THE DEVELOPMENT AND THE IMPLEMENTATION OF AN ARDUINO-BASED AUTOMATED IRRIGATION SYSTEM FOR HYDROAGRICULTURAL EFFICIENCY

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Abstract: *This study explores an Arduino-based automated irrigation system aimed at improving hydroagricultural efficiency through precision and adaptability. Using sensors to monitor soil moisture, temperature, and other environmental factors, the system enables real-time, plant-specific irrigation decisions. Arduino microcontrollers process sensor data to dynamically control irrigation frequency and duration, optimizing water usage and enhancing plant health. Tested in a cultivation scenario, the system demonstrates potential for sustainable agriculture by reducing water waste and improving crop management. This research contributes to precision agriculture, illustrating how technology integration can support efficient resource use and better crop management practices.*
Key words: *Automated irrigation, Arduino, Sensors, Plant monitoring, Hydroagricultural efficiency.*

1. INTRODUCTION

Water is a vital and limited resource, essential for agriculture, industry and daily life, and its efficient use has become a priority in the context of population growth and climate change. [1] As demand for water continues to increase and the quality of surface water resources is often compromised by industrial and agricultural activities, it is crucial to adopt irrigation technologies that minimise losses and ensure sustainable management of water resources. Such systems not only support agricultural productivity, but also protect the quality and availability of water for other essential uses, such as drinking water and ecosystem conservation. In a world affected by drought and environmental pressures, responsible water management is essential to ensure sustainable resources for the future. [2]

Water management involves a wide range of activities that require technical, economic, environmental and social solutions. Because groups with divergent interests are involved in the management of public resources, decisions must also include human values and judgments, which makes the effective management strategy

a complex process, with numerous elements and non-linear relationships. In this context, emphasis is placed on multi-criteria decision methods (MCDM) to facilitate the right decision-making in water resources management. The functionality of these methods has been extensively tested, including river basin planning, choice of irrigation methods, sustainable intensification of irrigated agriculture and assessment of ecological effects on surface water systems. In Greece, in the area of the Nestos river basin, three irrigation projects are being analysed to meet the water requirements of the prefectures of Kavala, Drama and Xanthi, with an additional challenge being the management of two hydropower dams, Thesauros and Platanovrisi. This management balances irrigation requirements, hydropower needs, and environmental requirements related to the area's valuable ecosystems. For the evaluation of the three proposed irrigation projects, a method based on fuzzy AHP (hierarchical analytical process) is used, which extends the traditional benefit-cost analysis and is useful in situations with insufficient quantitative data. [3] In agricultural basins, water resources, agriculture and ecology form an

interdependent network essential for the sustainability of the environment and agricultural production. [4] The availability of water directly influences the yield and quality of crops, and its rational use supports biodiversity and ecological balance. [5] However, over-irrigation can lead to water stress and negatively affect regional ecosystems. [6] In order to effectively coordinate water resources management, agriculture and ecology, a holistic approach is essential. An optimized model, such as the one based on bi-level programming, can handle multiple goals and resource conflicts. [7] In addition, the temporal variability and spatial heterogeneity of water, generated by climatic and geographical factors, make it necessary to apply robust methods of stochastic optimization for stable resource allocations. [8]

Drip irrigation is one of the most water-efficient irrigation methods, offering major advantages over conventional methods such as surface or sprinkler irrigation. This technology allows precise application of water to the root of plants, significantly reducing evaporative losses and deep runoff, leading to significant water savings and improved crop yields as can be seen in fig. 1. In addition to increased water efficiency, drip irrigation requires less work and allows for a controlled application of fertilizers and other nutrients, thus contributing to a more sustainable agricultural environment. However, the initial installation costs are high, which can limit the accessibility of this technology for extensive field crops such as corn, and system maintenance requires extra attention to prevent clogging of pipes. [9]

Fig. 1. Drip irrigation system

2. TYPES OF IRRIGATION

In agriculture, the most representative irrigation methods are: sprinkler irrigation; flood irrigation and drip irrigation.

2.1 The sprinkler irrigation

Sprinkler irrigation consists of spraying water in the form of artificial rain, distributing it evenly over the soil surface. This system uses a set of pipes and sprinklers, which spray the water in small particles, providing the plants with uniform and complete irrigation. The sprinklers are connected to a pumping system that provides the necessary pressure for water distribution.

The advantage of this method is that it mimics natural rain as can be seen in fig. 2 and can cover a large area, making it suitable for a wide range of crops, including vegetables and grains. It also helps to maintain a constant level of moisture in the soil, which is beneficial in areas with water scarcity. However, sprinkler irrigation is less effective in strong wind conditions, which can disperse water outside the desired area. Also, water evaporation is higher compared to drip irrigation, which can increase water consumption.

Fig. 2. Sprinkler irrigation

2.2 The flood irrigation

Flood irrigation is one of the oldest methods and consists of flooding the soil around the plants with a large amount of water, as can be seen in the fig. 3, thus ensuring quick and deep hydration. Usually, the water is allowed to flow freely in the canals between the rows of crops or over the entire surface of the agricultural land. This method is simple and does not require complex equipment, and is often used in the cultivation of cereals and plants resistant to excess water, such as rice.

Although it is an affordable and economical method, flood irrigation has major disadvantages: water consumption is very high,

and evaporation and infiltration losses are significant. It can also lead to soil salinization and erosion, affecting the structure and fertility of the land in the long term.

Fig. 3. Flood irrigation

2.3 The flood irrigation

The Drip Irrigation System is currently the most efficient irrigation method used in agriculture, being appreciated both for its significant reduction in water consumption and for its ability to increase crop productivity. This irrigation method uses technology to deliver a controlled amount of water directly to the root of the plant, through special pipes equipped with drippers, thus reducing water waste and evaporation.

The operation of the drip irrigation system is simple but ingenious. The water is transported through a network of pipes and distributed to the plants through small drippers, strategically placed along the rows of crops or near the individual roots of the plants. These drippers are adjustable and can be set to provide an exact amount of water according to the needs of each plant. The water is distributed slowly, steadily and precisely, which allows optimal absorption by the plants, minimizing losses and ensuring effective hydration. The system can be automated, and some farmers even use moisture sensors that constantly monitor the water level in the soil and activate irrigation only when necessary.

Compared to the other methods mentioned, drip irrigation offers superior control of water consumption and nutrients, allowing farmers to reduce water consumption by up to 50% and increase productivity by up to 90%. At the same time, this system limits soil erosion and helps prevent weed growth, as the water only reaches the desired areas, and the rest of the soil remains dry.

3. BARRIERS ENCOUNTERED IN THE DRIP IRRIGATION SYSTEM

Although drip irrigation is recognized as being extremely efficient, it also has several disadvantages that can affect its applicability in certain contexts. Here are some of them:

3.1 High initial costs

Drip irrigation systems require a substantial initial investment for the installation of pipes, emitters, and pumps, especially when opting for high-quality or automated equipment. This can pose a barrier for small farmers or those in regions with limited financial resources.

3.2 Frequent maintenance

The system is vulnerable to clogging and damage, particularly due to the accumulation of sediments, minerals, or algae in the emitters. It must also be protected against physical damage caused by animals or agricultural tools. Regular cleaning of the emitters and checking the pipes for potential cracks are essential to maintaining system efficiency.

3.3 Issues in water distribution

Although designed to provide a constant flow of water, the system can experience distribution variations due to uneven pressure in the pipes or emitter clogging. This can lead to unevenly irrigated areas, affecting the productivity of crops in those parts of the field.

3.4 Limitations regarding crop types and soil

Drip irrigation systems are most effective for low-density crops, where plants are arranged in rows or individually. In the case of very dense crops or sandy soils, where water infiltrates rapidly, ensuring uniform hydration can be challenging. Additionally, the system is less adaptable to uneven terrain, which can impact its efficiency.

These disadvantages, along with the specificity of the conditions under which it can be successfully utilized, indicate that, although

drip irrigation is highly effective, it is not always the optimal solution in all regions or for all types of crops.

4. IMPROVEMENT PROPOSAL

An innovative proposal to overcome the limitations of drip irrigation systems is the use of silicone hoses equipped with integrated nozzles and filters. This approach has the potential to improve irrigation efficiency, reduce maintenance costs, and ensure uniform water distribution.

Silicone hoses are flexible, easy to handle, and resistant to damage, making them ideal for use in various soil types and climatic conditions. Unlike PVC pipes or other rigid materials, silicone hoses can be shaped according to the contour of the land, adapting to uneven terrains and different types of crops. This aspect contributes to increasing system efficiency by ensuring uniform hydration of the plants.

The nozzles mounted on the silicone hoses will be designed to provide a controlled flow of water, allowing for precise adjustment of the amount of water delivered to each plant. The integrated filter will prevent the accumulation of sediments and clogging of the nozzles, thereby reducing the need for frequent maintenance. This feature is essential, especially in regions with variable water quality, where contaminants can affect the efficiency of the irrigation system.

Fig. 4. Nozzle

The implementation of this solution will significantly reduce initial costs, as silicone hoses are often less expensive than traditional irrigation systems. Additionally, the flexibility of the hoses will allow for faster installation and easier adaptation to future changes in crops or land structures. Furthermore, the use of adjustable nozzles will enable farmers to regulate irrigation according to the specific needs of the plants, thus optimizing water consumption and nutrient resources.

By replacing conventional pipes with silicone hoses equipped with integrated nozzles and filters, our proposal offers a versatile and efficient solution for drip irrigation. This will not only reduce costs and maintenance requirements but also enhance the overall efficiency of the system, ensuring uniform water distribution and adaptability to different soil conditions and crop types. As a result, farmers will benefit from a more sustainable and tailored irrigation system that contributes to more productive agriculture and more efficient resource utilization.

5. METHODOLOGY OF RESEARCH. OPERATION MODE OF THE ARDUINO-BASED AUTOMATED IRRIGATION SYSTEM

This system aims to improve agricultural efficiency by delivering optimized water supply to crops, addressing water conservation challenges and maximizing agricultural yield. Simultaneously, the system is designed to adapt to any type of terrain, with the main focus on efficiency and accessibility. The methodology includes research planning, component selection, system design, development, testing, and data analysis. Additionally, the system's operation will be evaluated, with emphasis on how each component interacts to achieve an adaptable and efficient automated irrigation process.

5.1 Issues in water distribution

The research is an experimental study designed to assess the effectiveness of an Arduino-based automated irrigation system. Following a quantitative approach, the study aims to collect objective data on irrigation efficiency, water use, and soil moisture content, as well as the system's adaptability across different regions and types of soil. The research design includes the following steps:

- Problem Definition: The primary issue identified is the lack of adaptability in conventional irrigation systems for different soil types. Soils with varying textures, such as sandy or clay soils, require specific

irrigation methods, and traditional systems struggle to meet these needs. This limitation either results in high costs for equipment that cannot adapt to all soil types or clogs in the irrigation outlets when used on incompatible terrains.

- Hypothesis Formulation: The research hypothesis is that an automated Arduino-based system, equipped with silicon tubing and nozzles with integrated filters, can ensure efficient irrigation adapted to the particularities of various soil types without clogging the distribution components.
- System Design: The system was designed to combine the accessibility of the Arduino microcontroller with a flexible, resilient water distribution system. This silicon tubing system with filtered nozzles prevents blockages caused by water impurities, providing an economical and low-maintenance solution.
- Testing and Data Collection: The system was tested on different types of terrain, and the data collected was analyzed to evaluate its performance in terms of water distribution, consumption, and maintaining optimal soil moisture levels.

5.2 Hardware and Software Requirements

Hardware Components:

- Arduino Mega: The Arduino microcontroller serves as the central unit, processing data from sensors and activating actuators to control water flow.
- Soil Moisture Sensor: Continuously monitors soil moisture levels and sends data to the Arduino, which determines when irrigation is required.
- Silicon Tubing with Filtered Nozzles: The water distribution elements consist of silicon tubing equipped with nozzles that include special filters to prevent clogging from impurities. These tubes are flexible and durable, accommodating varying terrain and ensuring uniform water distribution.
- Water Pump and Motor Driver: The pump is activated by the Arduino module and delivers water through the silicon tubes.

Software Components:

- Arduino IDE: Used to write, compile, and upload code to the Arduino board, enabling automated management of the system's operation.

5.3 Operating Mechanism of the Automated Irrigation System

The automated irrigation system collects and processes data in real-time to determine water requirements, following an efficient operating flow:

At system startup, sensors and the motor driver are checked. Soil moisture sensors continuously measure moisture levels and send data to the Arduino. Comparing these readings to preset values determines when the pump should be activated. At low moisture thresholds, the pump is activated to distribute water through the silicon tubes, equipped with nozzles with filters that prevent water blockages and ensure efficient soil hydration. This setup avoids clogging issues, which can occur in sandy or clay soils, ensuring consistent and even irrigation. The Arduino continuously monitors moisture levels, ensuring that the system maintains optimal humidity for various soil types without manual intervention.

5.4 Testing and Data Collection

The system was tested under different conditions, especially on sandy soils, to verify the consistency of irrigation and evaluate the prevention of nozzle clogging. The analyzed parameters included:

- Water Consumption: Measuring the system's efficiency compared to conventional methods.
- Soil Moisture Maintenance: Assessing the system's ability to maintain consistent moisture levels across varied terrains.
- System Reliability: Continuously monitoring the performance of the Arduino, sensors, and filtered nozzles to ensure optimal distribution without interruptions or clogging.

6. RESULTS AND DISCUTION

For the Results and Discussion section, the system was analyzed across one distinct

scenario, focusing on power consumption and installation method.

The scenario, in that case, the system was set up to irrigate 10 flower pots. The flowers were watered through a flooding method, which used a larger volume of water but did not yield the desired results, as much of the water drained into the overflow tray and evaporated. In terms of installation, the system presented a moderate level of difficulty.

The use of a silicone tube was undoubtedly an improvement, as it allowed flexible placement.

However, securing the tube in each pot without disturbing the roots required a sustained effort, achieved by using direct soil-fastening clips. Once the setup was successfully installed, power consumption was recorded to determine the system's energy usage in ensuring timely irrigation. It is worth noting that the system was deactivated at night to keep overall consumption as low as possible.

The results presented below are records taken over a 30-day period in July.
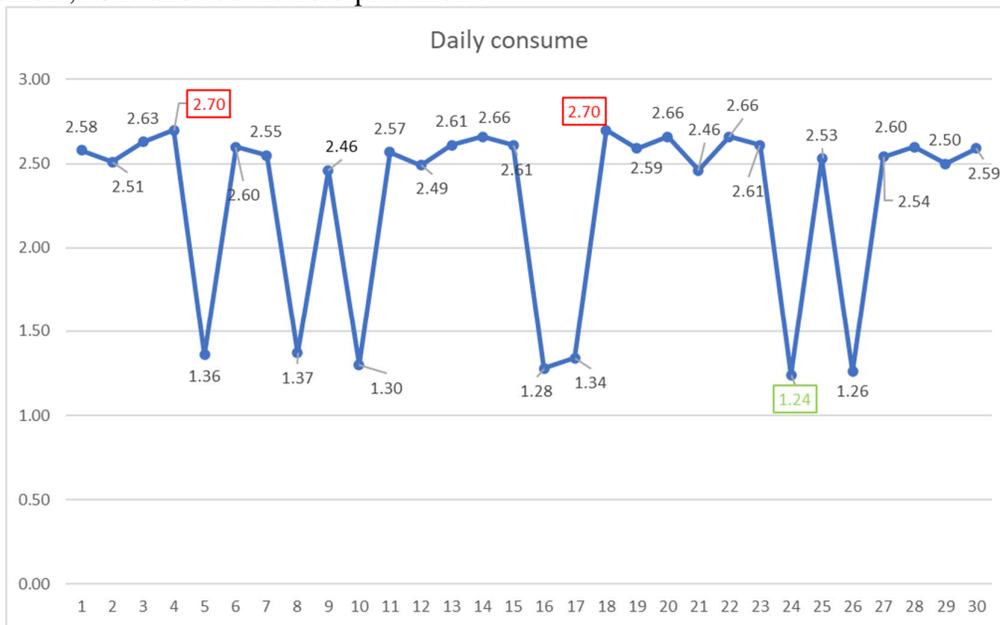

Fig. 5. The current consumtion chart

Overall, there is a consistent variation in energy consumption across different hourly intervals and a clear differentiation between values observed on sunny and rainy days. This difference is primarily due to increased watering demands on sunny days, when high temperatures and dry conditions drive more frequent use of the pump. In general, sunny days show higher daily energy consumption, ranging between approximately 2.5 and 2.7 Kwh, whereas rainy days see lower consumption levels, around 1.2 to 1.4 Kwh. These significant differences between the two categories are evident as, on sunny days, the soil dries out faster, necessitating a larger volume of water to maintain optimal moisture levels for plant growth. On rainy days, the need for irrigation decreases, as rainfall naturally contributes to soil moisture, thereby reducing pump usage and, consequently, energy consumption.

Hourly data indicate that the pump operates at higher capacity during the middle of the day, from 10:00 to 19:00, likely due to peak heat intensity during this period, which accelerates water evaporation from the soil. From 13:00 to 16:00, consumption peaks at around 1.0 Kwh on sunny days, suggesting more frequent watering or a higher pump flow rate to offset water loss from the soil. This trend of increased consumption during peak hours reflects the pump's adjustment to climatic conditions and irrigation needs.

In the early morning (07:00 - 10:00) and evening (19:00 - 22:00), consumption is generally lower, ranging from 0.1 to 0.2 Kwh on both sunny and rainy days. This behavior can be explained by lower temperatures during these intervals, leading to minimal water evaporation

and, thus, a reduced water requirement for plants. Additionally, this type of hourly scheduling can be optimized to reduce energy costs by avoiding irrigation during times when water loss from evaporation is minimal, maximizing the efficiency of the system.

In summary, the chart data highlight, as can be seen in fig. 5, that adjusting energy consumption and water pump use according to the type of day (sunny or rainy) and hourly intervals represents an effective resource management strategy in an automated irrigation system. High energy consumption on sunny days is justified by increased plant water needs, whereas reduced consumption on rainy days demonstrates the system's adaptability to environmental conditions, contributing to energy savings.

For better visualization, the following graph illustrates that the highest recorded current consumption occurred on days 4 and 18 with 2.7 Kwh, while the lowest was on day 24 with 1.24 Kwh.

7. CONCLUSION

The analysis of the energy consumption of the water pump in an automated irrigation system reveals not only the differences in consumption between sunny and rainy days but also the system's adaptability to the specific needs of watering individual potted plants. The use of an efficient pump, combined with flexible silicone tubing, has proven to be a viable solution for maintaining a consistent optimal moisture level, even under varying weather conditions. The flexibility of the silicone tubing provides a significant advantage in this type of installation, allowing for easy adaptation in confined spaces, fitting snugly around individual pots, and ensuring uniform water distribution.

However, the installation of such a system has proven to be more complex than that of irrigation systems used for large areas or rows of garden plants. Each pot needed to be connected separately to the central irrigation system, requiring additional attention to secure the tubing and ensure that each plant receives an appropriate amount of water. This labor-intensive process suggests that future developments could benefit from the creation of simpler mounting solutions, perhaps even modular kits for potted plant irrigation, which would reduce both installation time and complexity.

Regarding energy consumption, the analyzed data indicates that sunny days result in higher energy usage due to the increased water demand to compensate for evaporation losses. During the hours of 10:00 AM to 7:00 PM, when temperatures are at their peak, the pump's consumption reaches maximum levels, reflecting the intensified need for watering. Conversely, on rainy days, consumption is significantly lower due to the moisture provided by precipitation, which minimizes the need for additional water from the automated irrigation system.

Moreover, the system operates optimally in the early morning and evening when evaporation is minimal, resulting in reduced watering requirements. This adaptability of the system—both in terms of the type of irrigation (for individual pots) and its response to weather conditions and operating schedules—contributes to efficient resource consumption. The system's ability to automatically adjust based on external conditions significantly reduces energy consumption while ensuring adequate water distribution, even for plants with sensitive needs or those requiring strict moisture control.

8. REFERENCES

[1]Parikh, A. (1982). An econometric model of the agricultural sector of the Indian economy. In Journal of Policy Modeling (Vol. 4, Issue 3, pp. 395–411). Elsevier BV. https://doi.org/10.1016/0161 8938(82)90027-8

[2] Misaghi, F., Delgosha, F., Razzaghmanesh, M., & Myers, B. (2017). Introducing a water quality index for assessing water for irrigation purposes: A case study of the Ghezel Ozan River. In Science of The Total Environment (Vol. 589, pp. 107–116). https://doi.org/10.1016/j.scitotenv.2017.02.2 26

[3] Anagnostopoulos, K. P., & Petalas, C. (2011). A fuzzy multicriteria benefit–cost approach for irrigation projects evaluation. In Agricultural Water Management (Vol. 98, Issue 9, pp. 1409–1416). Elsevier BV. https://doi.org/10.1016/j.agwat.2011.04.009

[4] Fischer, S., Pluntke, T., Pavlik, D., & Bernhofer, C. (2014). Hydrologic effects of climate change in a sub-basin of the Western Bug River, Western Ukraine. In Environmental Earth Sciences (Vol. 72, Issue 12, pp. 4727–4744). Springer Science and Business Media LLC. https://doi.org/10.1007/s12665-014-3256-z

[5] Dalin, C., & Outhwaite, C. L. (2019). Impacts of Global Food Systems on Biodiversity and Water: The Vision of Two Reports and Future Aims. In One Earth (Vol. 1, Issue 3, pp. 298–302). Elsevier BV. https://doi.org/10.1016/j.oneear.2019.10.016

[6] Gordon, L. J., Finlayson, C. M., & Falkenmark, M. (2010). Managing water in agriculture for food production and other ecosystem services. In Agricultural Water Management (Vol. 97, Issue 4, pp. 512–519).

Elsevier BV. https://doi.org/10.1016/j.agwat.2009.03.017

[7] Sakawa, M., Nishizaki, I., & Uemura, Y. (2000). Interactive fuzzy programming for multi-level linear programming problems with fuzzy parameters. In Fuzzy Sets and Systems (Vol. 109, Issue 1, pp. 3–19). Elsevier BV. https://doi.org/10.1016/s0165-0114(98)00130-4

[8] Ortiz-Partida, J. P., Kahil, T., Ermolieva, T., Ermoliev, Y., Lane, B., Sandoval-Solis, S., & Wada, Y. (2019). A Two-Stage Stochastic Optimization for Robust Operation of Multipurpose Reservoirs. In Water Resources Management (Vol. 33, Issue 11, pp. 3815–3830). Springer Science and Business Media LLC. https://doi.org/10.1007/s11269-019-02337-1

[9] Bozkurt, Y., Yazar, A., Gençel, B., & Sezen, M. S. (2006). Optimum lateral spacing for drip-irrigated corn in the Mediterranean Region of Turkey. In Agricultural Water Management (Vol. 85, Issues 1–2, pp. 113–120). Elsevier BV. https://doi.org/10.1016/j.agwat.2006.03.019

Dezvoltarea și implementarea unui sistem de irigație automatizat bazat pe arduino pentru eficiența hidroagricolă

Acest studiu explorează un sistem de irigație automatizat bazat pe Arduino, conceput pentru a îmbunătăți eficiența hidroagricolă prin precizie și adaptabilitate. Utilizând senzori pentru a monitoriza umiditatea solului, temperatura și alți factori de mediu, sistemul permite decizii de irigare în timp real, adaptate la nevoile specifice ale plantelor. Microcontrolerele Arduino procesează datele furnizate de senzori pentru a controla dinamic frecvența și durata irigației, optimizând utilizarea apei și îmbunătățind sănătatea plantelor. Testat într-un scenariu de cultivare, sistemul demonstrează potențialul de a sprijini agricultura sustenabilă prin reducerea risipei de apă și îmbunătățirea managementului culturilor. Această cercetare contribuie la agricultura de precizie, ilustrând modul în care integrarea tehnologiei poate susține utilizarea eficientă a resurselor și practici mai bune de gestionare a culturilor.

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