TÉCNICO LISBOA

Instituto Superior Técnico

Ambient Intelligence 2023/2024

Smart Plant Watering System

PLANTGUARDIAN

ECO-WATERING

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Introduction

In our project, we aim to design an indoor irrigation system that incorporates practical technology to foster plant growth and health. Integrating humidity, temperature, and light sensors, our system will monitor environmental conditions, adjusting watering schedules and lighting based on the needs of each plant. This approach ensures that plants receive the right amount of water and light, optimizing their care and contributing to sustainable water use.

Inspired by existing research, projects, and papers, we plan to innovate by adding a camera to our system. This feature allows estimating the growth and the overall health conditions by taking pictures of the observed plants. The camera will take pictures and utilize image processing techniques to analyze the green values, determining whether the plant is growing or not. This provides direct feedback to the system, enabling precise adjustments to watering and lighting parameters.

Literature Review

For the literature review, we researched numerous papers and ended up with 3 in which they spoke in detail about many of the things that were a good starting point and have a lot of information that we will use. In the end, we ended up selecting only two of the three papers, considering that the bibliography contains links to the two presented here as well as to the third.

- First Paper

The paper "Smart Plant Watering and Lighting System to Enhance Plant Growth Using Internet of Things" published in 2023 by Yovanka D. Setiawan and colleagues [1] and presented at the 8th International Conference on Computer Science and Computational Intelligence (ICCSCI 2023), addresses the automation of plant care through IoT technology, focusing on optimizing growth conditions via a system controlling watering and lighting. This initiative reflects a growing interest in leveraging technology to support agriculture, particularly in enhancing plant health and productivity while ensuring efficient resource use.

Central to their work is the development of an Arduino-based system integrated with humidity, temperature, and light sensors. The research innovates by incorporating wireless connectivity, allowing for remote monitoring and management of plant conditions, and introduces a light intensity sensor to ensure adequate photosynthesis under varying sunlight conditions.

The proposed system aims to streamline agricultural practices, making them more effective and less prone to human error. Preliminary results demonstrate the system's potential in improving plant growth outcomes, suggesting significant benefits for sustainable agriculture. This approach aligns with the broader goals of our group's project by emphasizing the use of practical technology to foster plant health and sustainable water use, indicating a shared vision for enhancing indoor plant care through smart, user-friendly systems.

The paper successfully integrates Internet of Things (IoT) technology into an automated system for plant care, focusing on optimizing environmental factors such as humidity, temperature, and light, crucial for plant growth. This approach aligns with sustainability and efficiency, incorporating remote monitoring capabilities for user convenience. However, the system falls short in terms of user interaction, as it does not fully exploit the potential for users to customize care settings according to the specific needs of individual plants.It does not address system scalability or adaptability for different plant types, suggesting a one-size-fits-all approach. Our project aims to enhance these aspects by developing a more interactive web application, allowing for tailored care per plant species, and considering scalability for larger gardening setups. By addressing these gaps, we plan to offer a more user-friendly and adaptable indoor irrigation system, improving upon the foundation laid by the authors.

- Second Paper

The paper titled "Designing a Smart Garden for Automated Plant Watering using Flutter and Internet of Things in the Context of Industry 4.0" which was published in 2023, explores the development of an intelligent gardening system aimed at automating plant watering based on soil moisture levels. Authored by Khaerul Manaf and colleagues from various educational and research institutions [2], the study of 2023 addresses the challenge of inconsistent watering practices in educational institutions, which often leads to plant withering and decline.

The research focuses on developing an automated plant watering system to address the challenge of inconsistent plant care in educational settings. The system employs Flutter and IoT technologies to monitor soil moisture and automate watering, ensuring plants receive appropriate care without manual intervention. By categorizing soil into four moisture levels from water-rich to parched, the system activates watering when necessary, optimizing water use and plant health.

The research methodology includes a prototype-driven approach, which informs the automated watering process. Key components of the system's implementation involve the NodeMCU ESP8266 board for internet connectivity and Flutter for developing the accompanying Android application.

The results indicate that the IoT-based Smart Garden system can significantly improve plant care, ensuring plants are watered only when needed. This method demonstrates a promising solution for efficient and sustainable plant maintenance, highlighting the potential for broader adoption of IoT technologies in gardening and plant care. The study emphasizes the need for further research and development to enhance system reliability and scalability, aiming to contribute to environmental sustainability and smart gardening practices.

The paper exemplifies innovative use of technology to automate plant watering, demonstrating practical application in educational settings. It offers a detailed methodology for soil moisture categorization and system architecture, showcasing its potential for replication and research. However, the study keeps focus on only soil moisture, without considering other vital environmental factors like humidity, temperature, or light. Also, the system's user interaction and customization options are underemphasized, restricting its adaptability to varied user needs. Our project aims to address these limitations by incorporating a broader range of environmental sensors and enhancing user control through a web application, offering a more comprehensive and user-centric solution for indoor plant care.

Problem

The Smart Plant Watering System is conceived to revolutionize the care of indoor plants for hobbyists and small-scale growers by automating the intricate balance of irrigation and light exposure. The challenge lies in the common pitfalls of plant care— overwatering and underwatering—that stem from a lack of specialized knowledge among plant owners. These missteps are major contributors to plant stress and mortality, complicating the simple task of plant growth and maintenance.

Overwatering, whether by excessive volume or frequency, can suffocate plant roots, leading to disease or death. Conversely, underwatering, particularly during critical growth phases, can desiccate soil and roots, severely stunting or killing the plant. The variability of soil composition and environmental conditions further complicates these issues, demanding a more nuanced approach to watering than generic guidelines can provide.

Our system introduces a dynamic solution that tailors water and light to the specific needs of each plant species across different seasons. By leveraging sensor technology and advanced image processing, the Smart Plant Watering System not only adjusts irrigation and lighting schedules in real-time but also offers adaptability through user feedback and manual overrides. This ensures that plants receive optimal care regardless of the owner's physical presence or expertise level.

Furthermore, the principles of our system have the potential to be expanded into the realm of Smart Agriculture. This extension could be a sensor-driven approach to larger scale agricultural operations, where the precise management of water and light could significantly enhance resource efficiency and environmental sustainability.

Solution Requirements

R1: The system captures data from the sensors periodically.
R2: The system can access a remote dataset of reference images of plants in various health conditions.
R3: When the data captured from the soil sensors are below a threshold T, the water pump turns on.
R4: During the day, when the natural light is below a certain threshold L, based on the plant type, the system will activate a UV lamp.
R5: The system periodically captures an image of the monitored plant using the camera module. Image processing techniques are applied to analyze green values to assess plant growth and health conditions.

Assumptions

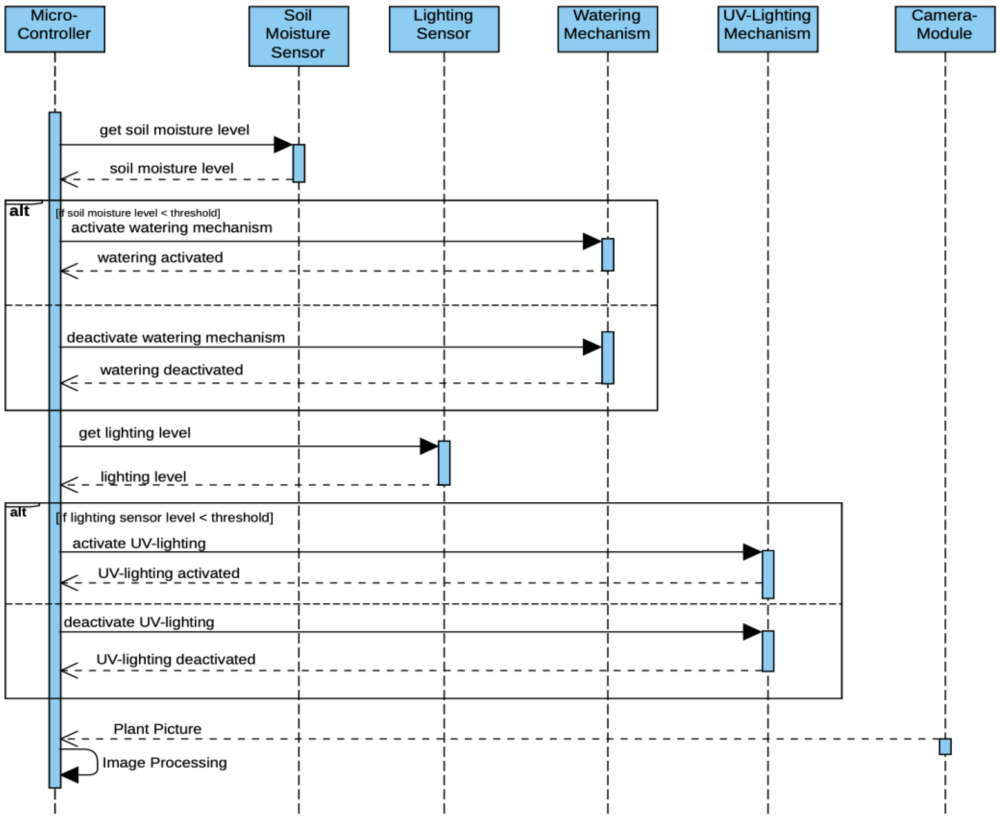
The system is expected to operate correctly when the following set of conditions are satisfied:

1. The water pump activates correctly and is not clogged: if the following condition is not met, the system will not be able to provide the amount of water needed and the plant would die.
2. There are no power outages: the current needed by the system is always provided through a small circuit running a low voltage in DC.
3. No electricity hazard: there must be no contact between the watering components and the electrical circuit.
4. The sensors have been calibrated and give no significant outliers.

Proposed Solution

The main functions of the proposed solutions should include:
Read The Moisture Level: Reading of the soil moisture level using the moisture sensor.
Determine Watering needs: Based on the soil moisture level and a specific, predefined threshold, determine if the plant needs watering.
Watering Mechanism: If watering is required, activate water pumps. Stop watering as soon as a desired humidity level is reached again.
Read Sunlight Levels: Reading of the sunlight levels using a light sensor.
Determine UV Lightning Needs: Based on the sunlight levels and a specific, predefined threshold, determine if the plant needs UV lightning.
Lightning Mechanism: If UV lightning is required, active UV lightning. Stop UV lightning as soon as the sunlight levels are sufficient for plant growth again.
Image Processing: Integrate a camera module to periodically capture images of the plant. These images are then analyzed using image processing to measure changes in green values.
Development Platform and Programming Languages for Implementation:
Due to the use of an Arduino Uno for our project, we are using C++ as the primary programming language for implementation. Arduino IDE is serving as the Development platform.

Assembling and Interconnection between Devices:
A Microcontroller will serve as a central controller between the sensors, UV-lightning, water pumps and the camera for image processing. The soil moisture and lightning sensors will be connected to the input pins of the board which enables a periodic reading of real-time data according to the current lightning and soil moisture levels. Additionally, the UV-lighting and water pumps are controlled by the output pins using relay modules or transistors.



Bill-of-Material

Hardware

- **Microcontroller**
- **Capacitive Soil Moisture sensor**
- **Water level sensor: in order to shut down the water pump.**
- **Photoresistor sensor**
- **Water Pump and tube**
- **Camera module**
- **Resistors**
- **UV Lamp**
- **Jumper wires, either male-female and male-male**
- **Breadboard**
- **Small aromatic plant**
- **Small water tank**

Software

Plant watering and light:

- **Arduino IDE -** Operating system
- **C++ -** Programming Language and Platform

Plant's image processing:

- **PyCharm -** IDE by Jetbrains
- **Python -** Programming Language and Platform

Program to get extract the serial monitor information:

- **Spyder -** Operating system
- **Python -** Programming Language and Platform

Setting up the Prototype

The system's initialization involved setting up the necessary pins for the light sensor, soil moisture sensor, water level sensor, water pump, and an LED indicator. For our prototype, we utilized an Arduino Uno microcontroller as the heart of the system. Alongside, we integrated a suite of sensors and actuators including the Whadda WPSE303 Soil Moisture Sensor for detecting soil dryness, the Whadda WPSE303 Water Level Sensor to monitor the water tank's status, and a Photoresistor Sensor for gauging light exposure. Watering is facilitated by a Mini Water Pump driven by a small actuator. Instead of implementing a full-scale UV lighting mechanism using a real UV-lamp, we demonstrated the lighting functionality with a small LED lamp.

Furthermore, the camera module OV7670 we purchased turned out to be incompatible with our Arduino Uno since the OV767X library is designed for a mbed architecture, not for AVR architectures. The mbed architecture is typically used in ARM-based microcontrollers as found in some newer Arduino boards (e.g. Arduino Nano 33 IoT, MKR series, etc.) so it would be a better approach to use one of these Arduino Boards for future projects. This was leading us to demonstrate the image processing functionality using image processing with our laptop camera instead. Finally, the most important player was a small basil plant, which was used to test the success of the system. The following pictures show the prototype of the PlantGuardian Eco-Watering.

Figure 1: Prototype of the PlantGuardian Eco-Watering

Implementation Steps

At the beginning of implementation, we had some problems with the acquired hardware (a mistake on our part) and had to delay its development for 2 days. After all components were purchased (sensors, cables and plant), all components were tested, and a first program was developed to test them.

After that, research was carried out to discover the most common types of plants for indoors and for soil humidity and sunlight. This research was one of the most important steps as plants must have well-defined limits to maintain growth and good health.[4][5][6][7]

We chose to implement 7 types of plants, and we obtain the following metrics:

Aromatic Plants: These plants, like rosemary, sage, and thyme, generally prefer well-draining soil and should only be watered when the soil has completely dried out. They thrive in locations that receive at least six hours of bright, indirect light daily.
Cacti and Succulents: They are adapted to dry conditions and prefer soil that dries out completely between waterings. Bright light, with some direct sunlight, is ideal for most cacti and succulents.
Foliage Plants: This category varies widely, but many common indoor foliage plants prefer soil that remains evenly moist without being waterlogged. Indirect, bright light is generally best, though specific light needs can vary.
Flowering Plants: These plants often require well-draining soil that stays slightly moist, especially during blooming periods. They typically need bright, indirect light to promote flower production, but again, this can vary by species.
Herbs: Like aromatic plants, herbs like moist but well-draining soil and should not be left to dry out completely. They usually need at least six hours of sunlight per day, with bright, indirect light being ideal for many herb varieties.
Air Purifying Plants: These plants vary in their soil moisture and light requirements, but many prefer soil that is kept evenly moist and placed in bright, indirect light. It's essential to research the specific needs of each plant in this category.
Edible Plants: Edible plants such as vegetables and fruits generally require soil that is kept consistently moist and fertile. They usually need at least six hours of direct sunlight per day, although some leafy greens can tolerate lower light levels.

After the research, the metrics were implemented in the code, and it was tested as seen in the ***Demos*** delivered with the ***README***. After the main code was developed, two other programs were also created so that the system could be implemented at home without the need for a computer and simply being dependent on power.

To monitor the growth of the plant over time, we introduced a small image processing pipeline developed in python. The script can be described in a few main steps. Foremost we read a pair of images from the */resources* folder relative to the root folder of the project. The first image represents the one grabbed at T0 and the second one at T1. Firstly, the images should be normalized to a fixed size of 640x480px since the camera sensor that we bought has this maximum resolution.
After that, we convert them to the HSL color space, since there is a better representation of the colors along the three channels:

- Hue: refers to the actual color itself, like red, green, or blue.
- Saturation: represents the intensity or purity of the color.
- Lightness: controls the brightness of the color. 0% lightness is black, and 100% is white.

Applying a median filtering to the image leads to a noise reduction that could be in the image. We define two masks in the HSL color space to get the different tones of green values and add them using the bitwise operator to the original image. All the pixels in the latter having a value not included in the masks will be removed having a value of 0, visually represented as black. Finally, we estimate the percentage of green pixels in the segmented image by dividing the number of greenish pixels by the total amount of pixels in the image that is equal to 640·480.

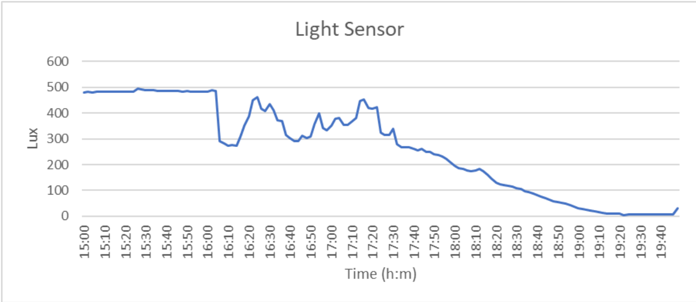
Due to the incompatibility issues explained earlier, the script should be run on the PC, however it uses the following libraries that are perfectly compatible with ARM chips mounted on the Raspberry boards:

- OpenCV: image preprocessing
- Numpy: numpy array data structures

Results

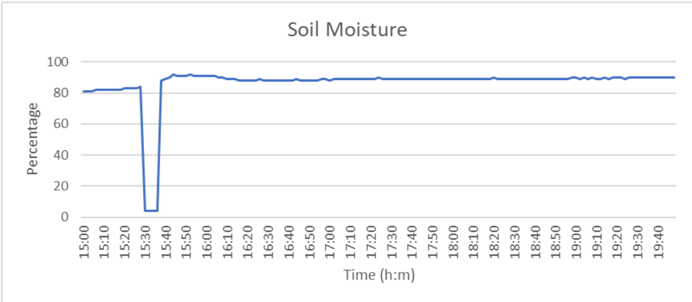
By running the standalone program for about 4 hours while the user was away from home. The following values refer to the Light Sensor, Soil Moisture and Water Level Sensor.

As we can see in the Light Sensor graph, the start of the data was at 3:00pm on a more or less cloudy day, so the values recorded are a bit above the threshold (400 for the Aromatic plants), sometimes having variations due to the clouds, throughout the afternoon the value decreases due to the solar activity.



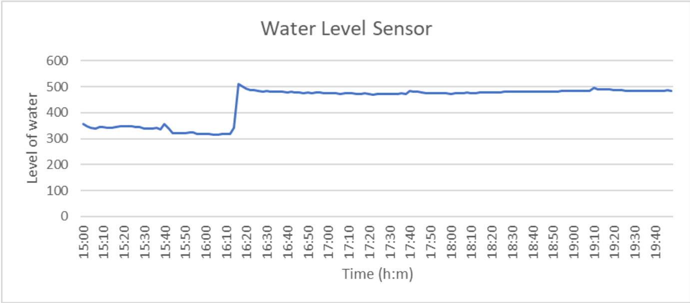
Graph 1: Values of the light sensor

Next we have a graph of Soil moisture, it doesn't vary much as it wasn't a very hot day nor with a lot of sun exposure. With user input, the same sensor was removed around 3:30 pm in order to activate the water pump and obtain some variation in soil moisture, which went from 84% to 92% and remained stable for the rest of the afternoon.



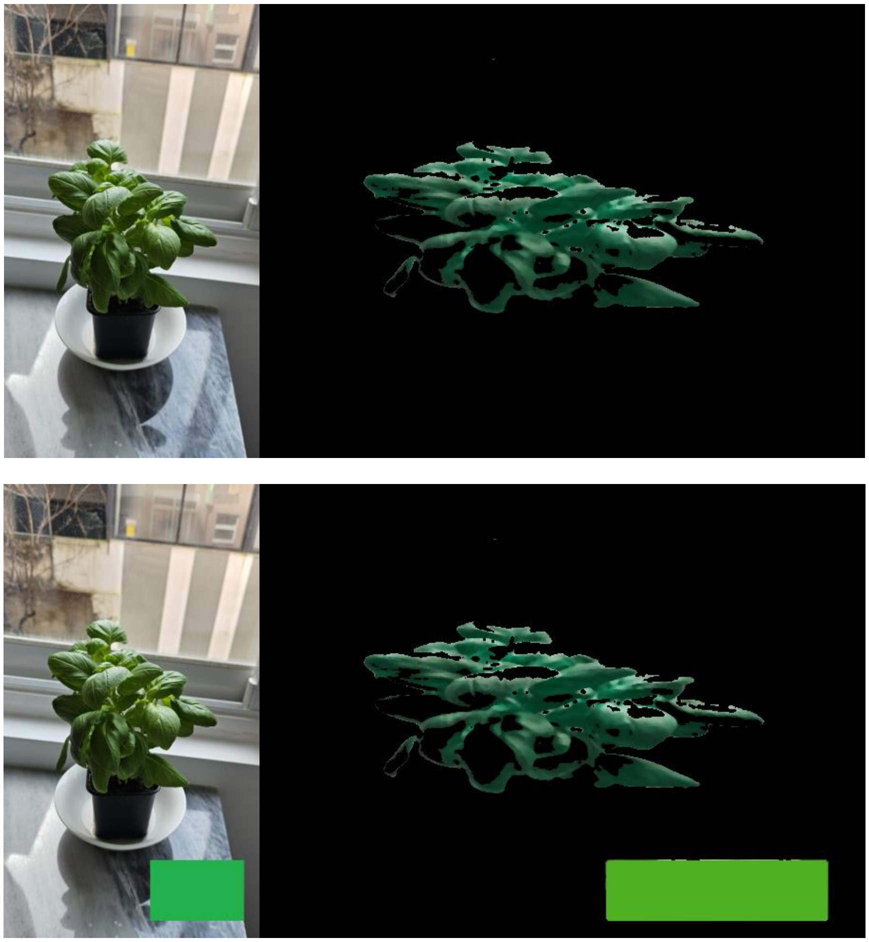
Graph 2: Values of the soil moisture sensor

Finally we have the graph of the water level sensor in the water tank. It lost some water around 3:30 pm and was filled around 4:15 pm as can be seen in the graph in question.



Graph 3: Values of the water level sensor

In the image scenario, we can observe the first image [Figure 3], the second one [Figure 4] where we artificially added a green rectangle to increase the amount of green and the output of the segmentation algorithm explained earlier.



Figures 3 and 4: Pictures of the before and after applying the image processing program.

The results show that it successfully detected the artificial green part and checking the console we see an increase from 28% to 43% of green pixels. Since there was an increase in the amount of green over time, the plant is in a growing phase and the system is working correctly.

Outlook

Future developments might explore enhancing image processing by utilizing a different type of microcontroller compatible with various camera modules. This would allow the camera module being connected to and become an integral part of the overall system. Future works could also aim to enhance an automated plant system by integrating the ability to adjust the water volume based on the plant's current soil moisture measurements instead of ambient humidity. Comparing this to the plant's predefined optimal value and factoring in the pot size, the system could determine a more precise water volume requirement. The necessary water volume would dictate the pump's activation time, considering the pump's flow rate to deliver the correct water amount.

Furthermore, predefining the plant type might be automated based on image recognition, requiring a large database of plant species and their optimal conditions for UV light and watering. This advancement could streamline the system's setup process, allowing it to automatically identify the plant type and adjust care parameters accordingly for a more tailored and efficient approach to plant care. Finally, the development of a comprehensive web application would serve to increase user-friendliness, acting as a central hub for remote system management. This application would offer real-time moisture monitoring, customizable settings for pot size and plant selection, access to a detailed watering history, and the ability to manually adjust the automated system settings.

Conclusion

In the culmination of our project, we have successfully designed and implemented an automated plant care system that leverages the capabilities of an Arduino microcontroller. This innovative system is adept at monitoring and responding to the essential needs of various types of plants, ranging from aromatic and edible plants to succulents, foliage, flowering, herbs, and air purifying plants. Through precise assessments of light exposure, soil moisture, and water tank levels, our system ensures the optimal care for each plant type based on its unique requirements.

Due to time constraints, we were unable to implement our original idea of developing a web application for real-time monitoring and interaction with the automated plant care system. This feature, envisioned to enhance user engagement and control through detailed data visualizations and personalized care recommendations, represents a significant opportunity for future work. Instead, we decided to focus on providing feedback on the system's effectiveness through image processing. This approach allows to visually assess plant growth, demonstrating the system's success despite the absence of the planned web application.

Bibliography

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[2] K. Manaf, A. B. Abd Rahman, Y. Setiawan, F. M. Kaffah, N. Lukman, and D. Pitoyo, "Designing a Smart Garden for Automated Plant Watering using Flutter and Internet of Things in the Context of Industry 4.0," in Proceedings of the 2023 17th International Conference on Telecommunication Systems Services and Applications (TSSA), 2023, doi: 10.1109/TSSA59948.2023.10367029.
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