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Smart IoT Irrigation System Using PID-PSO Optimization Method

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Abstract

An irrigation system stands as one of the most efficient real systems of sustainable water and farming fields. This work aims to enhances the proportional-integral-derivative (PID) controller by using particle swarm optimisation (PSO), which relies on the internet of things (IoT) for a smart irrigation system. The system employs a PID controller to dynamically adjust water flow by integrating environmental data, including humidity, soil moisture, and temperature, gathered by IoT sensors. PSO is utilised to optimize the PID parameters and overcome the limitations of traditional PID tuning. Furthermore, the proposed work improved stability, reduced overshoot, and provided faster response times. The experimental results indicated significant gains in crop health and water use efficiency. The moisture stabilizes and maintains the target of 60% with the optimized PID parameters in the case study. The smart system assisted in managing water resources sustainably by providing a scalable and energy-efficient precision agriculture solution.

Keywords: internet of things, irrigation, particle swarm optimisation, PID, soil-moisture

1. Introduction

The global demand for sustainable water resource management within the agricultural sector has become a primary catalyst, driving significant innovation and development [1-3]. An internet of things (IoT) dependent irrigation systems stands out as a pivotal advancement, offering unparalleled and robust monitoring and comprehensive management capabilities [1]. This technologically advanced system was meticulously designed to leverage an array of strategically deployed sensors. These sensors gather and transmit crucial real-time information regarding various parameters, including localized weather conditions. They are used for intelligently automating complex irrigation processes and ensuring optimal water delivery directly to crops while minimizing waste. This automation reduces labor costs and optimizes the usage of water, reducing unnecessary depletion of resources [1-4].

Several studies have investigated water management and irrigation systems, such as Obied et al. [5], where the researchers investigated ways to encourage ethical farming practices by integrating blockchain technology and advancements in the field of digital infrastructure technologies with IoT-based sensing in an energy-efficient manner. The main contribution of their study was the utilization of restricted sensing devices as reliable sources of data for a permissionless blockchain. For enhancing the energy of system management capabilities, Khan et al. [6] investigated an intelligent irrigation system. The authors designed a water-automated irrigation system with IoT and automation. In another work [7], an efficient water management were presented soil and weather monitoring system [7].

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Modern irrigation strategies increasingly rely on technology to optimize water usage and reduce human error. Glória et al. [8] presented an approach to water management in irrigation systems that can be used in agricultural fields or gardens, substituting wireless sensor networks for human interaction. Irrigation efficiency was made possible by this sustainable irrigation system, which results in financial and natural resource savings for the end user, including electricity and water, creating a more sustainable environment. Various authors worked on different AI algorithms, such as a water irrigation technology management that was implemented using machine learning [9]. The Pelican Optimization Algorithm (POA) and Particle Optimization Algorithm (PSO) were applied in [10] to determine the optimal path for an IOT robot that might be utilized in a good irrigation system. Additionally, in [11] an IOT robot was designed with neural network, genetic, and PSO algorithms for helping to manage the water in irrigation applications.

Most of the research connected to AI algorithms with irrigation systems aims to optimize the system. Shero et al. [12] suggested a mixture irrigation system model, and they used various parameter observations to make decisions. They tested their data on one of the banana trees in the 2020 timeframe, with 31.4% of the water requirement optimized. To perform irrigation more intelligently, a soft computing recommendation system based on the IoT was suggested. IoT sensors were located in the stadium to gather data on groundwater levels and crops. After that, the collected data was sent to a cloud repository, which was analyzed, and soft computing methods like neural networks were implemented to provide farmers with useful suggestions on their cellphones [13]. The application of particle swarm optimization (PSO) was combined with proportional-integral-derivative (PID) control systems, which presented a method to fine-tune irrigation practices further. Z. Sun [14] presented a PSO algorithm used for adapting the dynamic-inertial-weight to enhance PID performance and to control the water level system.

In this study, the PID parameters controller using the PSO algorithm were optimized to enhance the IoT irrigation system and control the water levels for soil-moisture. This is implemented by IoT components such as an Arduino microcontroller, sensors, and a water pump. This proposed PID-PSO optimization method was compared with many related works, and the results show that the proposed method achieves improved energy efficiency and water management compared to related work [15].

The remainder of this study is organized as follows. Section 2 presented the contribution. This is followed by Section 3, which describes the methodology of the proposed Smart IoT irrigation system. Section 4 describes the components and connections of the proposed irrigation system. Section 5 shows the obtained results from the proposed work. Finally, the conclusions about the proposed Smart IoT irrigation system are mentioned in Section 6.

2. Contribution

This work introduces significant and impactful contributions of smart agriculture and sustainable water management using the smart IoT irrigation system. The proposed system employs a PID controller to dynamically adjust water flow by integrating environmental data, including humidity, soil moisture, and temperature, collected by IoT sensors. The primary contributions in this work include:

(1) Designing and executing a practical IoT Irrigation System, which involves building an effective system capable of real-world operation and data collection.

(2) Dynamically control the water level of irrigation via PID, which enables highly responsive adjustments to irrigation.

(3) Optimizing PID controller (Kp, Ki, Kd) parameters using PSO to enhance the performance and efficiency of the PID controller for irrigation.

(4) Comparing the proposed PID-PSO optimization method with many related works, such as [15]. The findings indicate that the suggested method improved energy efficiency and water management compared with related work.

The intelligent system proposed and developed through this research offers substantial benefits for sustainable water resource management. By providing a scalable and energy-efficient precision agriculture solution, it directly addresses the critical need to conserve water while simultaneously boosting agricultural productivity. This proposed system allows farmers for lessing water-waste and getting health crops.

3. Methodology

The methodology is illustrated in the proposed flowchart methodology, which is shown in Fig. 1. It starts with the initialization of the PID-based IoT smart irrigation system parameters (such as target moisture level of 60%, initial soil-moisture level of 30%, time steps of simulation, and PID parameters (K_p, K_i, K_d). The next step is the optimized parameters of the PID using PSO, and the smart irrigation system uses a PID controller formula, which can be computed as [16]

$$u(t) = K_p \times e(t) + K_i \times \int e(t)dt + K_d \times \frac{de(t)}{dt} \tag{1}$$

where, $u\ (t)$ is the control pump power out ranged between 0% and 100%, $e\ (t)$ is an error, K_p, K_i, K_d are proportional, integral, and derivative of gains, and finally, t is time. The PID controller equation (1) of pump output can be rewritten as in formula (2). In this work, the pump power is adjusted, which can be represented as [16]

$$u(t) = K_p \times e(t) + K_i \times I(t) + K_d \times D(t) \tag{2}$$

where the integral term accumulated the past errors to avoid the long-term deviation, which can be illustrated as[16]

$$I(t) = I(t-1) + e(t) \times (\Delta t) \tag{3}$$

$I\ (t)$, $I\ (t-1)$ where present and last integral terms relative to the time, respectively, Δt is the step time. In this work, the step time has been chosen as 0.1 seconds. The derivative term of error relative to the time $D(t)$ is defined as the change of error, and it is useful for avoiding overshoot. This can be computed as [17].

$$D(t) = \frac{e(t) - e(t-1)}{\Delta t} \tag{4}$$

$e(t)$ and $e\ (t-1)$ are the present and the previous error relative to the time, respectively. The general error can be computed as [17].

$$e(t) = DM - AM \tag{5}$$

DM and AM are the desired and actual moisture. The PSO algorithm of soil moisture has been changed through time, depending on the pump output $u(t)$, as in the following formula [17].

$$M(t+1) = M(t) + u(t) \times AR \tag{6}$$

where $M\ (t+1)$ and $M\ (t)$ are the next and current soil moisture. The R represents the rate of absorption. In case the pump is turned off, the R = 0.05 and the moisture is decreased, and this can be computed as [17].

$$M(t+1) = M(t) - ER \tag{7}$$

ER is the rate of evaporation, and it is equal to 0.3. The cost function $(C\ f)$ is minimizing the total absolute error of Eq. (5) for PSO as illustrated below [17]:

$$Cf = \sum |\, e(t)\, | \tag{8}$$

The setting up of smart system's initial conditions and goal moisture is the first step in the procedure. After that, a smart irrigation control system controls target soil moisture levels using a PID controller. It is implemented by optimizing the parameters via PSO and getting the optimal set to evaluate the ideal PID values. The PID controller continually monitors soil-moisture in real time. Furthermore, the error between the current and goal values is computed. The modification of pump power is necessary to guarantee effective and automatic moisture regulation.

The PSO algorithm is used to reduce the overall error over time in order to optimize the PID parameters. Then, the PID controller described above is used to simulate the moisture response. Furthermore, the current reading of soil moisture is obtained from the sensor. When the pump is switched on, the moisture levels increase. When the pump is turned off, the soil dries naturally. The system is stopped when the loop of the simulation time is ended and when the pump reached to suitable level, as seen in Fig. 1.

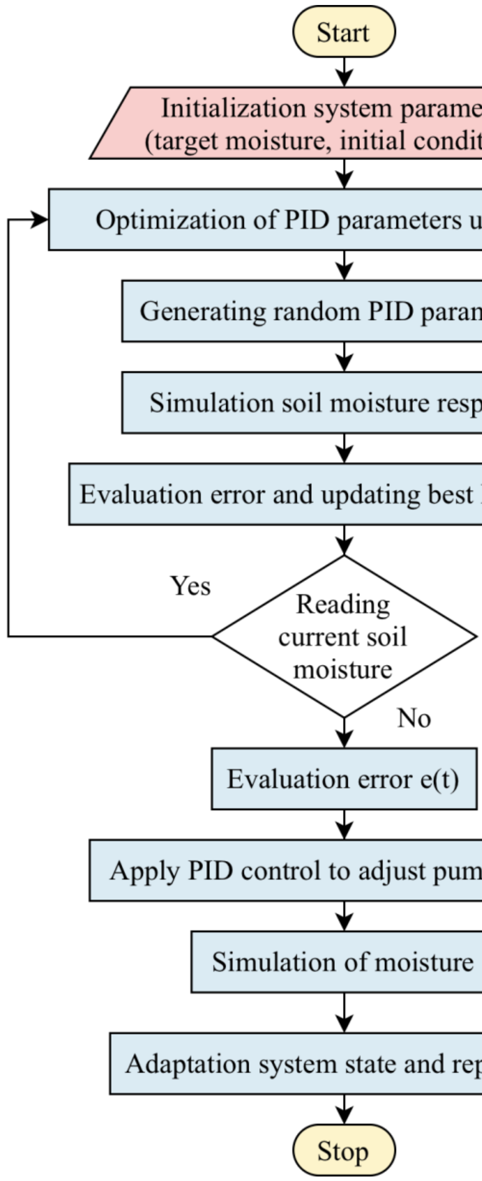

Fig. 1 The proposed flowchart

4. Proposed Irrigation System

This section describes the two parts of the smart IoT irrigation system. The first part presents the components of the proposed smart IoT irrigation system and includes a short description of the hardware components. The second part illustrates the connection of the hardware components to be a smart IoT irrigation system.

4.1. IoT Smart Irrigation System Using PSO Hardware Setup

The proposed hardware setup of this work component is described as follows:

(1) An Arduino Uno microcontroller [18] is the brain of the IoT smart irrigation system, which reads the sensor information and then controls the pump of water pump.

(2) A resistive sensor is used to measure soil-moisture levels and sends data to the Arduino Uno. It is selected due to its low cost. Moreover, it is used for humidity and temperature readings. The connection parts of this sensor are shown in Fig. 2 [19].

(3) The relay module works as a switch for controlling the water pump depending on the Arduino and PSO codes [20].

(4) A mini-water pump is used to supply water to the soil when activated, as shown in Fig. 2 [21].

(5) A battery with 9 volts is used to power the water pump.

(6) The USB connection from Arduino to the laptop is used to power the Arduino.

(7) The laptop for programming the circuit

(8) A cup of soil is used as a case study, as shown in Fig. 3.

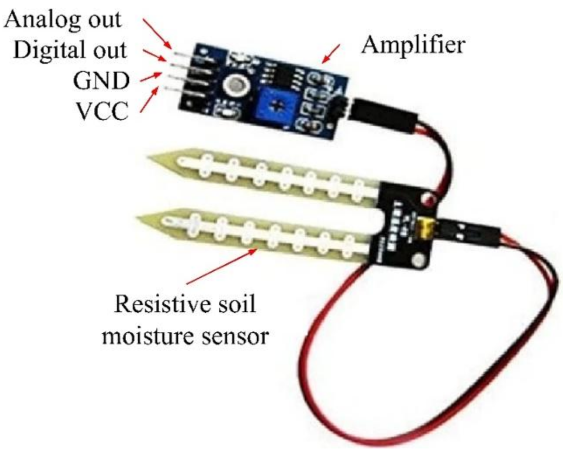

Fig. 2 The resistive soil-moisture sensor

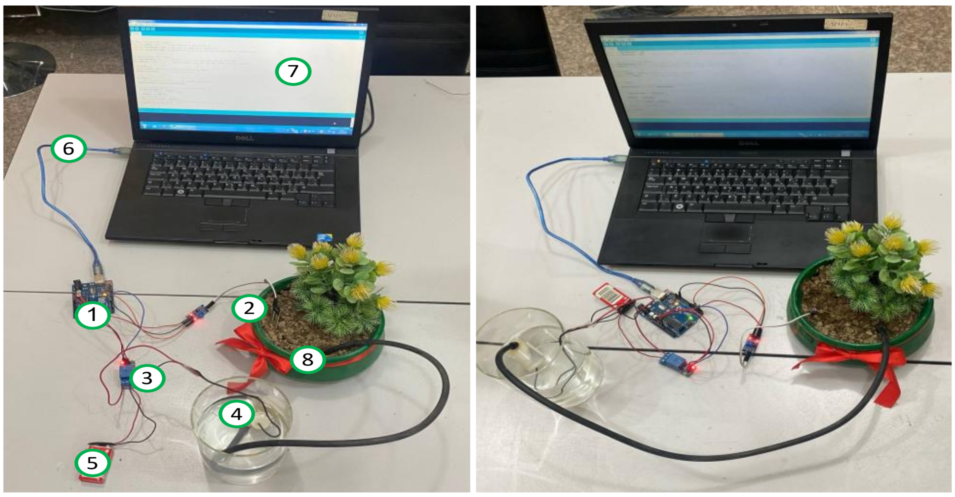

Fig. 3 The proposed IoT smart irrigation system

4.2. IoT Smart Irrigation System Using PSO Hardware Connection

The proposed circuit contains a soil-moisture sensing unit, which detects the level of moisture in the soil and sends an analog signal to the Arduino. The processing signal: The Arduino reads the sensor data, processes it using the PID controller, and determines if the soil needs watering. A relay is used to check the soil condition. When the soil is dry, the Arduino sends a signal to the relay module, then turns it in ON state. A pump operates as soon as the relay switches to the ON state, and then the water pump pumps water into the soil. An automatic shutoff triggers when the desired moisture level is reached. The Arduino turns off, and the relay stops the pump.

5. Results and Discussion

In this study, the data is interfaced with Python code to read and optimize the soil-moisture experimentally.

Eqs. (1)-(2) are the PID control law of the automatic irrigation circuit. While Eq. (3) evaluated the accumulated error. Eqs. (4)-(5) calculated the error between the desired and actual moisture. The Python program used PSO through differential evolution to optimize a PID controller for autonomous irrigation control as in Equations 6, 7, and 8. The objective is to use dynamic pump power adjustment to keep the soil moisture at a predetermined set-point. Fig. 4 shows how the moisture is stabilized and maintained around the target 60 percent % (set-point) of moisture as a case study. In this figure, the simulation runs 100 steps in 20 seconds.

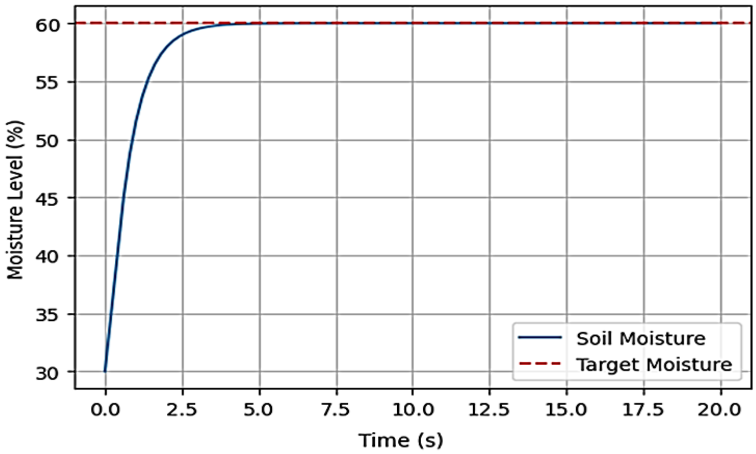

Fig. 4 The soil and target moisture levels of the IoT smart irrigation system

Fig. 5 shows how the pump adjusted the power with time. In this figure, the PSO algorithm finds the optimal PID controller parameters Kp, Ki, and Kd. When the bounds are restricted to values within (zero, 5) for Kp and (zero,2) for Ki and Kd, the program runs for 20 iterations to minimize the error. The best optimization of PID Parameters reached as Kp=5, Ki=2, Kd=1. These optimized PID parameters are used to control soil-moisture. Finally, the moisture increases when the pump is ON and decreases naturally otherwise. Fig. 6 shows the (root-mean-square-error) (RMSE) VS time of the proposed work, and it is equal to zero.

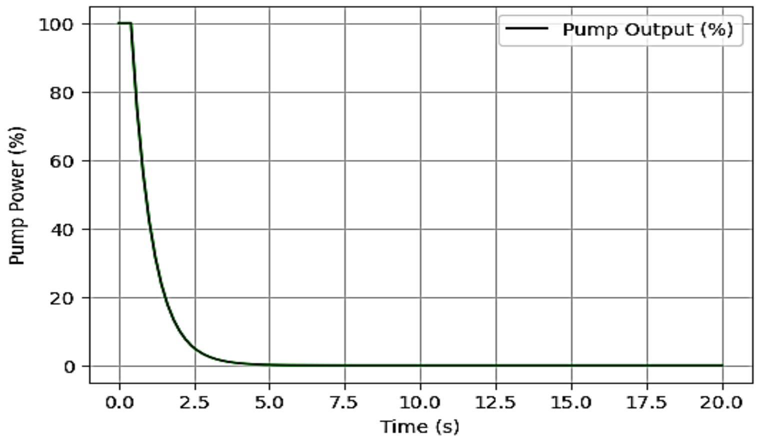

Fig. 5 The pump power against time of the IoT smart irrigation system

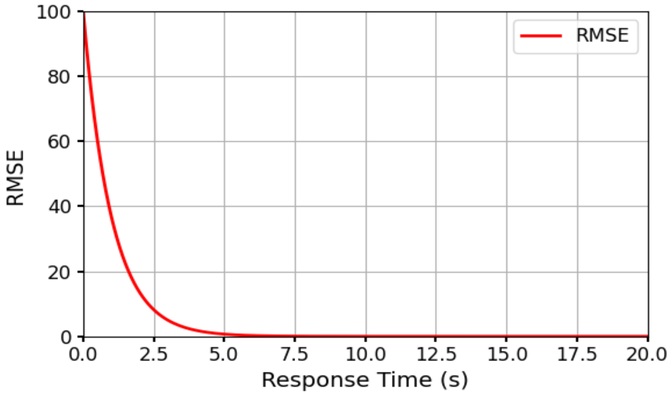

Fig. 6 The root-mean-square-error (RMSE) VS response time

Every associated study in the field of IoT-based smart irrigation offers distinct methods and perspectives due to each contribution, as described in Table 1. The proposed method presented a PSO-based real-time optimized PID control system that allows for effective and flexible water management in changing field situations. Although it is necessary to train a sizeable dataset, Santosh et al. (2024) [22] combined PSO with XGBoost for irrigation prediction, stressing data-driven decision-making and water savings. Singh et al. [15] show cases of PSO-PID efficacy in a smart home with water management automation, verifying energy efficiency through real-time control. A simple IoT system for irrigation via sensors and Arduino is presented by Kanimozhi and Vadivel [23], emphasizing cost-effective automation without any control or optimization method. Although Karar et al. (2020) [24] demonstrated water conservation through the use of neural networks for pump control, the system functions as a black box with little interpretability.

Table 1 The comparative research with the related work

Ref.	Optimization methods	Sensors of the system	The contributions
[22]	PSO and XGBoost	The same tools of this proposed work	Water savings were attained, and irrigation needs predictions were more accurate.
[15]	PSO and PID	Sensors for light and humidity	Achieved up to 37.49% energy savings; the efficacy of PSO-PID was confirmed.
[23]	None	The same sensors as the proposed work	enhanced water efficiency, automated watering based on environmental conditions
[24]	Neural Network of Multi-Layer Perceptron	The same sensors as the proposed work	Water conservation through automated water pump control
Proposed work	PSO for optimizing PID parameters	Sensors for soil moisture, temperature, and humidity	Increased accuracy in water management; less water waste via improved control and control the over- and down water levels in irrigation.

6. Conclusion

The suggested method of this work automatically adjusts the PID parameters for best performance by combining a PID controller with PSO. In addition, the real smart irrigation system has been designed and implemented by this proposed method. This smart system assures accurate water delivery, boosts crop yield, and supports sustainable water management by continuously modifying irrigation based on real of time the data. The main conclusions of this study are summarized as follows:

(1) The practical smart irrigation system was designed. The system controls the water level for irrigation using the suggested method by combining the PID and PSO for effective water management.

(2) The simulation shows that the PID controller has been adjusted using PSO and applied to a real IoT irrigation intelligent system. A pump output ranged from 100% to 0% in less time (5 seconds). This result has received a good and fast response due to the shorter time.

(3) The proposed smart irrigation system was compared with other related works, and the results indicate that the proposed method provides an efficient control of the over- and under-watering level within a short response time.

(4) The soil-moisture level rises gradually from 30% to the desired set-point (60%), attaining steady-state without oscillation or overshoot in around 6 seconds, as seen in the figures above. This demonstrates that the proposed smart system minimized water waste while exactly maintaining ideal moisture levels. High control accuracy, quick settling time, and energy efficiency, all essential components of a successful and long-lasting irrigation system, were demonstrated by the combined response.

(5) The computed RMSE is equal to zero.

(6) In this study, the moisture level reaches and stabilizes at the target set-point of 60% in 20 seconds.

Conflicts of Interest

The authors declare no conflict of interest.

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