Implementation of bio-inspired genetic algorithm in the Smart Irrigation System for analysing the dynamics of various crops

Shreya[a], Arunesh Kumar Singh[a] , Shahida Khatoon[a], and Devendra Kumar Chaturvedi[b]

[a]Department of Electrical Engineering, Jamia Millia Islamia, New Delhi, India;
[b]Department of Electrical Engineering, Dayalbagh Educational Institute, Agra, U.P

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Abstract: Effective water resource management is critical to increasing agricultural yield, crop growth, and food production. However, because of our prolonged pump operating hours, traditional, non-optimized field irrigation methods and techniques have resulted in tremendous water waste and decreased crop yields. Smart irrigation systems have become a viable answer to these problems. This work describes a smart irrigation system that uses electrical actuators and sensor-based feedback in conjunction with a bioinspired genetic algorithm (GA). By integrating various environmental factors- including soil moisture, temperature, humidity, solar irradiation, pH, NPK and VOCs, the proposed model treats the irrigation process as a dynamic control system. The performance parameters like including soil moisture, temperature, humidity, PH have been analysed under various solar irradiations and variable wind speed with the genetic algorithm(GA) which further provides optimal solution.

Keywords: mathematical modelling; irrigation, genetic algorithm, humidity, temperature

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1: Introduction

Math et al. [1] introduced a smart drip irrigation system utilizing IoT technology for the campus of the National Institute of Technology, Karnataka. In order to automate irrigation operations based on actual field conditions, the system combines temperature, water flow, and soil moisture sensors with a single open-source controller. For effective water management, a web-based application also integrates weather forecast data and enables remote monitoring of irrigation operations. The created technology reduces water waste and the requirement for human intervention by offering a scalable and reasonably priced precision irrigation solution.

Gulati et al. [2] Proposed a conceptual model for an automated drip irrigation system that relies on soil moisture assessment. The suggested method combines soil moisture sensors with a software-based control mechanism that compares the recorded moisture content to specified threshold levels. When the moisture level falls below the specified threshold, the irrigation system is automatically engaged. To increase measurement accuracy, the authors proposed placing three soil moisture sensors at varying soil depths. The irrigation schedule is determined by evapotranspiration conditions, which are approximated using meteorological parameters like as wind speed, air temperature, and solar radiation.

A LoRa-based wireless sensor network was used by Mathew et al. [3] to create an Internet of Things (IoT)-driven smart irrigation monitoring system that tracks soil temperature and moisture to determine crop water requirements. Evapotranspiration was calculated using the McGinnis-Borden formula after the sensor data was sent to the receiver. CROPWAT irrigation scheduling data was used to validate the computed values. Additionally, sensor data was moved to the cloud platform ThingSpeak for remote monitoring. The results validated the proposed system's capacity to predict evapotranspiration in microclimatic environments and enable ideal irrigation scheduling, consequently advancing smart irrigation systems and precision agriculture.

Abioye et al. [4] developed an IoT-based system for smart watering and plant health monitoring for mustard plants. The technique involved using flow meters and soil moisture sensors to monitor soil conditions and water use in order to plan drip irrigation, as well as taking pictures of plants to evaluate their health. Over the course of 35 days, the proposed system was tested in a greenhouse. During that time, 20,703 IoT data samples were gathered and processed using data-driven modeling techniques to create a predictive model. The findings show that the suggested method can effectively schedule irrigation and reliably assess soil moisture content.

By including a rice-specific module that replicates water balance and rice production processes such transplanting, puddling, irrigation, and fertilizer application, Jeong et al. [5] enhanced the SWAT+ hydrological model. Case studies from South Korea and Spain were used to validate the suggested approach, which comprised management criteria and water balance equations unique to rice in decision tables. With Nash-Sutcliffe Efficiency (NSE) values of 0.7-0.84 and Percent Bias (PBIAS) within ±10% in assessed watersheds, the results demonstrated better streamflow forecast and irrigation volume estimation when compared to the conventional Soil Conservation Service Curve Number (SCS-CN) technique. Additionally, the study discovered significantly higher amounts of surface runoff and evapotranspiration in rice fields, highlighting the need of accurately modeling pond water dynamics. For assessing water balance in rice watersheds and improving irrigation management, the authors discovered that the modified SWAT+ model is a trustworthy instrument.

IoT-based smart drip and sprinkler irrigation systems were thoroughly evaluated by Bhavsar et al. [6] to determine its functionality, technology, advantages, disadvantages, and applicability for various agricultural applications. This approach comprised evaluating current smart irrigation systems, comparing their performance and water usage efficiency, and tabulating the similarities and differences. The systems under investigation use environmental sensors to collect field data, which is subsequently sent to a server for processing and analysis. Based on the data analysis,

automated commands are developed to control irrigation in accordance with crop water requirements. The results showed that smart drip irrigation is particularly suitable for water-scarce areas, whereas smart sprinkler irrigation is beneficial for large agricultural fields and horticulture applications. The authors concluded that IoT-enabled irrigation systems can reduce water waste, improve water use efficiency, increase farm output, and enable remote monitoring and control, however their effectiveness varies depending on weather, farm size, and system requirements.

Automatic drip irrigation systems with different data collection, processing, and transmission techniques were proposed by Sales et al. [7] and S. P. Vimal et al. [8]. A WSAN-based system was developed by Sales et al. [7] to track nine meteorological indicators.This system consists of three types of nodes that connect via ZigBee and Wi-Fi modules. The collected data is transmitted to the cloud via GPRS, where web services process and integrate it with weather forecasts and third-party applications. In contrast, S. P. Vimal et al. [8] developed a considerably simpler system consisting of an ARM microcontroller, field sensors, and a GSM module. Sensors assess soil moisture, humidity, and temperature, and a GSM module sends the collected data to a mobile application, allowing water pump management. A comparative research reveals that the WSAN-based system provides more scalability, improved irrigation prediction capabilities, and increased flexibility via cloud integration and weather forecasting. These benefits arise from its capacity to monitor more environmental parameters and employ advanced irrigation algorithms, whereas the microcontroller-based system provides a simpler and easier approach to automated irrigation management.

Liu et al. [9] highlighted the applicability, advantages, and limitations of machine learning (ML)-based alternatives for smart irrigation systems in comparison to conventional irrigation decision-making techniques. The research entailed reviewing existing irrigation systems and investigating how machine learning models use environmental and crop-related data to optimize irrigation timing and water consumption. By identifying complex relationships between environmental elements and crop water requirements, the study demonstrated that ML-based strategies can improve irrigation precision and reduce reliance on experience-based recommendations. However, problems like limited data accessibility, high sensor costs, poor model interpretability, and challenges with small-scale farmers' adoption continue to exist. The authors discovered that integrating ML with new technologies, edge computing, and closed-loop irrigation systems could enhance long-term water management, cost effectiveness, and operational efficiency.

The impact of smart water management (SWM) tools, such as Camelion sensors and full-stop wetting front detectors, on maize yields in a smallholder irrigation scheme in Zimbabwe under medium- and high-emission climate change scenarios was assessed by the authors [10] using the Agricultural Production Systems simulator (APSIM). The impact of smart water management (SWM) tools, such as Camelion sensors and full-stop wetting front detectors, on maize yields in a smallholder irrigation scheme in Zimbabwe under medium- and high-emission climate change scenarios was assessed by the authors using the Agricultural Production Systems simulator (APSIM). The technique required modelling crop yield, nutrient dynamics, and soil moisture under both standard and enhanced irrigation techniques.

2: Structure of the proposed system

This study integrates crop dynamics and a control-oriented mathematical modeling technique for a multi-input smart irrigation system. The suggested system can be thought of as a nonlinear multi-input system in which actuation is used to modify system dynamics. The model links several environmental sensor inputs, such as soil moisture, air temperature, humidity, solar irradiance, wind speed, soil pH, soil moisture and humidity, VOCs, and NPK, to the system output, which is the pump voltage. Initially, a proportionate

Pump voltage (volts)	V_p
Air Temperature (degree C)	x
Air humidity (%)	y
Soil Moisture	z
Solar Irradiance	w
Wind Speed (km/hr)	p
pH of soil	r
VOCs	s
NPK Sensor	n
Flow rate of water	Q
Crop Health	CH
Irrigation	I

relationship between input and output is determined, with pump voltage being inversely correlated with soil moisture and dependent on environmental factors.

Farming requires water. A fundamental tenet of agriculture is the relationship between crop vitality and irrigation: fields thrive when properly managed; even rich soil fails to yield when neglected. Rainfall alone is rarely sufficient or reliable enough to meet the needs of agricultural crops, particularly in semi-arid regions or during dry spells. This gap is filled by irrigation [4]. Equation 1 displays the mathematical formula for crop health and irrigation.

$$CH \propto I \propto Q(t) \quad (1)$$

Where,

CH = Crop health

I = Irrigation

$$CH = aI + b \quad (2)$$

Where,

a = response factor

b = base health condition

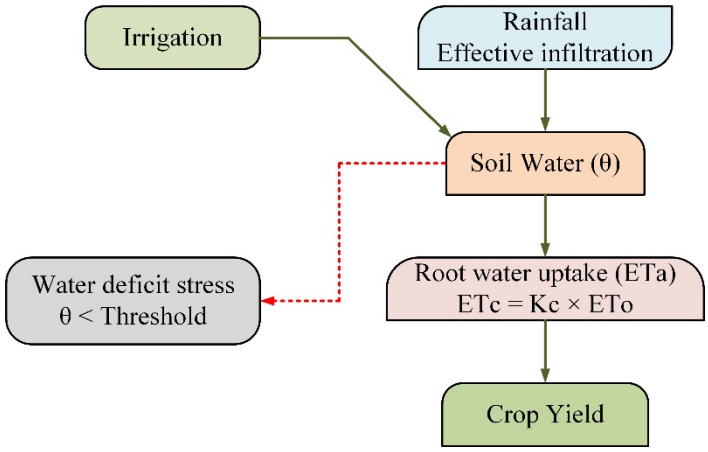


Figure.1 Crop heath connection with irrigation

Eight input parameters are taken into account by the system: soil moisture, solar irradiance, air temperature, air humidity, wind speed, VOCs, soil pH, and NPK; pump voltage is the output parameter. Since the DC pump's terminal voltage can be adjusted to influence the amount of water given to the soil, pump voltage is regarded as the output parameter. The voltage applied directly affects the pump's

speed. This implies that altering the voltage modifies the pump's speed, which in turn influences how much water reaches the soil [11]. The smart irrigation system has been assessed with GA is shown in Figure .2

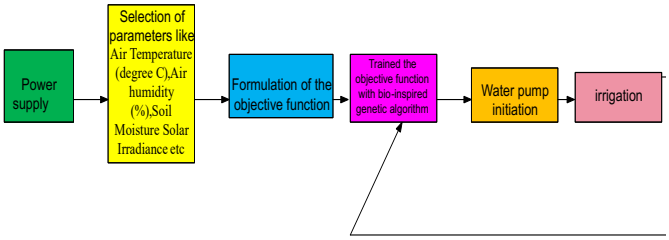


Figure 2 . Implementation of GA in smart irrigation System

Rate of flow of water ∝ pump voltage

$$Q(t) \propto V_p(t) \quad (3)$$

For modelling purposes, the irrigation system is defined by its control inputs and outputs. The primary input to a system (the actuation variable) is the pump's voltage, Vp (t). The system's outputs are the water flow rate, Q (t), and the soil moisture content, z (t). External factors that affect the dynamics of the system are referred to as environmental variables. The following equation illustrates the relationship between the smart irrigation system's recognized input and output:

$$V_p(t) \propto x(t) \quad (4)$$

$$V_p(t) \propto w(t) \quad (5)$$

$$V_p(t) \propto p(t) \quad (6)$$

$$V_p(t) \propto r(t) \quad (7)$$

$$V_p(t) \propto s(t) \quad (8)$$

$$V_p(t) \propto n(t) \quad (9)$$

$$V_p(t) \propto \frac{1}{z}(t) \quad (10)$$

$$V_p(t) \propto \frac{1}{y}(t) \quad (11)$$

$$V_p(t) \propto \text{Crop Dynamics}(t) \quad (12)$$

By examining how each input parameter influences the soil's moisture content, these equations can be justified:

$$V_P \propto \frac{x(t)w(t)p(t)\,r(t)\,s(t)\,n(t)}{z(t)\,y(t)} \quad (13)$$

Using the proportionality from the model, define:

$$V_p = K\frac{x(t)\,w(t)\,p(t)\,r(t)\,s(t)\,n(t)}{z(t)\,y(t)} \quad (14)$$

Where, K is a gain constant

A threshold-based switching method is employed to avoid unnecessary operations:

$$V_{Pump}(t) = \begin{cases} 0, & V_p(t) \le V_{th} \\ 2V_p, & V_p(t) > V_{th} \end{cases} \quad (15)$$

Where,

$V_{Pump}(t)$ = Effective voltage applied to pump

V_{th} = Threshold voltage

The soil moisture variation is governed by the balance between irrigation input and transpiration losses:

$$\frac{dz(t)}{dt} = -T(t) + Q(t) \quad (16)$$

Where,

z (t) = Soil moisture content, T (t) = Evapotranspiration loss, Q (t) = Irrigation input from pump

3: Implementation of genetic algorithm:

The genetic algorithm is an optimization technique for controlling or training the unknown parameters of the transfer functional. The three stages of the genetic algorithm are reproduction, mutation, and crossover. The best strings will be selected for reproduction from the easily accessible string mating pool. Crossover, which involves flipping every bit between the two best strings, is employed after reproduction. Then, at a predefined place, a specific string undergoes a mutation—a random shift from 1 to 0 or 0 to 1.

The evolutionary algorithm is used to train the objective function, as shown in Fig. 3 and explained in a flowchart. The objective function's requirements were taken into account when selecting the standard variable: Three inhabitants; string length: 6, Pm = 0.025, Pc = 0.55

The pertaining value of 'f' that belongs to 5 variable only. These five variables will be estimated by the expression as given in Eq.25

$$f^r = f^{\min} + \frac{f^{\max} - f^{\min}}{2^l - 1} y^r \quad (17)$$

where 'r' is iteration, y^r is length of the binary string.

Eq.(18) will be used for attaining the new constraint variables

$$(f^r)_{new} = \frac{1}{(1 + \frac{\alpha' \varepsilon^r}{f^r})} \quad (18)$$

α' is step size and its value is 0.7 and the error is mentioned in Eq.(19)

$$\varepsilon^r = F(R_2(s))^r - F(R_2(s))^{ref} \quad (19)$$

Fig.3 Flowchart illustrating the steps of genetic algorithm

4. Results and discussion

Table.1 Measurement of various crops parameters under variable solar irradiations

Solar irradiations (W/m^2)	Temperature	Humidity (%)	PH	Soil moisture (%)
20	17.8	56.9	7.8	59.6
25	18.6	59.6	7.9	61.6
35	19.2	63.2	8.3	63.8
55	21.3	67.8	8.6	64.9

Table.2 Measurement of various crops parameters under variable wind speed

Wind speed (m/s)	Temperature	Humidity (%)	PH	Soil moisture (%)
15	18.9	58.9	7.9	61.3

Wind speed (m/s)	Temperature	Humidity (%)	PH	Soil moisture (%)
30	19.7	60.3	8.1	63.6
45	20.3	62.9	8.4	66.9
55	22.9	64.6	8.8	68.7

The measurement of various crops parameters like PH, humidity, soil moisture, temperature under variable solar irradiations and variable wind speed using genetic algorithm is shown in Table.1 and Table.2 respectively. The Variation of soil moisture and irrigation water with irrigation zone with genetic algorithm is shown in Fig.4 and Fig.5

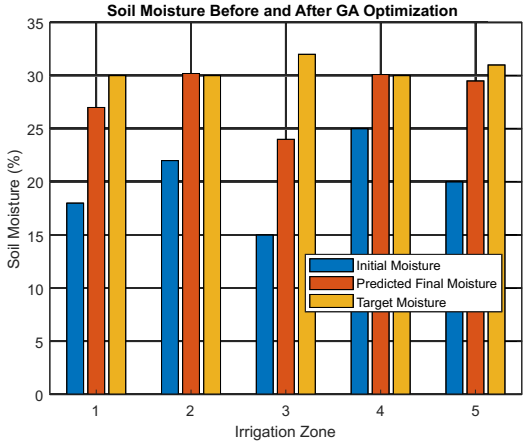


Fig.4 Variation of soil moisture with irrigation zone with genetic algorithm

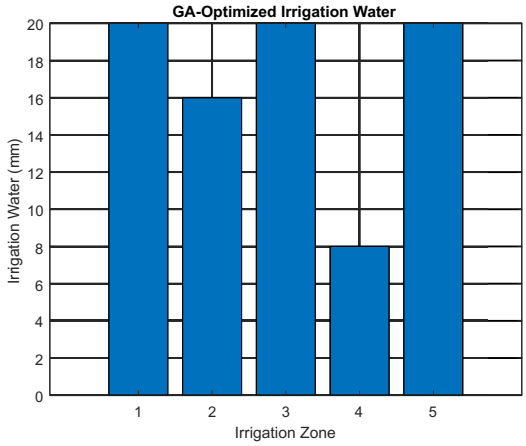


Fig.5 Variation of irrigation water(mm) with irrigation zone using genetic algorithm

5. Conclusion

*Increasing agricultural yield, crop growth, and food production all depend on efficient management of water resources. However, conventional, inefficient field irrigation systems and practices have led to significant water wastage and lower crop yields due to our extended pump operation hours. An effective solution to these issues is now smart irrigation systems. This article describes a smart irrigation system that combines a bioinspired genetic algorithm (GA) with electrical actuators and sensor-based feedback.

* The suggested model addresses the irrigation process as a dynamic control system by incorporating a number of environmental parameters, such as soil moisture, temperature, humidity, sun irradiation, pH, NPK, and VOCs. The genetic algorithm (GA) has been used to analyse the performance characteristics, such as soil moisture, temperature, humidity, and PH, under different sun irradiations and varying wind speeds. This analysis further yields an optimal solution.

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