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Abstract

California’s escalating water shortage, aggravated by ongoing climate change and persistent droughts, necessitates urgent action to preserve this valuable resource. According to the United States Environmental Protection Agency, 50 percent of water used for landscape irrigation and agriculture are wasted through evaporation, wind, and runoff due to overwatering of crops. Equally important is preventing the under watering of crops, as they can face life-threatening conditions amid California’s harsh climate. To strike the delicate balance between water conservation and crop health, this paper explores a method employing soil moisture sensors for precise irrigation control. The sensors measure soil water content, enabling targeted water delivery when levels are low and immediate cessation when optimal moisture is achieved. The system is managed through an Arduino microcontroller, which efficiently regulates the irrigation process based on data gathered through the moisture sensors. The Arduino processes the information received and triggers the water supply, delivered through a pump and a hose. A sprinkler attachment at the end of the hose ensures even water distribution across all plant areas, effectively preventing overwatering in any specific spot. The results indicate over a 45 percent decrease in water use while demonstrating healthier plants. This approach presents a promising solution to California’s water scarcity while ensuring sustainable crop growth and efficient resource consumption. The future plans involve using solar energy to power the device’s batteries and incorporating artificial intelligence (AI) technologies to detect various factors such as plant species, soil type, terrain, and real-time weather conditions. By leveraging these advanced technologies, the research aims to transform irrigation management for enhanced water efficiency and environmental sustainability concerning California’s agricultural practices.
Smart Water Management: Addressing California’s Water Scarcity through a Soil Moisture Detection Based Irrigation System

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Abstract

California’s escalating water shortage, aggravated by ongoing climate change and persistent droughts, necessitates urgent action to preserve this valuable resource. According to the United States Environmental Protection Agency, 50 percent of water used for landscape irrigation and agriculture are wasted through evaporation, wind, and runoff due to overwatering of crops\(^1\). Equally important is preventing the underwatering of crops, as they can face life-threatening conditions amid California’s harsh climate. To strike the delicate balance between water conservation and crop health, this paper explores a method employing soil moisture sensors for precise irrigation control. The sensors measure soil water content, enabling targeted water delivery when levels are low and immediate cessation when optimal moisture is achieved. The system is managed through an Arduino microcontroller, which efficiently regulates the irrigation process based on data gathered through the moisture sensors. The Arduino processes the information received and triggers the water supply, delivered through a pump and a hose. A sprinkler attachment at the end of the hose ensures even water distribution across all plant areas, effectively preventing overwatering in any specific spot. The results indicate over a 45 percent decrease in water use while demonstrating healthier plants. This approach presents a promising solution to California’s water scarcity while ensuring sustainable crop growth and efficient resource consumption. The future plans involve using solar energy to power the device’s batteries and incorporating artificial intelligence (AI) technologies to detect various factors such as plant species, soil type, terrain, and real-time weather conditions. By leveraging these advanced technologies, the research aims to transform irrigation management for enhanced water efficiency and environmental sustainability concerning California’s agricultural practices.

1 Introduction

The four primary types of irrigation include surface, sprinkler, drip (precision), and subsurface methods\(^4\). Although surface irrigation is the most widely employed, it leads to significant water loss through evaporation compared to the other methods. The drip irrigation technique is gaining popularity due to its enhanced efficiency and minimized runoff effects \(^6\), prompting the implementation of a precision irrigation system in this prototype.
Furthermore, the escalating rates of evapotranspiration resulting from global warming and the depletion of nonrenewable groundwater resources underscore the growing significance of monitoring irrigation water usage. Moisture detection technology provides farmers with the capability to track water consumption accurately and manage resources more effectively.

The arid climate of California’s agricultural regions usually lead to either an overuse or underuse of water for crops. An underuse in water leads to crops drying out from heat, while an overuse leads to several consequences including a wastage of scarce groundwater and runoff leading to soil erosion or further pollution of downstream areas.

Modern agriculture currently stands at the crossroads between further technological innovation and resource conservation. In this context, the research helps navigate the subject of water conservation in California through the use of advanced technology.

2 Methods and Materials

2.1 Materials

The heart of this study involves an Arduino microcontroller—a compact computational unit that serves to execute programmed functions. In this case, the Arduino facilitates the coordination and control of tasks associated with the irrigation control. The Arduino, connected to both the soil moisture sensor and the water pump, regulates control of the water based on programmed inputs from the moisture sensors. Similar to precision agriculture principles, the proposed system seeks to optimize resource use by precisely determining the water required, all while adapting to real-time variations in soil moisture.

Our emphasis on technological precision is grounded in the imperative to mitigate water wastage—a critical concern in the arid agricultural regions of California. The Arduino microcontroller processes data from strategically positioned soil moisture sensors, enabling targeted and efficient irrigation, drawing off the ideas of precision agriculture. This approach not only ensures the meticulous use of water but also safeguards crop health and productivity.

The implementation of the smart irrigation system involved the utilization of specific materials and equipment to achieve precision in water management. A sensitive soil moisture detector (3.3V - 5V, using a LM393 chip) was strategically placed in the soil to serve as the primary data source for the irrigation system. The prototype was constructed around the use of an Arduino UNO REV3 microcontroller board, programmed to interpret real-time data from the soil moisture sensors and make informed decisions regarding the initiation and cessation of the irrigation process. A 2 channel 5V relay connected to the microcontroller to modulate the status of water control. The other end of the relay connected to a 2.5V-6V Micro Submersible Water Pump which delivered the water to the plants through a hose and sprinkler end. Figure 1 shows the proposed setup of the prototype.
Figure 1: Proposed Layout of Prototype Structure

Figure 2: Physical Layout of Prototype Structure
2.2 Data Acquisition

The acquisition of data played a central role in assessing the impact of the smart irrigation system on home plant health, incorporating a comparative methodology. The soil moisture sensors, strategically positioned within the pots of both the experimental and reference groups, facilitated the measurement of soil moisture content at varying depths. These sensors seamlessly interfaced with the Arduino microcontroller.

In adherence to an experimental design, a reference group was established, comprising home plants subjected to conventional watering practices. Conditions were standardized between both the experimental and reference groups, taking into account factors such as light exposure, temperature, and soil composition. This careful standardization aimed to isolate the effects of the implemented irrigation system, allowing for a direct and meaningful comparison.

The comprehensive dataset obtained through the Arduino-driven data acquisition process, supported by MATLAB software, laid the foundation for subsequent comparative analysis. This multifaceted dataset facilitated a nuanced exploration of the smart irrigation system’s impact on plant health in direct relation to traditional watering methods.

Plant health assessments were conducted utilizing visual qualitative factors, encompassing aspects such as leaf color, stem strength, and texture. This approach provided a nuanced evaluation of the impact of the smart irrigation system on plant well-being.

2.3 Data Analysis

The analysis of the comprehensive dataset obtained through the Arduino-driven data acquisition process utilizing MATLAB software, the collected data on soil moisture levels, and visual qualitative assessments of plant health. Statistical analyses, consisting mostly of observing moisture level consistency, were performed to discern any significant differences between the experimental and reference groups.

Quantitative assessments focused on variations in soil moisture content over time, revealing distinct patterns indicative of the implemented system’s influence. Comparative analyses of visual qualitative factors, including leaf color, stem strength, and texture, provided an understanding of the overall impact on and change of plant health. Through this testing, patterns emerged that showed the greater consistency in soil moisture and overall greener plants that substantiated the benefits of the smart irrigation system prototype in fostering healthier plant conditions.
3 Results

3.1 Water Usage

The data collected shows a remarkable reduction in water use for the smart irrigation group. In comparison to the control group, which received an average of about 12 ounces of water per day, the irrigation system led to a significant decrease, bringing water intake levels down to approximately 6.58 ounces a day. These results signify a 45.2% reduction in water usage, further underscoring the efficiency of the smart irrigation system to provide optimal water levels.

3.2 Soil Moisture Consistency

Figure 2 shows a chart comparing the soil moisture consistencies of the reference group and the irrigation system implemented group. Data was collected each hour over a 48-hour period and monitored through the MATLAB software when connected to the Arduino system. The measurements run from 200-1025; a value of 200 represents full moisture, while a value of 1025 corresponds to no moisture. The irrigation system was programmed to release water into the plant after the moisture level fell below a value of 800, which corresponds to slightly dry soil for the plants experimented on. The data shows drastically fluctuating values for the control, indicating inconsistency in the moisture levels, while the irrigation system produced constant results.

![Comparing Soil Moisture Consistency over 48 hour Period](image)

Figure 3: Moisture Consistency between control group and proposed system
3.3 Qualitative Comparison

The qualitative assessment of plant health between the two groups provided insight into the impact of the implemented irrigation system on various visual indicators: leaf color, stem strength, and texture, that reflected overall plant health.

The enhancement in leaf color in the plant subjected to the irrigation system displayed itself through the leaves’ vibrant and green hues. The bright green, indicative of rich photosynthetic activity, was consistent throughout the plant, on all leaves and throughout the entirety of each leaf. The control group showed a less vibrant overall color and its leaves had visible brown discoloration, showing signs of possible reduced oxygen uptake from overwatering.

An assessment of stem strength revealed that the plants watered through the irrigation system had slightly stronger, upright stems while the control group stems appeared to be bending over and slightly flimsy. Additionally, the control group showed more leaf loss than the irrigation implemented plants.

Finally, the qualitative analysis extended to leaf and stem texture, revealing an improvement in the irrigation group. The leaf tissues for the irrigation group displayed consistent strength and firmness throughout the plant, while the control group had several leaves throughout the plant that appeared flimsy with uneven consistency in thickness with regard to the leaf tissue.

Collectively, these qualitative observations help further support the beneficial role that the irrigation system played in positively influencing overall plant health, displaying discernible improvements in leaf color, stem strength, and plant texture.
Figure 4: Figure 4: Control Group Plants
4 Discussion

Our results showcase the potential of the smart irrigation system to optimize healthy plant growth while decreasing excess water use. The irrigation system, providing consistent moisture rather than erratic water deposition, provides a great benefit, as erratic watering often leads to drying out seeds and plant stress which may invite pests.

The proposed system also produced visual characteristics indicative of healthier plants than the control group: vibrancy and consistency in the leaves of the experimental group indicate healthy physiological processes when compared to the control. The sturdier stems communicate greater structural integrity and show signs of greater overall resilience. Finally, a consistency in texture showing overall strength and firmness rather than the occasional inconsistencies in the
control group support the finding that the smart irrigation system produced, overall, healthier plants.

These results are especially significant in the context of California’s ongoing struggle with water conservation: the United States Environmental Protection Agency, stated that 50 percent of water used for landscape irrigation and agriculture is wasted through evaporation, wind, and runoff due to overwatering of crops, and a household with an improperly maintained irrigation system can waste up to 25,000 gallons of water annually\(^1\). The 45.2% decrease in water use that our proposed system provided, although it was done on a much smaller scale, can be used as a blueprint to further contribute to water conservation efforts in California.

5 Limitations of the Study and Future Research

There exist a few areas in this study that may be improved upon and serve as a basis for future related studies. First, the study consists of a particularly small scale, with possible inconsistencies that may occur when performed again. Additionally, due to the study being performed on house plants, we cannot generalize it to diverse plant species in outdoor environments with different conditions. In the future, the study can be performed with a multitude of diverse plant species, a larger number of test subjects, and in varying environmental conditions to obtain more accurate results that can be generalized to a greater number of species and applied in varying environments.

This research serves as a prototype for a smart irrigation system that works towards minimizing water wastage and preventing excess erosion and runoff while providing crops with adequate water to withstand California’s arid agricultural climate. To build off this prototype, we can implement greater factors for the system to consider when managing water distribution. A few possible conditions to be added include detecting plant species, soil type, terrain, and real-time weather conditions to adjust water distribution and make it optimal for each specific plant. In order to obtain even more specific water deposition amounts, we can utilize AI technology to holistically interpret all these factors and more. Implementing this technology would provide plants with the optimal amount of water they require, providing them with enough to sustain themselves in the harsh heat, while minimizing erosion and runoff, overall contributing positively to the water crisis in California.
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