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Optimizing Water Efficiency in Urban Farming with an Automated Smart Drip Irrigation System

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Abstract. Urban farming is becoming increasingly important in tackling food security challenges, especially in densely populated areas. A key concern in urban agriculture is the efficient use of water. This study focuses on optimizing water use in urban farming through the implementation of an Automated Smart Drip Irrigation System. The system uses sensors to monitor soil moisture levels and automatically adjusts water delivery to crops based on real-time data. This approach significantly reduces water waste compared to traditional irrigation methods, ensuring plants receive the precise amount of water they need for optimal growth. The study aligns with Sustainable Development Goals (SDG) 11 and 12, promoting sustainable cities and communities, as well as responsible consumption and production. It presents a comparative analysis of water usage between conventional irrigation systems and the automated smart drip system, highlighting major improvements in water conservation and crop yield. The findings show the potential of smart irrigation technologies to support sustainable urban farming, providing a scalable solution to the global water scarcity challenge and encouraging responsible water management in agriculture.

Keywords: *Smart irrigation; water efficiency; traditional irrigation; automated irrigation system*

Introduction

The global situation today is influenced by two urgent issues: the rapid increase in the world's population and the continued deterioration of the environment. As the population grows, so does the need for vital resources like food, water, and energy—placing significant stress on the Earth's ecosystems and threatening the long-term health of natural systems (Hossain et al., 2018; Sagar, 2017; MA, 2005). This demand-driven pressure, combined with unsustainable human activities, speeds up environmental problems such as climate change, deforestation, land degradation, desertification, and ocean acidification. These connected issues are already affecting global food and water supplies, especially in vulnerable regions, and are likely to worsen in the coming decades.

Among all natural resources, water is one of the most critically affected. It plays an irreplaceable role in human survival, public health, food production, and economic development. However, water resources are being degraded at an alarming rate due to a combination of climate variability, changes in land use, urbanization, and overexploitation of aquifers and watersheds (Zhang et al., 2017; Damkjaer & Taylor, 2017). The pressure is particularly evident in agriculture, where irrigated farming consumes up to 70% of global freshwater supplies. While irrigation supports the majority of global food production, it also significantly contributes to water stress, especially in areas already affected by drought, poor infrastructure, or mismanaged water systems.

In the Philippine context, irrigation remains one of the most important parts of agricultural production. It has historically made up one-third to nearly half of the Department of Agriculture's total yearly budget (Inocencio et al., 2015). However, despite heavy spending, the country still faces ongoing problems such as limited irrigation coverage, wasteful water use, and outdated manual systems. These inefficiencies not only cause a lot of water loss but also restrict crop productivity, especially with more unpredictable rainfall patterns caused by climate change.

To address these growing concerns, recent research and development efforts have shifted toward implementing sustainable irrigation solutions that optimize water-use efficiency while maintaining productivity. One of the most effective strategies is the adoption of automated and semi-automated irrigation systems, which have been proven to reduce water waste, lower labor requirements, and enhance crop yields through precise control (Rad et al., 2015; Karim & Frihida, 2017). These systems adjust water delivery based on crop demand and soil conditions rather than depending on fixed schedules.

A key driver of this transformation is the Internet of Things (IoT)—a fast-growing technology that links physical devices like sensors, controllers, and actuators to the internet for real-time communication and decision-making. In agriculture, IoT plays a central role in precision farming, enabling farmers to gather detailed environmental data and automate their irrigation systems accordingly. Sensors placed in the soil can measure moisture levels, temperature, and nutrients, while cloud-based platforms analyze this data and activate irrigation only when needed. The integration of IoT into smart irrigation has also opened new possibilities for urban agriculture, where space and resources are limited, and efficiency is crucial. These systems not only help save water and lower operating costs but also make farming more accessible to people with limited technical knowledge, through mobile apps and easy-to-use dashboards. Additionally, they support broader environmental goals by reducing runoff, preventing overwatering, and decreasing energy consumption.

As the world continues to face resource scarcity, urban growth, and environmental instability, the move toward smart, data-driven agriculture becomes not just innovative but essential. Technologies like IoT-enabled smart irrigation systems serve as a scalable, sustainable, and impactful response to these issues—providing a way to feed growing populations while conserving vital resources.

Methodology

This section describes the systematic approach used in designing, developing, and evaluating the Automated Smart Drip Irrigation System. The methodology is divided into several main phases: project planning and development, prototype building, implementation, and testing. Each phase was carefully planned to ensure the system's functionality, reliability, and efficiency. Field testing was conducted to gather real-world data and assess performance, while statistical methods were used to optimize operation parameters for maximum water efficiency and crop health.

A. Project Design and Development

The project aimed to automate water distribution in urban farming, with a focus on maximizing efficiency and reducing waste. At its core is an Arduino Uno microcontroller, serving as the main processing unit. It connects to capacitive soil moisture sensors that constantly monitor soil moisture levels. When the moisture level drops below a user-set threshold, the microcontroller sends a signal to activate solenoid valves, allowing water to flow from the main reservoir to the crops through a drip irrigation hose.

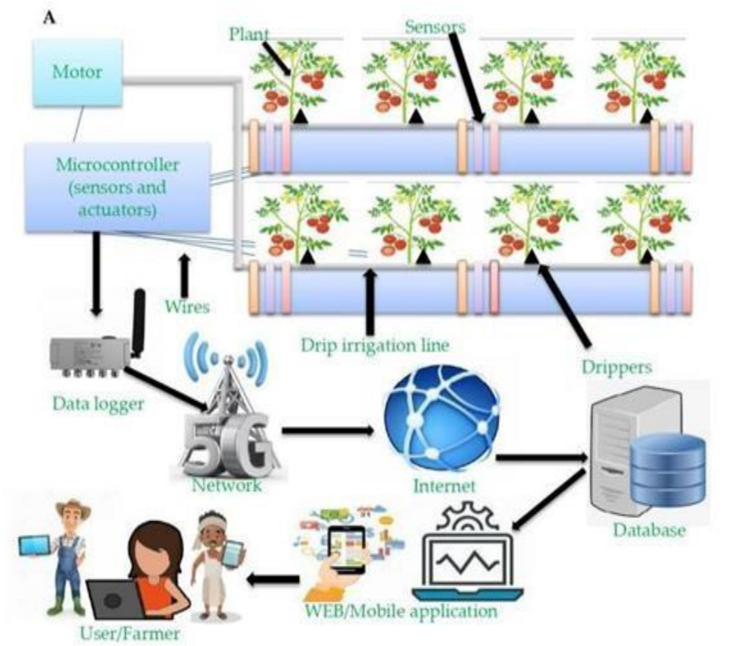

Fig. 1. Theoretical Framework of the System

The system continuously monitors soil moisture levels with sensors connected to a microcontroller. When moisture falls below a certain point, it automatically activates solenoid valves to water the plants. A network module transmits real-time data to a mobile app, allowing users to oversee and manage the irrigation remotely. The design aims to deliver water promptly while minimizing manual labor and water waste.

B. Conceptual Framework

The IPO (Input-Process-Output) model was used to conceptualize the system operation. Inputs include environmental data (moisture, weather), power supply, and crop requirements. Processes involve sensor data processing and automated actuation. Outputs are improved water efficiency, reduced waste, and enhanced crop growth.

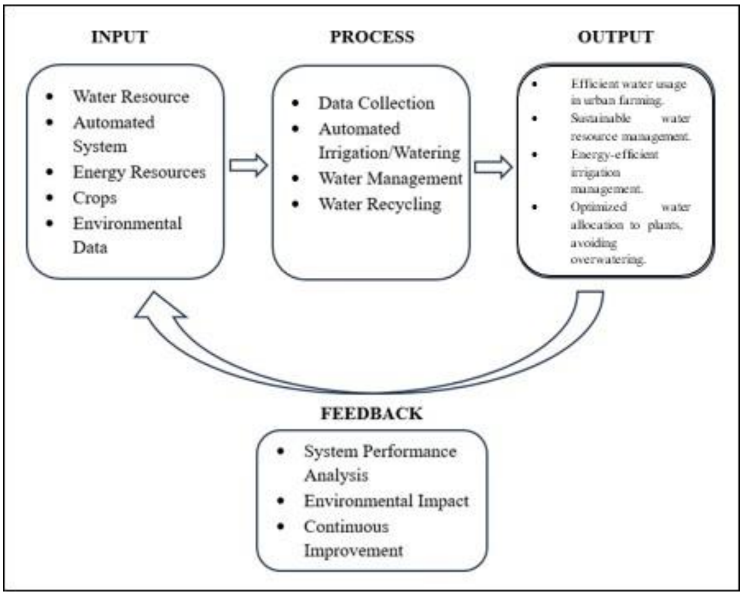

Fig. 2. Conceptual Framework of the System

The IPO model effectively illustrates the innovative irrigation system's structured operation. Defining the inputs, processes, and outputs demonstrates how environmental data and automation work together to optimize irrigation. The result is a reliable, efficient system that conserves water, reduces manual labor, and supports healthier crop growth, making it well-suited for sustainable urban farming.

C. Building the Prototype

After completing the design validation phase, the prototype was physically assembled using the specified hardware components. The soil moisture sensors were carefully embedded into the root zone of the plants, where they could accurately detect real-time moisture levels critical to plant growth.

All electrical components—including sensors, relays, and power regulation modules—were systematically wired to an Arduino Uno microcontroller, which served as the system's brain. To protect the electronics from environmental factors such as rain, dust, and heat, the entire control unit was securely housed in a waterproof casing mounted near the test site.

For power, the system utilized a 220V AC electrical source to ensure stable operation. To enhance its reliability and sustainability, a solar backup system was also integrated, allowing the irrigation setup to continue functioning during power outages or in off-grid locations. This dual-power approach ensured uninterrupted operation, contributing to both efficiency and resilience of the irrigation system.

This phase also involved initial testing of each component—checking sensor response accuracy, valve timing, and wireless communication—to confirm that the system operated as designed before field implementation.

Fig. 3. Electrical Components of the System

Figure 3 shows the assembly of key components for the innovative drip irrigation system, including a relay module, wires, a power source, and a water pump. These parts are connected to automate water delivery based on sensor input.

Fig. 4. Physical Components of the System

Figure 4 shows the water reservoir connected to a hose, which serves as the primary source for drip irrigation. The hose distributes water directly to the plants, controlled by the automated system based on soil moisture levels.

Fig. 5. Connecting the hose to the central hose of the Farm

The image shows the drip hose fixed to the central water supply hose using a T-connector and clamps. This setup ensures a secure and leak-free connection for stable water flow into the irrigation system.

D. Implementation

The final prototype was installed and implemented at Sharon Farm in Quezon City, which served as the pilot site for real-world testing of the innovative drip irrigation system. A designated garden bed was selected as the controlled area for the study. Over two months, the system was observed during regular farming operations to evaluate its functionality, consistency, and reliability. Key performance metrics were recorded, including daily water consumption, soil moisture readings, and crop health indicators such as leaf color, growth rate, and yield.

The system's automation was tested under different weather conditions to ensure it responded accurately to changing soil moisture levels. In addition to technical data, feedback from farm personnel was collected to evaluate user-friendliness and potential for practical adoption. The successful deployment at Sharon Farm demonstrated the system’s ability to reduce water usage while maintaining optimal plant health—supporting its potential for wider use in urban agriculture.

Fig. 6. Implementation of the Pipes and the System

This figure shows the actual setup of the irrigation system, including the connection of pipes and hoses from the water reservoir to the planting area. The system was installed to automate water distribution, ensuring efficient delivery to crops via sensor-triggered controls.

Fig. 7. Solar installed in front of the Garden

The figure displays the solar panel positioned strategically in front of the garden to maximize sunlight exposure. It serves as a renewable power source for the innovative irrigation system, ensuring continuous operation even during power interruptions.

E. Data Gathering and Testing

Field testing was carried out at Sharon Farm in Quezon City, where the innovative drip irrigation system was deployed in an actual garden setting. The testing phase lasted two months, allowing researchers to observe the system's performance under varying weather and soil conditions. Throughout the duration, key performance indicators such as daily water consumption, soil moisture levels, crop health, and harvest yield were closely monitored and recorded.

The primary goal of this phase was to assess the system's effectiveness in optimizing water usage without compromising crop productivity. To systematically evaluate different operational conditions, the team applied the Taguchi Design of Experiment (DOE) methodology. This statistical approach allowed the identification of the most influential factors—such as irrigation timing, moisture threshold, and watering duration—and helped determine the optimal settings for each. By using an orthogonal array, the researchers conducted efficient experiments with minimal trials while still obtaining meaningful insights.

The results from this testing phase not only validated the system's functionality but also provided evidence of its potential to improve resource efficiency and promote sustainable practices in urban farming.

Fig. 8. Actual Picture of the System Installed

L9 Array

Experiment Number	Column 1	Column 2	Column 3	Column 4
1	1	1	1	1
2	1	2	2	2
3	1	3	3	3
4	2	1	2	3
5	2	2	3	1
6	2	3	1	2
7	3	1	3	2
8	3	2	1	3
9	3	3	2	1

Fig. 9. Orthogonal Array Used in the Testing

Figure 9 presents the orthogonal array applied during the testing phase using the Taguchi Method. It was used to identify the optimal combination of factors—such as irrigation time, sensor threshold, and watering duration—that influence water efficiency and crop response.

Table 1.
Combination of Factors based on the Taguchi Method

Experiment	Time (mins)	Soil Moisture (%)	Water (L)
1	10	30	**15**
2	10	40	**20**
3	10	50	**25**
4	15	30	**20**
5	15	40	**25**
6	15	50	**15**
7	20	30	**25**
8	20	40	**15**
9	**20**	**50**	**20**

In the design of experiments, the study used an L9 orthogonal array from the Taguchi Method to evaluate the effects of key parameters on system performance systematically. This method allows efficient experimentation by testing only a subset of all possible factor combinations, while still providing reliable insights into each factor's influence.

Three main factors were selected for the experiment: Irrigation Time, Soil Moisture Threshold, and Water Volume Used. Each factor was tested at three levels, making it suitable for the L9 array structure. The base combination consisted of a 15-minute irrigation time, a 40% soil moisture threshold, and 20 liters of water. This configuration served as the reference point against which other combinations were compared.

The L9 array was constructed to cover nine different experimental runs, each representing a unique combination of the three factors. By using this approach, the study avoided testing all 27 possible combinations (3 factors × 3 levels ×

3 interactions), significantly saving time and resources while still obtaining statistically significant results.

The use of this orthogonal design ensured that each factor's individual effect could be isolated and analyzed. This enabled the identification of the most influential variables that contribute to improved water use efficiency and crop growth, supporting the overall objective of optimizing the innovative drip irrigation system for real-world application.

Results

The deployment of the system resulted in up to 40% water savings compared to traditional watering methods. The Taguchi DOE identified optimal combinations of timing and soil moisture levels for efficient irrigation. Additionally, crop health indicators, such as leaf chlorophyll content and height, were consistent with or better than those in control plots. The integration of IoT enables remote monitoring and control, reducing the need for manual labor. These results demonstrate that automated drip irrigation not only conserves water but also supports higher productivity.

Table 2.
Data Gathered from the Taguchi Experiments

Experiment	Time (mins)	Soil Moisture (%)	Water (L)	P1	P2	P3
1	10	30	15	4.86 L	4.374 L	6.864 L
2	10	40	20	4.658 L	4.982 L	5.549 L
3	10	50	25	4.172 L	5.184 L	4.901 L
4	15	30	20	6.379 L	7.169 L	6.743 L
5	15	40	25	6.561 L	7.472 L	6.986 L
6	15	50	15	7.412 L	6.865 L	6.44 L
7	20	30	25	8.262 L	8.829 L	9.558 L
8	20	40	15	8.343 L	9.72 L	9.315 L
9	20	50	20	9.072 L	10.61 L	8.748 L

Table 2 shows that the innovative irrigation system achieved water savings of over 57.7% compared to the traditional method. Moreover, the innovative drip system delivers water directly to the plant roots, minimizing evaporation and runoff and promoting optimal plant growth.

Table 3.1.
Signal-to-Noise Ratio Results

Experiment	*Sum*	*Average*	*Variance*	*SN Ratio*
1	16.10	5.37	1.74	12.18
2	15.19	5.06	0.20	21.00
3	14.26	4.75	0.27	19.18
4	20.29	6.76	0.16	24.66
5	21.02	7.01	0.21	23.73
6	20.72	6.91	0.24	23.03
7	26.65	8.88	0.42	22.72
8	27.38	9.13	0.50	22.21
9	28.43	9.48	0.99	19.57

The S/N ratio results reveal valuable insights into the robustness and reliability of the irrigation system under various experimental conditions.

Table 3.2.
Analysis of Variance

Source of Variation	SS	df	MS	F	P-value	F crit	Decision	Conclusion
Treatment	77.18	8.00	9.65	18.34	3.57818E-07	2.51	Reject Ho	There is significant difference
Error	9.47	18.00	0.53					
Total	86.65	26.00						

The computed Analysis of Variance (ANOVA) results reject the null hypothesis, indicating a significant difference between the variables being tested. In the context of the study, this means that the factors—such as Time (minutes), Soil Moisture (%), and Water Usage (L)—have a statistically significant impact on the outcome.

Conclusion

The results of this study demonstrate that the Automated Smart Drip Irrigation System provides an effective and sustainable solution for improving water efficiency in urban farming. The system recorded water savings of up to 57.7 percent compared with traditional manual watering, a reduction enabled by its direct root-zone delivery mechanism, which minimizes evaporation and runoff. The Taguchi Design of Experiments further confirmed that specific combinations of time intervals and soil moisture thresholds significantly influence irrigation efficiency, enabling the identification of optimal operating conditions. Crop health indicators such as chlorophyll content and plant height also showed that plants irrigated through the automated system performed as well as, or even better than, those in control plots, indicating that increased water efficiency does not compromise plant growth. The integration of IoT-based monitoring strengthened the system’s functionality by allowing remote supervision and reducing manual labor, making irrigation more consistent, reliable, and responsive to environmental changes. Moreover, the Signal-to-Noise Ratio and ANOVA results validated the system's robustness by demonstrating that the experimental factors produced statistically significant differences in performance.

Given these findings, the automated system offers a promising model for scalable, data-driven irrigation solutions in urban agriculture. To build on this study, future research may explore long-term system performance across multiple planting cycles and under various climatic conditions to better understand durability and seasonal impacts. Additional studies could also include a broader range of crop types to determine whether the system’s optimal parameters differ across plant varieties. Incorporating renewable energy sources such as solar power may further enhance sustainability, while integrating predictive analytics or AI-driven scheduling could improve automation accuracy by accounting for weather forecasts and evapotranspiration rates. Evaluating the system's economic feasibility, particularly its cost-effectiveness and return on investment for small-scale farmers, would also provide valuable insights. Finally, research on user acceptance and adoption barriers within urban farming communities could help refine implementation strategies and improve accessibility. Overall, with continued enhancement and validation, the automated innovative drip irrigation system has the potential to significantly advance water-efficient, climate-resilient, and sustainable urban food production.

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