Design and implementation of an automated irrigation control for home plantations

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ABSTRACT

In today's society, keeping our gardens attractive is complex, especially if you need more time to care for them. This can cause the plant to wilt if it is not watered occasionally to keep the soil moist. In summer, this problem tends to get worse because the temperature tends to rise and reach high degrees. The objective is to design an automatic and manual irrigation system with a humidity detector through hardware programming and free software to solve this. The necessary components will be identified and selected, humidity thresholds will be established, and the adoption of technologies such as internet of things (IoT), Arduino, and humidity sensors will be promoted to solve the problem in automated irrigation systems. The technical specifications of the components are described, and the circuit design is presented. A programming algorithm will be developed to control the frequency and duration of irrigation, as well as the state of the water pump. Implementing the automated system will allow precise water supply control, contributing to the healthy growth of plants and crops in green areas.

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1. INTRODUCTION

Increasing water scarcity and inadequate management of water resources have caused a severe global problem related to water conservation. In the Peruvian context, inappropriate water management during the irrigation process of green areas has resulted in poor maintenance of these areas [1]-[5]. This situation is mainly attributed to conventional irrigation systems, such as flood or furrow irrigation, which could be more efficient and lead to significant water waste [6]-[8].

Rondinel-Oviedo and Sarmiento-Pastor [9] examines how residents' water consumption habits (internal factors) and climatic conditions (external factors) impact household water consumption. Quantitative data from the provider and qualitative data from 900 surveys in different areas of Lima are used. The results are analyzed and compared to understand how these factors affect water consumption. These findings are essential for formulating water management policies and designing residential infrastructures that promote efficient and sustainable use of water resources.

Faced with this problem, the main contributors have explored the development and design of innovative irrigation systems as an effective solution to avoid water waste and increase the productivity of green areas [10]-[12]. Various studies have shown that adequate irrigation regulation through automated systems allows for uniform water distribution, contributing to creating homogeneous urban green spaces [13], [14]. In this sense, previous research has implemented automated systems based on technologies such as

Arduino, soil moisture sensors, and wireless communication modules (Bluetooth, internet of things (IoT)) to monitor and control the irrigation process in hydroponics and crops [15], [16]. These systems have proven effective in optimizing water consumption, reducing waste, and saving labor [17].

While automated solutions exist for large-scale agricultural irrigation, a gap remains in innovative, adaptable irrigation systems for domestic applications and home garden crops [18]. Most existing systems lack an intuitive interface that allows the end user to easily interact and control the irrigation process based on their preferences and the specific needs of their plants [19]. Furthermore, there is a need to integrate multiple technologies, such as soil moisture sensors, microcontrollers, and wireless communication modules, into a compact, low-cost, and easy-to-deploy system for home crops [20]. This would allow home users to reap the benefits of irrigation automation and optimization, thereby contributing to water conservation and the healthy growth of their plants [21].

The work's main objective is to design and implement an automated irrigation and soil humidity control system for domestic crops using accessible and open-source technologies. The specific objectives of the design and development approach are as follows: identify and select suitable components, such as soil moisture sensors, microcontrollers, and wireless communication modules, that enable cost-effective and efficient implementation of the system. To properly program the irrigation control algorithm, define optimal soil moisture thresholds and ranges for different types of plants and domestic crops. Develop an efficient scheduling algorithm that controls the frequency and duration of irrigation, as well as the status of the water pump, based on soil moisture readings and user preferences. Design and implement an integrated electronic circuit that incorporates all the selected components and allows autonomous and reliable operation of the system. Perform exhaustive tests of the system's functionality, efficiency, and precision, evaluating its performance in different scenarios and home growing conditions. Promote the adoption of open-source technologies, such as Arduino and IoT, in developing accessible and sustainable automated irrigation solutions for home users and small farmers.

As new contributions, the design and implementation of a functional prototype of an automatic humidity and irrigation control system using Arduino Uno, designed explicitly for domestic crops, is presented. The proposed system incorporates the following innovative features: an intuitive user interface based on Bluetooth and RemoteXY allows users to interact and switch between automatic and manual modes according to their preferences, providing personalized control of the irrigation process. Integrating a low-cost capacitive soil moisture sensor monitors plant conditions in real-time and determines when watering is necessary, thus avoiding water waste. An efficient scheduling algorithm that controls the frequency and duration of irrigation and the status of the water pump ensures accurate water delivery, optimizes resource consumption, and promotes the adoption of accessible and open-source technologies, such as IoT, Arduino, and humidity sensors, to solve the problem of inefficient irrigation in small-scale automated systems.

In summary, this work presents an innovative and accessible solution for automated irrigation control in domestic crops, taking advantage of open-source technologies and focusing on the end-user experience. The substantial contribution lies in integrating low-cost components, an adaptive control algorithm, scalability and versatility, and promoting sustainable solutions for efficient water management in non-industrial environments. In the subsequent sections of the manuscript, the component selection process, circuit design, and implementation of the proposed system will be described in detail. The results obtained will be presented, including tests of functionality, efficiency, and accuracy of the system, demonstrating how the automated approach allows precise water supply control and contributes to the healthy growth of plants and crops in domestic green areas. Likewise, the study's practical implications, limitations, and possible future lines of research and development in this field will be discussed. Finally, the importance of promoting the adoption of accessible and sustainable technologies for efficient irrigation management in domestic environments and small crop areas will be highlighted.

2. METHOD

The present study focuses on designing and implementing a functional prototype of an automated irrigation and soil humidity control system for domestic crops. The experimental setup comprises critical elements: the system development has two stages or phases. The first phase involves assembling components and developing the algorithm. Phase two involves testing to refine and present the system.

2.1. Leveling variables

The Arduino UNO R3 board is a development board that uses the ATMEGA microcontroller, which can be programmed in C language. This board has a variety of digital and analog ports, which allow the connection of different electronic components. This facilitates the customization and adaptation of the project to the specific needs of the developer, providing a versatile and accessible platform for the creation of a wide range of applications and electronic prototypes [22]. The technical values of the Arduino 1 are shown in Table 1. In the development of the circuit, Bluetooth will be connected directly to the Arduino Uno on pins 3 and 2 (Rx, Tx), whose characteristics are described in Table 2. At the same time, it will be connected to a relay that will signal the pump that can be activated if the soil is dry.

Table 1. Technical specifications of Arduino Uno

Arduino Uno	SMD Rev3
Microcontroller	ATmega328
Voltage	7-12 V
Digital input-output pins	14 (6 can be used as PWM outputs)
RAM	2 KB

Table 2. Technical specifications of Bluetooth module

Bluetooth	HC-05
Voltage	3.3 V–6 V
Operating current	30 mA
Default password	0000 o 1234
Operation range	10 m (33 feet)

The main component in the project is the capacitive sensor, as this device is essential to provide the necessary information in the form of an analog reading. This information is critical because it varies continuously in response to changes detected by the sensor, thus allowing accurate data to be obtained about the environment or specific conditions being monitored. With this analog data, the necessary code can be written and developed to program the Arduino board, which will act according to the variations detected by the capacitive sensor [23]. The technical values are shown in Table 3.

Table 3. Technical specifications of the humidity sensor

Capacitive soil moisture sensor	SEN-HS-CAP V1.2
Voltage	5 V DC
Operating current	5 mA
Analog reading range	0 a 615
Baud rate of operation	9600

2.2. Proposed system

For the project to be developed, it is proposed that two pins (7, 8) will be established in the circuit for each programming mode so that interference is not generated when going from the automatic state to the manual mode. Arduino Uno-compatible SMD will be used [24]. Arduino Uno is an open-source microcontroller with digital and analog I/O pins connecting to different expansion boards and other circuitry soil moisture sensors. The capacitive soil moisture sensor v1.2 allows us to monitor the humidity level of the plants and thus reminds us when they need to be watered. The 1-channel relay module is a device that is used for power load switching. This device will allow us to control the water pump, closing the passage if necessary, depending on the state in which the plant is. The Hc-05 Bluetooth module lets us connect our project to a smartphone through Arduino and wirelessly connect to a PC or cell phone. The transmission of information is carried out directly to the programmer; due to the connection to the serial pins of the microcontroller, the voltage levels must be considered water pump. The mini water pump shown can move liquids from one container to another. The function of this pump is that it can pass the water toward the pot where the plant will be found. This pump is connected to the relay and, in turn, to a 9 V battery. Please take a look at Figure 1.

2.3. Implementation

Circuit assembly as shown in Figure 2, the circuit connection scheme will connect the water pump to the relay module controlled by the Arduino board. In turn, the soil moisture sensor will measure the moisture level in the pot to determine when watering is necessary. With this automated irrigation circuit, it will be possible to maintain precise control of the water supply for plants and crops at home, allowing healthy and optimal growth.

2.4. Algorithm development and programming

First, the parameters necessary for irrigation are defined, such as the frequency and duration of irrigation, the amount of water needed for each plantation, and the ambient temperature. Then, a home screen design is developed with support for the RemoteXY platform [25], a graphical interface editor designed mainly to support the Arduino board. Through this interface, we will define the status of the execution mode (Automatic or manual) and the pump's operating status. We will use an LED light as an indicator to show the pump's status, which can be seen in Figure 3. Likewise, the graph in Figure 4 will show records of humidity levels.

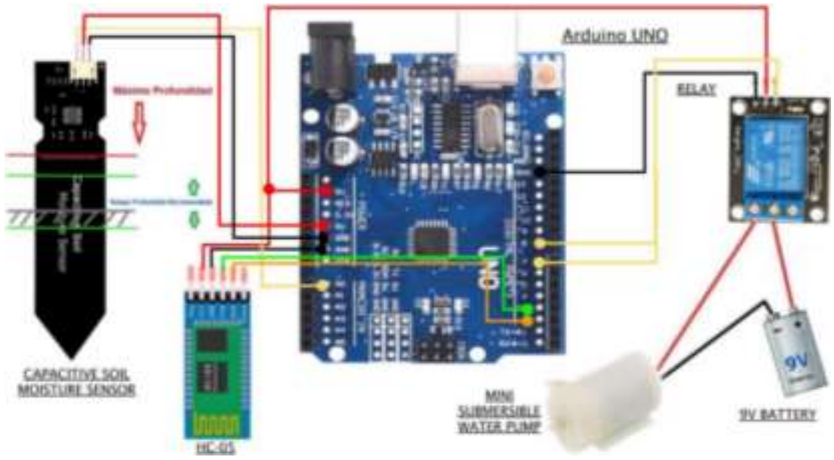

Figure 1. Circuit design

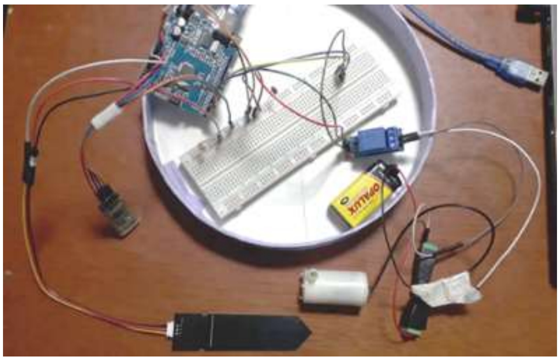

Figure 2. Assembled circuit

Figure 3. Irrigation control platform's design

Figure 4. Humidity control platform

The algorithm is developed according to Figure 5, in which the irrigation request is made through the RemoteXY interface, which is set to Automatic mode. In that case, it will be evaluated if the soil moisture is below the predefined level, in an optimal state, or above the established group, and according to this analysis, the microcontroller will send the activation order to a solenoid valve to allow the flow of water towards the crop. On the contrary, if the control through the RemoteXY interface is in manual mode, the pump will be activated and deactivated using a switch.

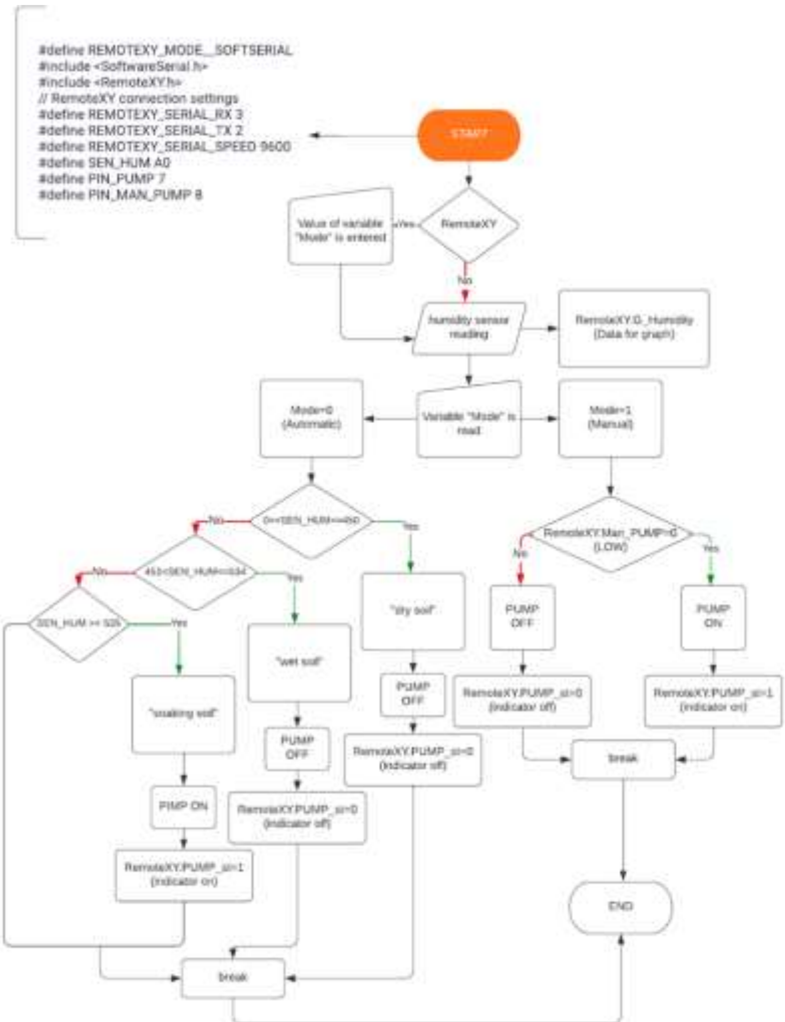

Figure 5. Circuit code design

2.5. Testing

Irrigation controller functionality tests are run: this involves checking whether the irrigation controller can detect the water needed for growing plants in different environments and terrains. It is necessary to download the app "RemoteXY: Arduino control".

- Safety test and error prevention of the irrigation controller.
- Verify that the irrigation controller is equipped with safety protections, such as overloads and voltage stabilization devices, to avoid system failures that can cause damage to property or people's health.
- Test the irrigation controller material design.
- Test the communication capacity of the irrigation controller.
- Test the functionality of commands via RemoteXY.
- Efficiency test of the irrigation controller.

2.6. Failures

- False contact between circuit connections.
- Not considering the specific needs of each type of plant being grown.
- Using low-quality materials or those unsuitable for outdoor use may affect the system's durability.
- Not correctly defining the variables for the programming can result in a waste of water or a lack of irrigation that affects the growth of the plants.

2.7. Revision

The proposal presented for designing and implementing an automated irrigation control for home crops is a practical and effective solution for irrigation management in this crop type. A good description of the problem to be solved is appreciated, indicating the main limitations that arise from manual irrigation, such as the lack of control and precision in the amount of water supplied to the plants and the need to be physically present to carry out the irrigation process. The solution approach is addressed in detail, considering the technical aspects necessary to develop the automated irrigation control system, such as selecting the appropriate sensors to measure soil humidity and environmental temperature, the choice of the control, and the programming necessary for its operation.

3. RESULTS AND DISCUSSION

3.1. System container design

A container was made to house the automatic irrigation system. A temporary base was designed with cardboard that exposed the Bluetooth module so as not to interfere with the signal, and it had a tab to protect it from possible waterfalls ass shown in Figure 6. The container has a compartment to place the system power cable and a lid that allows the connections to be inspected without disassembling the entire system as shown in Figure 7. In addition, it has a small compartment to place the hose when it is not installed, taking advantage of the fact that the water tank is at a low height to benefit from the pressure of the liquid as shown in Figure 8.

Figure 6. Front view

Figure 7. Right side view

Figure 8. Left side view

3.2. System installation and testing

In Figure 9, the system was installed in a pot with the chosen plant, with the rear part of the design next to the plant. Tests were conducted to verify that the system establishes constant communication with Bluetooth. For details as shown in Figure 10.

Figure 9. System installed in a flowerpot

Figure 10. Cellular with connection to RemoteXY interface

3.3. Control and monitoring interface

In Figure 11, the interface allows you to control the irrigation system manually or automatically. Depending on the plant status, the user can activate or deactivate the pump manually. In Figure 12, the interface graphically displays the plant humidity level based on the established ranges, subtracting 700 from the analog value obtained from the sensor to compensate for oscillations.

Figure 11. Home screen manual-automatic mode Figure 12. Display of humidity sensor reading values

3.4. Auto mode and trend charts

As we can see in Figure 13, in automatic mode, the system monitors the status of the plant and turns the pump on or off depending on the degree of humidity detected. In Figure 14, the graph represents the value read from the sensor, so the trend line starts semi-flat when the sensor is not installed in the pot, and then when it is inserted into the dry soil, there is a curve indicating dry soil. In Figure 15, in the graph, the trend line begins semi-flat in the previous value indicative of dry land; this changes after being irrigated by the automatic mode and reaching the humid level. In Figure 16, in the graph, the trend line begins semi-flat in the previous value, indicative of moist soil; this changes after being rinsed in manual mode and reaching the wet level.

Figure 13. Manual mode

Figure 14. Dry moisture trend graph

Figure 15. Dry to wet moisture trend graph

Figure 16. Wet to soaked moisture trend graph

The results obtained in this study support and corroborate the findings of previous research that have demonstrated the benefits of automated irrigation systems in the domestic environment. These systems not only optimize water use but also contribute to reducing energy consumption and the labor required in irrigation tasks. A distinctive feature of our work is implementing a manual mode in addition to the automatic mode. This functionality gives the user the flexibility to intervene and take control of the irrigation process based on their specific preferences or needs. This can be particularly useful when manual adjustment, such as unusual weather conditions or personal preferences in plant care, is required.

However, it is essential to recognize some limitations of the present study: the capacitive humidity sensor had a lower analog reading range than the technical data sheet specified. This discrepancy may have introduced bias or inaccuracies in the data collected, potentially affecting the accuracy of the irrigation system. The study focused only on one sample plant, which limits the generalization of the results to other vegetation types with different water requirements or soil characteristics. For future research, evaluating the system performance using more accurate and adequately calibrated humidity sensors would be beneficial. Extending the study to a more diverse variety of plants and growing conditions would be valuable in obtaining more generalizable results applicable to natural agricultural environments.

4. CONCLUSION

With an intelligent monitoring and control approach, automatic irrigation systems have been shown to significantly improve water use efficiency and optimize energy and labor resources in domestic and agricultural environments. Our study has validated the feasibility and effectiveness of an automatic irrigation system that combines a capacitive humidity sensor, an Arduino control module, and a wireless user interface developed on the RemoteXY platform. This innovative system allows automated and manual irrigation control, adapting to the user's preferences and needs. Although limitations were identified, such as the sensor's analog readout range and targeting a single plant, the results support the promise of automated irrigation systems. Opportunities for future research are seen, such as using more precise sensors, diversifying the plants studied, and integrating additional technologies, such as weather sensors and artificial intelligence algorithms, for more sustainable and resource-efficient agriculture. In conclusion, this study paves the way for developing and implementing intelligent and adaptive automated irrigation systems to optimize natural resources.

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