlimited range of communication. However, this design has some significant drawbacks. Firstly, even the most basic mobile plan in Canada costs around $20 per month [36]. If farmers need to equip multiple soil moisture sensors with mobile plants, it will greatly increase the overall cost of using the system. Secondly, soil moisture alerts could get mixed in with other regular SMS messages, reducing their effectiveness as notifications. As a result, this design was ultimately not chosen.

3. Justification for the Choice of Design

Besides the shortcomings in the alternatives, the current fielded design has two major benefits: first, compared to the other options, it is significantly cheaper and more reliable, as it is quite difficult to interfere with and disrupt data transferred through physical wires, and as wires are much cheaper, specifically, over ten times cheaper than phones and infrared sensors [39]. As one of the attributes of our clients is those who cannot afford expensive equipment this is important. Second, it is much easier for the user to install the device with wired communication, and no additional purchases, installation, adjustments, or fine-tuning of the device is needed.

2.2 Technical Analysis

2.2.1 Scientific and Mathematical Principles & Applications

Mathematical Principle – Average Data
The device collects a varied amount of data over time [26]. This also means that there is going to be some degree of difference between values that have limited effect on the overall result [26]. For this reason, the mathematical principle of average will help as it will show outliers as well as find the center-point value. Below is how to compute the average of a dataset: $$\overline{x} = \frac{(x_1 + x_2 + x_3 + \ldots + x_n)}{n}$$ **Application:** This will help the device as it will serve as a method to analyze large sets of data without having to deal with high variance in data. This formula is also imperative when determining the percentage of errors as there needs to be a standard to measure the errors off from. In this project, each data sent to the receiving module is the average of 3 consecutive results from data collection, thus increasing the accuracy and reliability of the data received.
Mathematical Principle - Parity Check
Errors may occur during data transmission between two devices, especially in wireless communication. Parity checking is a basic data validation algorithm. It works by calculating the parity (odd or even) of the sum of the binary data being transmitted, resulting in a parity code. This code is sent along with the data during transmission. To verify whether an error occurred during the transmission, the receiver simply recalculates the parity of the received data and compares it with the original parity code. [27] $$P = \left(\sum_{i=1}^{n} b_i\right) mod\ 2$$

b_i represents every bit of data being transferred during the transmission.
The formula calculates the sum of every bit of data (b_i) and then calculates the modular of the sum to get the parity code for error checking.

Application:

Errors may occur when transmitting soil moisture data between two STM32 development boards, which could lead to either missed irrigation alerts or false alarms. By using a parity check algorithm to validate the soil moisture data, such issues can be largely prevented. Such an algorithm is implemented in the software design above, by using C++'s bit manipulation operators, a parity bit is appended to the end of each packet of information sent, which tells the receiver whether the information has been corrupted, as mentioned above.

Scientific Principle – Ohm's Law

Ohm's law states that the relationship between voltage, current, and resistance can be represented by the following formula:

$$V=IR$$

This means that the electric current through a conductor around two points is directly proportional to voltage [28]. It also means that there is a proportional relationship between them [28].

Application:

This formula will be used to determine the power used in the device by using it to find power in terms of voltage and current, instead of current and resistance, by combining it in Joule's law, as outlined in the next principle.

Scientific Principle – Joule's Law

Joule's Law states that the power of a heating generated by electrical current equals to the product of its resistance by the square of the current and can be represented by the following formula [32]:

$$P = I^2R$$

This formula can be rearranged using Ohm's Law to form this equation:

$$V = IR$$

$$R = \frac{V}{I}$$

$$P = I^2(\frac{V}{I})$$

$$P = IV$$

Application

This formula will be used to determine how much power the individual part to the device is going to be used. This is integral to ensure the safety of the system and calculating that our devices meet the safety requirements. In the energy analysis section below, this formula is used to determine key design parameters, specifically, how much power should be used by the product.

Engineering Standards - IEEE

IEEE standards for citation will be used to cite all references. This is adherence to engineering practices and is commonly used in professional engineering projects [40].

Application

This standard is used in our references and throughout all documentations, thus ensuring our communication to be professional and standardized.

Engineering Standards - UART

The UART Protocol standards for universal asynchronous receiver / transmitter and is a simple, two-wire protocol for exchanging serial data. UART transmissions are commonly used in wired communication, as it is available in many microcontrollers and has a simple yet efficient manner of transmitting data [34].

Application

Since the UART protocol is available on all STM32 microcontrollers, it will be used in the product to communicate between the two modules. However, although UART has a built-in parity check function, this project prefers a more reliable method of lower-level parity check using bit shift operators, as mentioned above.

Scientific Principle – Galvanic Corrosion

Galvanic corrosion refers to the degradation of metal caused by an electrochemical reaction when two dissimilar metals are in contact in the presence of an electrolyte (such as soil with moisture) [20].

Faraday's Law of Electrolysis [25].

$$M = \frac{Q}{v \cdot F}$$

In the simple case of constant-current electrolysis, $Q = I \cdot t$.

$$m = \frac{I \cdot t \cdot M}{v \cdot F}$$

- m - the mass of metal corroded
- I - the current
- t - the time the current flows
- M - the molar mass of the metal
- v - the valency of the ions
- F - Faraday's constant

Application

Based on this principle, to reduce the corrosion of soil moisture sensor (consists of two electrodes) and thus increase the lifetime of this product, the sensor should be designed to only be powered when reading values. This is achieved by powering the sensors VCC pin with a digital output pin on the STM32 dev board. As the sensor accepts 3.3V, which matches the voltage of the digital output of the dev board, keeping the digital output as true/false can turn on/off the sensor.

3. Costs

3.1 Manufacturing Costs

STM32 – $46.10 + tax = $55.48 for each STM 32

- Manufacturer : STMicroelectronics – Main Address: Chemin du Champ-des-Filles 39 Plan-les-Ouates, 1228, Geneva, Switzerland
- Distributor: W Store – Address: South Campus Hall, 200 University Ave West, Waterloo, ON N2L3G1
- Note that two STM32 microcontrollers were bought and used, this is accounted for below in the total cost.

Breadboard – $3.30 + tax

- Manufacturer: Shenzhen Hongjilong Technology Co., Ltd. – Shenzhen, Guangdong, China 518000
- Distributor: Rigidware – Address: Engineering 7, 200 University Ave W #1419, Waterloo, ON N2L 3G1

Buzzer – $1.85 + tax

- Manufacturer: Shenzhen Hongjilong Technology Co., Ltd. – Shenzhen, Guangdong, China 518000
- Distributor: Rigidware – Address: Engineering 7, 200 University Ave W #1419, Waterloo, ON N2L 3G1

Wires – $4.99 + tax

- Manufacturer: Elegoo Inc – Jian'an Road, Longhua District, Shenzhen, Guangdong Province, China
- Distributor: Amazon Inc. – Address: 440 Terry Ave N, Seattle - Waze.

Soil Humidity Sensor – $9.99 + tax + Free Shipping

- Manufacturer: Elegoo Inc – Jian'an Road, Longhua District, Shenzhen, Guangdong Province, China
- Distributor: Amazon Inc. – Address: 440 Terry Ave N, Seattle - Waze.

LED – $0.99 + tax

- Manufacturer: Shanghai Gawin Electronic Technology Co., Ltd. – Room 515 Jiurun Business Building No. 1658 Husong Road Songjiang District, Shanghai, China 201615
- Distributor: Rigidware – Address: Engineering 7, 200 University Ave W #1419, Waterloo, ON N2L 3G1

Total Cost:

Product	Amount	Price		
STM32	2	$46.10		
Breadboard	1	$3.30		
Buzzer	1	$1.85		
Wires	1	$4.99		
Soil Humidity Sensor	1	$9.99	Total Before Tax	Total After Tax
LED Lights	1	$0.99	$113.32	$128.05

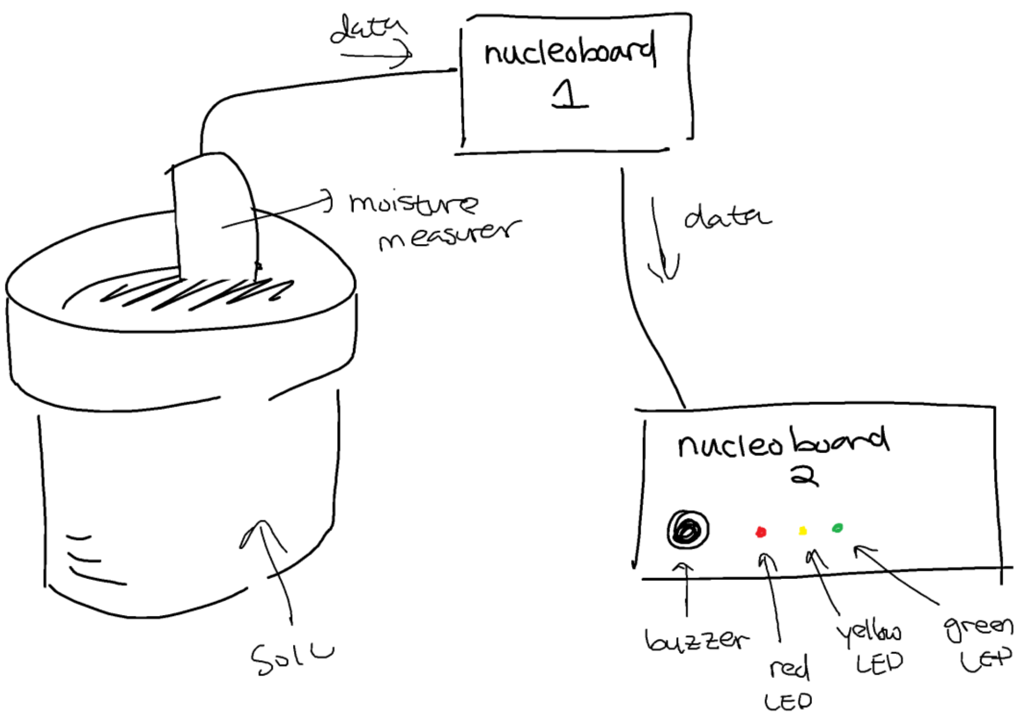
3.2 Manuals

3.2.1 Installation Manual

1. Carefully place the soil moisture measurer in the soil and place the microcontroller-container 1 on the ground near it.
2. Plug USB-2 cable of the STM32 into a power source of less than 5V.
3. Check all the wiring to make sure it is secure, including wiring on the soil moisture measurer, breadboard, STM32 Nucleoboard.
4. Test the soil moisture measurer in water to ensure that it is functioning properly. The value of soil moisture of water should be around 95%-100%.
5. Test the LED and buzzer connection by repeating step 5 in air instead of water. Since the humidity of the air is low, the buzzer should sound, and the yellow LED should light up.
6. Test the soil moisture measurer using dry soil. The LED should glow yellow, and the buzzer should sound.
7. If at any point the red LED turns on, then repeat steps 3-7 after reconnecting the USB-2 cable and wiring on the breadboard.

3.2.2 User Manual

1. Place the soil moisture measurer in the soil and the receiving module at a location of your convenience. Dispose of any waste properly.
2. If the RED light and BUZZER on the receiving module turn on, then the soil moisture level is lower than recommended. Consider watering the soil.
3. If the YELLOW light and BUZZER turn on, then there is an issue with the device. Consult troubleshooting.
4. If the GREEN light turns on, then the soil moisture level is higher than recommended, and no action needs to be taken.



3.2.3 Troubleshooting

- Check the wire connections from the STM32 Nucleoboard as well as the soil moisture sensor to see if they are still connected securely.
- If the issue persists, consider replacing the cables. New cables can be purchased online or at electronic component shops. It is advised that cables are replaced regularly, or at least once every year.
- If the issue persists, consider replacing the sensor, especially if it had been exposed to water and dust for long periods of time.

4. Risks

4.1 Energy Analysis

Using specifications from the vendor and manuals of devices, as cited, it can be found the power expended to be.

- Soil Moisture Measurer [29]
    - Input Voltage Range: 3.3V to 5V
    - Maximum supply current = 2mA
    - Using the maximum values: P = I * V = 2 mA * 5V = 0.01 W
    - Using the actual values: P = I * V = 2 mA * 3.3 V = 0.0066 W
- Buzzer [30]
    - Maximum supply current = 10mA
    - Input Voltage Range: 1V-2V
    - Maximum Power: P = I * V = 10 mA * 2V = 0.02 W
- STM32 Nucleoboard [41]
    - Maximum supply current = 50 mA
    - Input Voltage Range: 3.3V-5V
    - Maximum Power: P = I*V = 50 mA * 5V = 0.25 W
- Note that none of the above components contain a battery, and the capacitors in the STM 32 will not be used, as the software above does not contain such usage, thus no energy storage will occur within the system.
- 0.02 + 0.0066 + 0.25 = 0.2766 W
- Maximum Power Consumption: 0.2766 W, 0.012 A
    - Standard: USB-2 Port: 2.5 W, 500 mA [31]. This far exceeds the power & current needed as calculated above.
    - Standard: Project requirement: Under 30 W, as per rubric.
    - 0.2766 W << 30 W, thus the energy consumption would not reach the maximum with any reasonable timeframe.

4.2 Risk Analysis

Risks Associated with Everyday Use:

1. Aging and degradation of the circuit through daily use may cause leakage of electricity, posing a potential fire and shock hazard in the farm.
2. Sound notification may cause significant disruption to the user, especially those who are sensitive to sudden, loud noises, posing a health hazard.
3. Since acid and metal produce salt and hydrogen in a chemical reaction with very low activation energy, should acid rain get in contact with the STM board or the sensor, it is quite possible for the system to be eroded by acid rain and thus cease to function, and more importantly, leak harmful salt substances into the soil, which is an environmental hazard and may threaten the yield of the farmer further.

Risks Associated with Improper Use

1. Supplying inappropriate amounts of voltage into the product may cause overheating of the electrical circuit, which, if put next to flammable objects, creates a fire hazard.
2. Due to the STM32 Nucleoboard and soil moisture measurer being made of metal and plastic, should it be disposed improperly, an environmental hazard will be posed. This is particularly hazardous because electronic waste associated with such parts can contain harmful chemicals or byproducts of the degradation of such, thus providing an environmental hazard.
3. Potential for electric shock if wires are cut or damaged, for instance, if the user handles the device with excessive force while it is powered.

Risks Associated with Unintended Use of Device:

1. If the sensor is left in water for an extremely long time, for instance, if the user attempts to measure the humidity of water, the circuitry may short circuit, posing a fire and shock hazard.
2. It the sensor is used to measure the humidity of non-soil objects, for instance, the wetness of the ground, the data returned would be inaccurate, and the user may be notified incorrectly, thus causing them to add humidity, i.e. pour

water, onto objects that are already sufficiently wet, which may cause health hazards, such as slipping hazards.

Malfunction Possibilities

1. Wires: There may be issues with the wire connection as the wires are thin and may become worn down. This would cause the exposure of the conducting copper wires, which, besides hurting the operation of the device, would also create a fire and electric shock hazard.
2. Moisture Measurer Damage: There may be issues with the soil moisture measurer itself after prolonged periods of time in extremely moist or extremely dry soil. This would create inaccuracies in the soil moisture measurement, while also creating microparticles and electronic waste that hurts the environment.

Failure and Failsafe Mechanisms

Risks Associated with Everyday Use:

1. Users are advised to replace the wires regularly in troubleshooting.
2. Users are advised to dispose of electronic waste properly in the user manual.
3. The system should be waterproof; thus, it would not encounter acid rain.

Risks Associated with Improper Use

1. The installation manual outlines the maximum voltage of the power source.
2. Users are advised to dispose of electronic waste properly in the user manual.
3. The user is instructed to carefully handle the sensor in the installation manual.

Risks Associated with Unintended Use of Device:

1. For both, the user is instructed to put the device in soil in the user manual.

Malfunction Possibilities

1. Users are advised to replace the wires regularly in troubleshooting.
2. The issue would be spotted automatically by the parity check, thus indicating the error to the user, who will proceed to replace the sensor and stop the environmental hazard.

5. Testing and Validation

5.1 Rationale

For requirement 1, the device is to be operated in different soil conditions with increasing soil humidity, controlled by a lab-condition soil moisturization sensor. The buzzer and red LED should be on at soil humidity of lower than 35%. This is measured in test 1.

For requirement 2, the device is left in dry soil so its sound level can be measured in test 4. Note that the ambient sound level will be removed mathematically by subtracting the measurement of the

For requirement 3, the timestamp of the sensor module having detected the soil humidity and the timestamp of the receiving module having received the communication from the sensor module are both recorded by a logic analyzer listening to the output of both the sensor and the communication between the STM 32s, as the pin connected to the logic analyzer will be set to high when the sensor module detects data, and when the receiving module receives data. This is measured in test 2.

For requirement 4, the device is left in wet soil, and two different power sources are connected to test if the device functions under the maximum and minimum operating voltages. This is measured in test 3.

For requirement 5, the device is operated in soil moisture level of 30%, determined with an accurate lab-grade soil moisture sensor. The device is connected to a logic analyzer to output its data. By taking the difference between the result on the logic analyzer and the moisture level reported by the lab-grade moisture sensor, or 30%, the error and accuracy of the device is determined. This is measured in test 5.

5.2 Testing Plan

Prior to conducting tests: Prepare 5 samples of soil with varying humidity at 20%, 30%, 50%, 80%, and 100%, with a volume of 150 cm^3 each. The humidity of the soil samples is to be confirmed prior to testing with a lab-grade soil moisture sensor. The soil samples can be prepared by getting a large sample of soil, splitting it into 5 different samples, and heating up each sample for a different amount of time, and intermediately measuring the moisture level to ensure that it reaches the desired level.

Test 1: Testing the soil moisture in low moisture soil to ensure it has a wide enough measuring range, thus fulfilling requirement 1.

a. Test setup:
    i. Device is connected to an appropriate power source and is functioning.
    ii. The sensor is to be submerged in soil at 20%, 30%, 50%, 80%, and 100% humidity level, each for a minute, from highest to lowest.
b. Environmental parameters:
    i. Ambient humidity: the ambient humidity should be controlled to be around 30-40%, or the average room humidity.
    ii. Ambient lighting: the ambient lighting must not exceed 20,000 lumens to ensure the LED lights are visible.
c. Test Inputs: The moisture data of the five soil samples.
d. Measurement Standard: Reading from device is listed as percent of wfv from 0.0 to 1.0 as a scale. The soil humidity is confirmed prior to testing using an accurate lab-grade soil moisture sensor.
e. Pass/Fail Criteria: If both of the following cases occur, the test passes; otherwise, the test fails.
    i. Within 1 minute of sensor being submerged in soil samples of humidity 100%, 80%, and 50%:
        1. GREEN LED is on
        2. RED LED is off
        3. BUZZER is off
    ii. Within 1 minute of sensor being submerged in soil samples of humidity 20% and 30%:

1. GREEN LED is off
2. RED LED is on
3. BUZZER is on

Test 2: Communication Delay for requirement 3.

a. Test setup:
    i. Both STM 32 boards are connected to a logic analyzer listening to both the output from the soil humidity sensor to the sensor module, and the output from the sensor module to the receiving module.
    ii. Edit the software of the STM 32s to set the pin connected to the logic analyzer to high:
        a. For the sensor module, when input is received from the sensor;
        b. For the receiving module, when transmission is received from the UART pin.
    iii. The logic analyzer is to be connected to a computer with a logic analyzer graphical interface open.
    iv. The logic analyzer interface is to begin collecting data.
    v. Device is to be connected to a power source and inserted into wet soil.
    vi. After 3 minutes, the difference in the timestamp of the peaks caused by the latest soil humidity sensor output and the communication between the STM 32s is to be noted and calculated.
b. Environmental Parameters;
    i. Ambient temperature should be within 10 degrees Celsius of 23 degrees Celsius, or room temperature, to ensure the conductivity of wires remains the same.
c. Test inputs: soil data, pre and post-packaged by the sensor module.
d. Measurement Standard: the time module embedded within the logic analyzer will be used to capture the timestamps of the peaks from the detection of moisturization of soil and the receiving of information package.
e. Pass/Fail Criteria: If the difference in the time stamp of the sensor detecting data and the receiving module receiving the information

package from the sensor module is less than 30 ms, the test passes; otherwise, the test fails.

Test 3: Operating Voltage Tests for requirement 4

a. Test setup:
   i. Device is connected to a power source (specified below) and inserted into wet soil.
   ii. After 1 minute, the device is removed from the wet soil and inserted into the dry soil as prepared in test 1.
   iii. Repeat steps i and ii for another power source (specified below).
b. Environmental Parameters:
   i. Ambient temperature should be within 10 degrees Celsius of 23 degrees Celsius, or room temperature, to ensure the conductivity of wires remains the same.
c. Test Inputs:
   i. Connect the device to a:
      1. 3.5V power source.
      2. 5V power source.
d. Measurement Standard: A voltmeter is to be used to measure the voltage of the power source prior to connecting the device, it should be within 0.1V of the specified voltage in the inputs above.
e. Pass/Fail Criteria: If the device functions properly under both input conditions, i.e. the GREEN LED remains on when the sensor is in wet soil, and the RED LED and BUZZER are on when the sensor is in dry soil, then the test is passed; otherwise, the test fails.

Test 4: Testing Sound Level for requirement 2.

a. Test setup:
   i. Device is connected to a power source, with the sensor inserted in dry soil as prepared in test 1.
   ii. A sound level meter is placed 10 center meters away from the device.
   iii. The sound level meter is to record the noise produced with the buzzer on. Then, the device is disconnected from the power source, and the sound level meter is to re-measure the ambient noise level. Both data are to be recorded.
b. Environmental Parameters:

i. Ambient sound: the ambient sound should be as close to 0 dB as possible.
ii. Ambient humidity: the ambient humidity should be controlled to be around 30-40%, or the average room humidity.

c. Test Inputs: low humidity data.
d. Measurement Standard: Sound made by the buzzer is measured by a sound level meter (or decibel meter).
e. Pass/Fail Criteria: if the difference between the noise produced with the buzzer and the ambient sound level is greater than 80 dB, the test passes; otherwise, the test fails.

Test 5: Measurement Accuracy of the Soil Moisture Measurer

a. Test Setup:
   i. Device is powered.
   ii. The sensor is to be submerged in soil at 30% humidity level, predetermined by a lab-grade soil moisture measurer.
   iii. The sensor module is to be connected to a logic analyzer.
   iv. The logic analyzer is to be connected to a logic analyzer interface.
   v. The software of the sensor module is to be edited so that data received by the device is to be outputted onto the pin of the logic analyzer as an analogue value.
   vi. The logic analyzer interface is to begin collecting data within 1 minute of the device being powered.
b. Environmental Parameters:
   vii. Ambient temperature should be between 10 degrees Celsius to 23 degrees Celsius, or room temperature, to ensure the conductivity of wires remains the same.
   viii. The ambient humidity should be controlled to be around 30-40%, or the average room humidity.
c. Test Inputs: Soil Data
d. Measurement Standard: accurate lab-grade soil moisture measurer, which will determine the soil at 30%.
e. Pass/Fail Criteria: As per the requirement, if the reading on the logic analyzer interface is within ±0.051% of the 30% humidity reported by the lab-grade soil moisture sensor, the test is passed; otherwise, the test fails.

6. References

[1] A. and A.-F. Canada, "Current drought conditions," *agriculture.canada.ca*, Dec. 01, 2022. Available: https://agriculture.canada.ca/en/agricultural-production/weather/canadian-drought-monitor/current-drought-conditions. [Accessed: Sep. 16, 2024]

[2] Region of Waterloo, "Agriculture," *www.regionofwaterloo.ca*, May 09, 2018. Available: https://www.regionofwaterloo.ca/en/regional-government/agriculture.aspx

[3] Deanna, "What do plants need during a dry spell? - SynergyAG | Saskatchewan Crop Retail," *SynergyAG | Saskatchewan Crop Retail*, Jun. 05, 2019. Available: https://synergy.ag/what-do-plants-need-during-a-dry-spell/. [Accessed: Sep. 16, 2024]

[4] L. Sushama, N. Khaliq, and R. Laprise, "Dry spell characteristics over Canada in a changing climate as simulated by the Canadian RCM," *Global and Planetary Change*, vol. 74, no. 1, pp. 1–14, Oct. 2010, doi: https://doi.org/10.1016/j.gloplacha.2010.07.004

[5] A. Hossain *et al.*, "Next-generation genetic engineering tools for abiotic stress tolerance in plants," *Elsevier eBooks*, pp. 153–197, Jan. 2021, doi: https://doi.org/10.1016/b978-0-323-90943-3.00008-0

[6] A. Hossain *et al.*, "Emerging roles of plant growth regulators for plants adaptation to abiotic stress–induced oxidative stress," *Academic Press*, pp. 1–72, Jan. 2022, doi: https://doi.org/10.1016/b978-0-323-91005-7.00010-2

[7] S. C. Government of Canada, "Ontario is an agricultural powerhouse that leads in many farming categories," *www150.statcan.gc.ca*, Jun. 15, 2022. Available: https://www150.statcan.gc.ca/n1/pub/96-325-x/2021001/article/00006-eng.htm

[8] Canada, "The Daily — 2016 Census of Agriculture," *Statcan.gc.ca*, 2016. Available: https://www150.statcan.gc.ca/n1/daily-quotidien/170510/dq170510a-eng.htm?indid=10441-1&indgeo=6. [Accessed: Sep. 16, 2024]

[9] J. Pavia, "As the time to plant crops approaches, local farmers mull options to deal with drier conditions," *CBC*, Mar. 25, 2024. Available: https://www.cbc.ca/news/canada/kitchener-waterloo/drought-tolerant-seeds-farming-waterloo-region-1.7152252. [Accessed: Sep. 16, 2024]

[10] S. Jiang and W. Fang, "Misinformation and disinformation in science: Examining the social diffusion of rumours about GMOs," *Cultures of Science*, vol. 2, no. 4, pp. 327–340, Dec. 2019, doi: https://doi.org/10.1177/209660831900200407

[11] M. Shaffril *et al.*, "Diversification of agriculture practices as a response to climate change impacts among farmers in low-income countries: A systematic literature review," *Climate services*, vol. 35, pp. 100508–100508, Aug. 2024, doi: https://doi.org/10.1016/j.cliser.2024.100508

[12] S. Wallander, E. Marshall, and M. Aillery, "USDA ERS - Farmers Employ Strategies To Reduce Risk of Drought Damages," *Usda.gov*, 2017. Available: https://www.ers.usda.gov/amber-waves/2017/june/farmers-employ-strategies-to-reduce-risk-of-drought-damages/

[13] "Soil Moisture and Irrigation | SoilSensor.com," SoilSensor.com, Sep. 25, 2018. https://soilsensor.com/soil/soil-moisture-and-irrigation/ (accessed Sep. 18, 2024).

[14] "Assistive Listening Devices | Hearing Health Care, Inc.," Hearing Health Care, Inc., Dec. 22, 2020. https://www.hear4life.com/hearing-aids/accessories/assistive-listening-devices/ (accessed Sep. 18, 2024).

[15] RTINGS, "RTINGS.com," RTINGS.com, Dec. 08, 2022. https://www.rtings.com/monitor/tests/inputs/input-lag (accessed Sep. 18, 2024).

[16] B. Li et al., "Accuracy calibration and evaluation of capacitance-based soil moisture sensors for a variety of soil properties," Agricultural Water Management, vol. 273, pp. 107913–107913, Nov. 2022, doi: https://doi.org/10.1016/j.agwat.2022.107913.

[17] "Soil Moisture Sensor Probes Frequently Asked Questions (FAQ)," *Vegetronix.com*, 2024. Available: https://www.vegetronix.com/Products/VH400/Soil-Moisture-Probe-FAQ#:~:text=The%20probe%20can%20be%20powered. [Accessed: Sep. 18, 2024]

[18] "STM32F4 Series - STMicroelectronics," STMicroelectronics, 2024. https://www.st.com/en/microcontrollers-microprocessors/stm32f4-series.html (accessed Sep. 18, 2024).

[19] IEC (International Electrotechnical Commission). "IP ratings". IEC.ch, https://www.iec.ch/ip-ratings. [Accessed: Sep. 18, 2024].

[20] "Soil Moisture Sensor Interfacing with Arduino UNO," © *2018 ElectronicWings*, 2019. https://www.electronicwings.com/arduino/soil-moisture-sensor-interfacing-with-arduino-uno (accessed Sep. 17, 2024).

[21] Bosch Sensortec, "Pressure Sensor BMP390," Bosch Sensortec, 2024. https://www.bosch-sensortec.com/products/environmental-sensors/pressure-sensors/bmp390/ (accessed Sep. 18, 2024).

[22] "STANDARDS IEEE Standards for Safety Levels with Respect to Human Exposure to Electric, Magnetic, and Electromagnetic Fields, 0 Hz to 300 GHz IEEE Standards Coordinating Committee 39 Developed by the IEEE International Committee on Electromagnetic Safety," 2019. Available: https://kolegite.com/EE_library/standards/IEEE%20Standards%20for%20Safety%20Levels%200%20to%20300%20GHz.pdf. [Accessed: Sep. 18, 2024]

[23] James Clerk Maxwell, *Dynamical Theory Of The Electromagnetic Field.* S.L.: Blurb, 2020.

[24] How, "GroPoint Soil Moisture Sensing," GroPoint Soil Moisture Sensing, Feb. 11, 2021. https://www.gropoint.com/new-blog/how-do-soil-moisture-sensors-work (Accessed Sep. 18, 2024).

[25] R. G. Martinsen and A. Heiskanen, "Electrodes," in *Elsevier eBooks*, 2023, pp. 175–248. doi: 10.1016/b978-0-12-819107-1.00005-4.

[26] J. Frost, "What is the Mean in Statistics?," *Statistics By Jim*, Aug. 21, 2021. Available: https://statisticsbyjim.com/basics/mean_average/

[27] GeeksforGeeks, "Error detection codes: Parity bit method," GeeksforGeeks, Aug. 13, 2024.https://www.geeksforgeeks.org/error-detection-codes-parity-bit-method/ (accessed Sep. 26, 2024).

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

[29] "Capacitive Soil Moisture Sensor Module v2.0 - X2 Robotics in Canada," *X2robotics.ca*, 2024. Available: https://x2robotics.ca/capacitive-soil-moisture-sensor-module-v2-0. [Accessed: Oct. 27, 2024]

[30] "Magnetic Buzzer-KP12-G185B – KEPO Tech," *Kepotech.com*, 2023. Available: https://www.kepotech.com/product/magnetic-buzzer-kp12-g185b/. [Accessed: Oct. 27, 2024]

[31] "CMD Ltd - Connecting Power, People and Organisations," *CMD Ltd*, 2016. Available: https://www.cmd-ltd.com/advice-centre/usb-chargers-and-power-modules/usb-and-power-module-product-help/usb-charger-faqs/

[32] All About Circuits, "Calculating Electric Power | Ohm's Law | Electronics Textbook," *Allaboutcircuits.com*, 2017. Available: https://www.allaboutcircuits.com/textbook/direct-current/chpt-2/calculating-electric-power/

[33] STM32CubeIDE installation guide. UM2563 STM32CUBEIDE installation guide - user manual (2024). Available at: https://www.st.com/resource/en/user_manual/um2563-stm32cubeide-installation-guide-stmicroelectronics.pdf (Accessed: 27 October 2024).

[34] Rohde, "Understanding UART," Rohde-schwarz.com, 2024. https://www.rohde-schwarz.com/ca/products/test-and-measurement/essentials-test-equipment/digital-oscilloscopes/understanding-uart_254524.html (accessed Oct. 27, 2024).

[35] "Infrared Communication basics | IrDA | IR,Infrared tutorial." https://www.rfwireless-world.com/Tutorials/Infrared-Communication-IrDA-tutorial.html

[36] "Super affordable wireless home phone," *Virgin Plus*. https://www.virginplus.ca/en/phones/home-phone.html?province=ON&geoResult=ON

[37] M. Meter, "Digital Soil Moisture Meter, Handheld," sisco.com, 2023. https://www.sisco.com/soil-moisture-

meter?affiliate=ads&gad_source=1&gclid=Cj0KCQjw7Py4BhCbARIsAMMx-_KO0x3LfBXO6ontqk723u4R4rQe4PVtuawx9ei_kjI4ZSkXKYlZxMUaAjh0EALw_wcB (accessed Oct. 28, 2024).

[38] "Gouevn Soil Moisture Sensor Meter, Plant Moisture Meter Indoor & Outdoor, Hygrometer Moisture Sensor Soil Test Kit Plant Water Meter for Garden, Farm, Lawn (No Battery Needed) : Amazon.ca: Patio, Lawn & Garden," Amazon.ca, 2024. https://www.amazon.ca/Moisture-Sensor-Outdoor-Hygrometer-Battery/dp/B07RDDLCBJ/ref=asc_df_B07RDDLCBJ/?tag=googleshopc0c-20&linkCode=df0&hvadid=706745350690&hvpos=&hvnetw=g&hvrand=9244217592886347744&hvpone=&hvptwo=&hvqmt=&hvdev=c&hvdvcmdl=&hvlocint=&hvlocphy=9001027&hvtargid=pla-822500635157&mcid=609a7290d95c3b10a058712c2aa7136f&gad_source=1&th=1 (accessed Oct. 28, 2024).

[39] "The Pros and Cons of Wireless vs. Wired Communication Systems." Linkedin.com, 2024. https://www.linkedin.com/pulse/pros-cons-wireless-vs-wired-communication-systems-tnrobinsonelec/ (accessed Oct. 28, 2024).

[40]"How to Cite References: IEEE Documentation Style." Available: https://ieee-dataport.org/sites/default/files/analysis/27/IEEE%20Citation%20Guidelines.pdf

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