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Research Article

Leveraging IoT and Genetic Algorithm-Based Clustering for Enhanced Environmental Management in Smart Greenhouses: A Novel Approach for Sustainable Agriculture

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ABSTRACT

The growing problems of water deficit and the imperative need for organic farming have widened the demands for more efficient use of resources in green houses. In this regard, the presented research offers a novel solution the use of Internet of Things (IoT) technology in combination with a genetic algorithm based-clustering to improve water management and increase crop yields in greenhouses. IoT devices allow controlling important parameters of the environment like temperature, soil moisture, wind speed, etc., that helps to control irrigation accurately. The genetic algorithm-based clustering technique, as proposed in the paper, reduces water usage by dynamically interactively for irrigation which optimizes plant health and crop yield. These findings highlight the feasibility of the referred IoT and genetic algorithms for sustainable greenhouse management particularly on water scarce environments. This paper provides benefit-making knowledge contributes to the development of smart agriculture needed to confront these global issues through improving resource use efficiency and sustainable agriculture production..

Keywords: IoT, Genetic algorithm, Clustering, Greenhouses, Water Management, Crop Productivity, Sustainability.

INTRODUCTION

One of the greatest problems of the modern world is to guarantee that food is plentiful and of a good quality. According to United Nations data, while the world population stands at 7.5 billion today, it is projected to increase to 9.7 billion by 2050, that is the reasons for the need to feed seven billion people more efficiently and with less harm to the polity. This needs to be explored within the systems and solutions that seek to be more sustainable and as a result respond to issues brought about by scarcity of resources, climate change and the general wrong use of water and energy resources. Therefore, the use of information processing technologies especially in agriculture for instance Internet of Things (IoT) and artificial intelligence (AI) has been evidently seen as a way of boosting agricultural production [1].

IoT technologies can help the growth/ increase of agricultural crop production since the farmers and researches obtain real information on soil [2], water [3], pesticides [4], fertilizer [5] and organic fertilizer [6] used in farming. It also plays a role of better resource management and ability to assist in the decision-making process in agricultural activities. Climate change and global warming continue to pose the greatest risks to the world. However, the study persists to concentrate on making the world a better place for the generation to come. As a result, IoT technologies [7] have introduced many values [8][9] they have helped the creation of networks for better environmental control such as temperature control, humidity control, light intensity, and carbon dioxide control which can boost the productivity of agriculture [10].

One of these innovations is smart greenhouses, because they let control of climate factors like temperature, humidity, or light intensity. That means that besides enhancing the rate of plant growth, they also minimize the impact of climate on crop yield. IoT sensors convey current environmental data to farmers, which is very crucial at the moment. However, the task of making useful decisions from this data is a challenge, which calls for the right analytical structures and tools [11].

Technologies incorporated in smart agriculture show the need to improve IoT and related technologies in optimally utilizing the aspects of agriculture. The use of IoT systems in greenhouses is very important in modern agriculture by providing an opportunity to monitor environmental indicators such as moisture, temperature of the soil, and the like, these technologies are very useful in creating conditions that contribute to the sustainable development of agriculture [12].

Other researches have as well demonstrated the possibility to interconnect IoT with genetic algorithms in smart agricultural systems. For instance, in the application of evolutionary algorithms in smart homes, approximately 30% energy use reduction has been realized and the crop detect rate has been boosted by at least 20% [13]. Besides, smart irrigation systems have also contributed to the conservation of water and some of the depletive effects of agriculture [14].

In this work, therefore, we propose A Novel Approach for Sustainable Agriculture. The main objectives of the research are: It comprises two general objectives: (i) enhancing water control and conservation in relation to agricultural practice, and (ii) enhancing productivity of agriculture and the quality of produced. However, to assess the appropriateness and efficiency of these methods, The study will use real-world data for simulation.

The central research question is: As to the current performance, how can smart greenhouses enhance their current status by applying IoT and genetic clustering models? How can mitigate modern agricultural issues by these innovations?

LITERATURE REVIEW

2.1 The importance of IOT in smart agriculture:

Currently smart agriculture is continuing its development and becomes better by the application of Internet of Things (IoT) and Genetic Algorithms (GA). Technological improvements enable researchers to manage water effectively and improve crop yields of plants raised under green houses. Irrigation issues in smart greenhouses have been addressed through the implementation of several technologies, for example, sensors, environmental data capturing, artificial intelligence, among others.

To enhance the use of IoT technologies in data acquisition and processing to study real-time environmental factors such as soil moisture and temperature, Mahapatra et al. found that IoT contributes positively to enhancing the utilization of agricultural resources especially for irrigation and thus contributes to the advancement of sustainable agriculture and farm productivity [15].

A current study done by Tawfeek et al. has pointed out the need for optimizing water usage in greenhouses by extending the use of IoT and Artificial Neural Networks (ANNs). Their research incorporated smart sensors to monitor inline real-time data on environment factors like temperature and humidity. This collected data was then used in order to enhance the efficiency of irrigation processes and generally enhance the use of water for irrigation as well as to enhance the agriculture capabilities [16].

In the same vein, Ali et al. implemented IoT and data mining for enhancing the nature of agriculture. In their study, they used smart sensors in collecting environmental information or conditions including soil moisture and temperature for the establishment of efficient irrigation that will reduce water wastage and improve crop production [17].

In another study, I. Ullah et al. pointed out that IOT enhance climate in green house to conserve energies. They used an IOT to control the environmental condition including temperatures and humidity which will be set to give the best for plant growth with minimal wastages of energy. This work increases the understanding of the role of IOT in attaining sustainable smart agriculture by optimizing the utilization of resources [18].

2.2 The role of genetic algorithms in improving irrigation:

In an advanced study, Zhu et al. utilized Smart improved algorithms to make right decisions related to green houses. They were able to design irrigation models that harness soil moisture and air temperature and slashed their water use by nearly half. The findings of this research indicate that these algorithms can enhance the application of waters in irrigation while at the same time optimizing the environ such environment for plant growth [19].

In the context of development of industry 4.0, Bersani et al. By analyzing the reflection of Internet of Things (IOT) in terms of facilitating the monitoring and controlling of smart homes. The findings they obtained pointed out that integrating IOT with AI approaches can enhance the effectiveness of water and energy utilizing in agriculture, whereby the productivity raises, and wastage in fundamental resources decreases [20].

Chen and Hu in a study conducted in the current period designed a smart control system for agricultural greenhouses applying improved genetic algorithm for multiple energy. And the conclusions drawn from this study are that this system can increase the effective energy utilization to the specified level needed for the plant growth. Further, an adaptive algorithm has been used to enhance more effective utilization of the system under varying environmental conditions to minimize energy wastage as well as to enhance agricultural production [10].

In their current research study Bülbül and öztürk reformulated the water consumption control problem through a hybrid model of a GA-algorithm and an ANN algorithm. They discovered that this model of irrigation control can give valuable control with comparatively little wastage of water. This study expands genetic algorithms' application in increasing irrigation systems' effectiveness with the addition of other artificial intelligence approaches [21].

In this context, Goodarzian et al. The meta-heuristic algorithms are most effective to implement in agricultural supply chain where mainly more focus can be provided in minimizing carbon dioxide emissions and water consumption. Thus, the combination of IOT with GA is much more constructive to offer new solutions for managing the water resource, particularly for irrigation concerns, and thus leads to overall favorable use of these resources as implied in their study [22].

Despite the great progress in smart irrigation technologies used today, the majority of current systems used are programmed models and cannot capture the dynamic changes of the environment each irrigation season.As pointed out by Preite et al. this absence hampers the ability of such systems to enhance the maximum sustainability. At the same time, for the systems, which relied on data analysis in real time mode, and adaptive algorithms, including genetic algorithms, the rather inspiring results indicating a significant increase in the effectiveness of water use were received [23].

This underscores the need for a better or a more sophisticated one for that matter such as the one adopted in this study, which involves integrations of IOT with GA with a view of optimally tweaking the irrigation schedule in consonance with the environmental ailments. Vianny et al. examined the probable water use risks in the interconnection of machine learning and the Internet of Things into smart water management in precision irrigation systems. These systems can change irrigation management at any time using real information like the content of the soil, moisture specifications, weather, and crop requirements among others in order to reduce wastage of water and improve on the production of crops. Therefore, this also enhances the taking of, among other positives, larger amounts of water in a sustainable manner 'the conservation of which is critical in minimizing the effects of agriculture on the environment [24].

Contribution and Distinction

the present work can be distinguished from other related works that have applied IoT or genetic algorithms for optimizing water usage in various greenhouses by implementing superior genetic algorithm based-clustering technology to scrutinize environmental data more precisely. The most significant improvement is the incorporation of real data from several sensors like temperature, humidity, and moisture level of the soil for the ideal irrigation schedule depending on the conditions of each moment. We also place emphasis on real-time data analysis; this has helped to reduce water consumption greatly improving on agricultural sustainability. The static irrigation models or traditional algorithms used in previous studies, were less effective compared to this method based on the advanced predictive analysis and artificial intelligence, which would further enhance the efficiency of the irrigation systems and decreases water wastage.

METHODOLOGY

This study proposes a novel approach to optimize water consumption and enhance productivity in smart greenhouses by integrating Internet of Things (IoT) technologies with genetic algorithm based-clustering. The methodology is divided into the following key steps:

4.1 Design of the Internet of Things (IoT) based system

In the following work, we develop an IoT-based system to control the environment of a greenhouse plant. The system consists of the following components:

1- Sensors:

- Soil moisture sensors: For monitoring the actual soil moisture, and proper irrigation.
- Temperature and humidity sensors: to control the changing climatic conditions of the interior environment of the greenhouse.
- Wind speed sensors: to regulate the air of the greenhouse and to keep constant conditions for plants.
- Smart controllers: for a control of irrigation to be taken over by automation by the use of sensor information.

2- Data transfer:

Collected data from the sensors are then transmitted wirelessly to a central system where data analysis is done in real-time using Wi-Fi, LoRa, and ZigBee [25,26]. Figure 1 presents the overall architecture of IoT-based system that shows how various sensors, controllers and transfer protocol are connected to make a smart greenhouse environment.

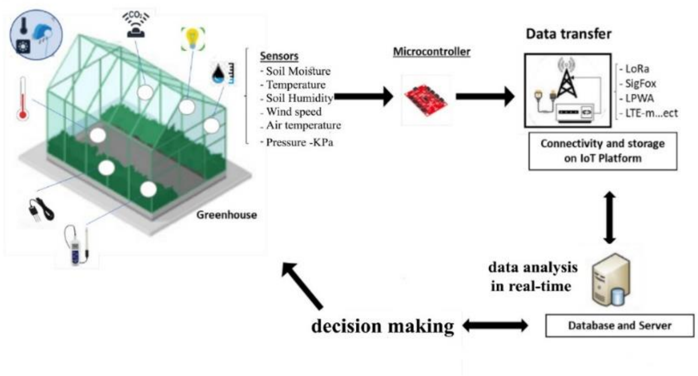

Figure 1: The overall architecture of IoT-based system

4.2 Data Collection and Preprocessing

To develop and test the model, data set from Kaggle was used, which is consisting 10000 records in order to predict the right quantum of water for irrigation. include the parameters of soil moisture status and temperature and wind speed, the parameters which form the basis of most calculations relating to irrigation needs.

4.2.1 Data preprocessing Steps:

○ Normalization: is a very important step to reduce the difference between values and it is also very important to make the genetic algorithm achieve the balance between reducing water consumption and increasing productivity in the normal range of 0 to 1 using the formula.

$$X\_normalized = (X)/(X\_max) \quad (1)$$

○ Handling Missing Values: Missing or incomplete data points were addressed by either:

- Remove the entire row if there are missing values in the row
- Imputing missing values by assigning them with replaceable average numbers most often zero.

○ Feature Selection:

Others include soil moisture, temperature, and wind speed which relate to irrigation management were chosen for analysis.

Data Splitting: For the purpose of model assessment, the dataset was split into training (80 percent of records) and testing (20 percent of records).

4.3 Using the GAs (Genetic Algorithms-based clustering)

Genetic clustering is an optimization technique that mimics the process of biological evolution in nature, and this study uses this technique objectively to optimize agricultural water consumption and increase productivity through a model developed through a multi-objective evolutionary algorithm. the figure 3 show a flowchart of how the genetic algorithm works.

4.3.1 Selection of parameters used in the genetic algorithm

The basic parameters have enabled the genetic algorithm to achieve its research objectives by acting as its operational inputs. These parameters are subject to optimization and analysis by the system to make the most of the resources. The importance of each parameter present will be explained within the proposed framework:

1. Soil Moisture

Soil moisture is the primary factor that determines when plants need watering because it determines whether the irrigation system should be turned on or off.

The evaluation function used is:

$$water\_consumption\_score = max(0, 1 - abs(soil\_moisture - 0.65)). \quad (2)$$

Water use efficiency reaches its peak at 0.65 moisture levels without impacting plant growth according to the evaluation function.

2. Temperature

Plants require specific irrigation strategies based on temperature levels because temperature affects both evaporation rates and transpiration along with the amount of water they need to survive. The control of this factor becomes essential because it influences photosynthesis alongside determining optimal growing conditions.

The evaluation function used is:

production_score = max(0, 1 - abs(temperature - 25) / 0.5). (3)

Temperature at 25°C stands as the optimal environmental condition which results in maximum agricultural productivity levels. The irrigation system requires modification when growth efficiency suffers from any deviation beyond this thermal limit.

3. Wind Speed

The velocity of wind determines how quickly water evaporates through the soil surface which results in fast dryness that demands more irrigation. Wind speed determination contributes to deciding how much water should be used for each irrigation cycle because it impacts water usage efficiency.

The evaluation function used is:

prod wind_speed_score = max(0, 1 - (wind_speed - 0.5) / 10). (4)

0.5 km/h is considered the optimal speed that limits water loss due to excessive evaporation. The higher the wind speed, the greater the negative impact on water consumption efficiency.

4. Water Consumption

Evaluating smart irrigation efficiency requires measurement of water consumption because this factor reveals how effectively the model saves water while maintaining farming output levels. An evaluation function integrates all former criteria to identify optimal solutions for this goal.

the fitness function has the following formula:

Fitness_function=(water_consumption_score,0.7 × production_score + 0.3 × wind_speed_score) (5)

It should be noted that the weight of production_score is higher than the weight of wind_speed_score = 0.7 and at the same time wind_speed_score = 0.3 because the goal is to improve agricultural production.

4.3.2 Steps of the Genetic Algorithm:

1-Initialization:

A population of potential solutions (chromosomes) was created randomly and it was implied that each chromosome is an irrigation strategy. The solution is values such as: the amount of water used, the timing of irrigation, and the control of temperature and humidity.

Suppose each chromosome consists of the following values: [0.7, 25, 0.5]

- 0.7 Target soil moisture level.
- 25 Optimum temperature for plants (in °C).
- 0.5 Wind speed to be maintained.

A random set of possible solutions is generated so that more than one irrigation strategy is explored.

2-Fitness Evaluation:

Each chromosome was evaluated based on two objectives:

- Minimizing water consumption.
- Maximizing crop productivity.

3-Selection:

On average the better fit chromosomes replicated and passed on there genes to the next generation.

4-Crossover and Mutation:

Crossover: Two parent chromosomes were brought together and resulted into offspring with same/ similar features.

Suppose we have two irrigation methods tested for the following traits:

Parent 1: [0.7, 24, 0.5]

Parent 2: [0.6, 26, 0.4]

The result of the single-point cross analysis at the second locus produces the following offspring:

Child 1: [0.7, 26, 0.5]

Child 2: [0.6, 24, 0.4]

Result:

The exchange of genes between the parents leads to the generation of efficient irrigation strategies.

Mutation: Random perturbations were made in order to keep search for new solutions divergent and cover as many genes of populations as possible.

A practical example of mutation in our research:

We will examine a random chromosome that emerges from crossover:

[0.7, 26, 0.5]

After implementing a random mutation we can modify the temperature value from 26 to 25 to result in:

[0.7, 25, 0.5]

Our analysis demonstrates that mutations prevent the algorithm from ending in local solutions so it can discover fresh alternatives.

5-Termination:

The algorithm stopped working when the best solution was reached or reached the maximum generation value. As we can see, the best solutions we reached were within 50 generations, which means that the evolution reached the stage of stability in the ideal irrigation.

Figure 2 shows the flow chart of the genetic algorithm and the sequence of steps and options for genetic improvement.

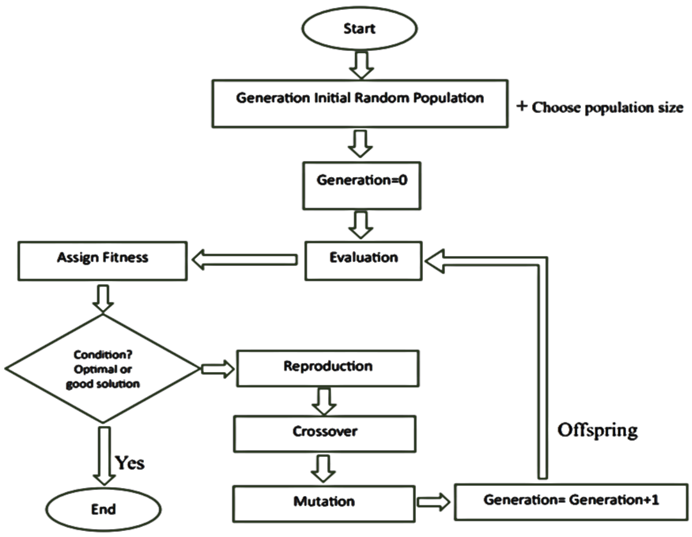

Figure 3: Flowchart of Genetic Algorithm

4.4 Work tools

4.4.1 Execution Environment

We utilized the model on a computer with sufficient technological features to enhance computations of the results. The specifications are as follows:

- Processor (CPU): Intel Core i7-8750H
- Random Access Memory (RAM): 16 GB.
- Operating System: Windows 11 Home 64 bit.

4.4.2 Programming Environment

o Anaconda environment was employed with Python 3.9. In terms of the features of the programming language used, we would like to point out that more data preprocessing libraries were used such as NumPy, Pandas, and Scikit-learn. Matplotlib was used in the creation of the graphs.

- Loading and preprocessing the data.
- The main step of the project that has focused on applying the genetic algorithm for the purpose of clustering and optimization.

Measuring the performance of the model in terms of water saving and increased productivity.

RESULTS AND DISCUSSION

This section presents the detailed results obtained from the application of the proposed model, which is based on the integration of Internet of Things (IoT) technologies with genetic algorithms to improve irrigation management in smart greenhouses. The model was implemented using the Python programming language, where the clustering and analysis algorithms were developed based on real data from the Kaggle platform. The analysis focuses on two main metrics: reducing water consumption and increasing productivity, providing a quantitative and qualitative analysis of the performance.

5.1 Reduced water consumption

Realistic outcomes on the savings on water usage was realized through the proposed model where IoT data was collected and followed by genetic algorithms to find suitable irrigation policies. Key findings include:

- Water saving: The used model helped to achieve the collected 30 percent decline in water usage as compared to regular irrigation.
- Dynamic adaptation: Water wastage was minimized by the ability of the system to allow automatic control of the irrigation schedule according to the changes in soil moisture and weather conditions.
- Optimal use: Genetic algorithm calculated the quantities of water needed by each section of the greenhouse and thus required water was supplied better.

In the present work, the proposed system demonstrated considerable savings in water consumption over the traditional method, as seen in Figure 3.

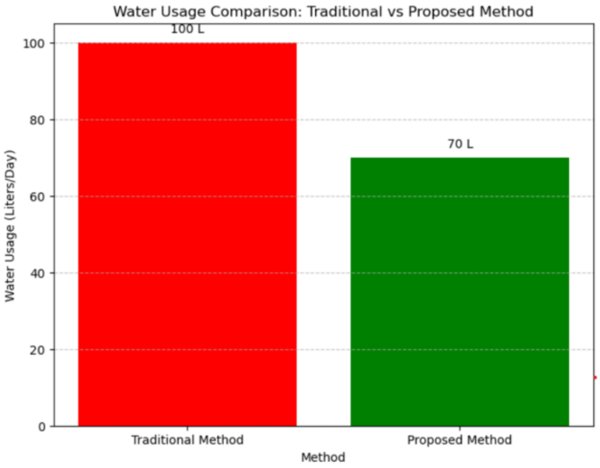

Figure 3: shows a 30% reduction in water consumption.

5.2 Increased productivity

Improved irrigation management resulted in a significant increase in crop productivity, with the following results achieved

Increased yield: Based on the matters explained above, the proposed model helped realise an approximate 20% boost in crop yields on account of enhanced environments and water distribution.

Ideal growing conditions: Physical conditions of soil moisture and climate were kept at their best level in order to ensure good plant healthy and high quality of the crops.

Resource efficiency: Since water and other resources were used efficiently this changed the scenario of agricultural environment.

The analysis of the proposed system and the relation between water use and crop productivity is presented in figure 4.

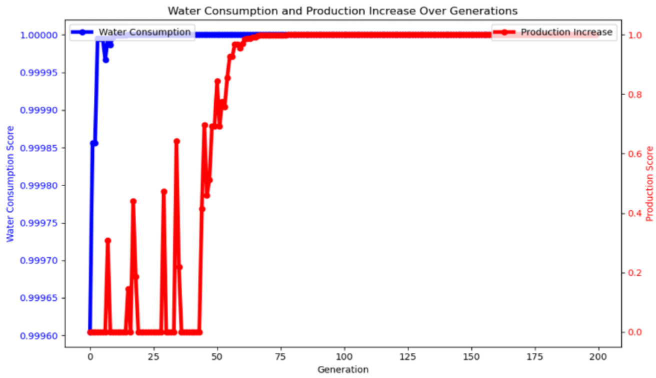

Figure 4: Water Consumption and Production Increase Over Generations

5.3 Sustainability

There are no doubts that proposed model helps also to save water and improve productivity which are crucial for crops sustainability. Sustainability is achieved through the following aspects:

Environmental Sustainability: The model saves an important natural resource in by cutting back on water usage by 30% conservation and sustainable utilization of water.

Economic Sustainability: The increase in the productivity of water use by 20% improves the chances conservation of farmers' economic returns because other forms of irrigation with water are uneconomical in the long run.

Social Sustainability: Higher crop yield and better quality enable to ensure communities constant supply of quality agricultural produce thus promoting food security.

Another important characteristic of the model is the flexibility to match remanufacturing resources with other resources available in the market to avoid wastage of resources. This way it supports a sustainable form of agriculture which meets the needs for agriculture produce without jeopardizing the resource base.

Overall, following the concept of the proposed model, one can find real-life solutions to the modern issues connected with agricultural production and increase the productivity at the same time, implementing the principles of sustainable development.

5.4 Performance Evaluation

The model was developed based on the test dataset of gene where the clustering algorithm was developed in Python environment using genetic algorithm. The main results include:

Increased accuracy and flexibility: The proposed system outperformed traditional systems in terms of accuracy and flexibility, as it responded to the actual needs of plants and the environment dynamically. Figure 5 The graph shows the evolution of fitness (for training and test data) and accuracy across generations.

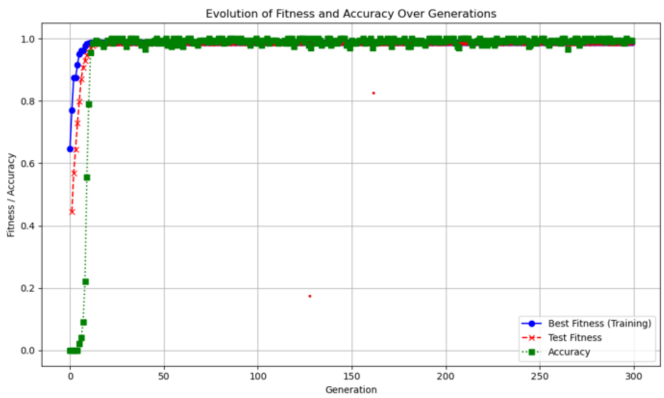

Figure 5: Evolution of Fitness and Accuracy Over Generations

Convergence speed: The genetic algorithm demonstrated that it is possible to reach the best solution in the 50 generations, thus highlighting the effectiveness of the method.

Scalability: To demonstrate scalability of our model and to distinguish that our proposed model is effective and can be applied to larger numbers of plants in greenhouses.

Figure 6 shows that the genetic algorithm is working correctly and improving the cluster distribution over generations. A lower WCSS value means that the points are getting closer to the centers of their clusters, which is the goal of clustering.

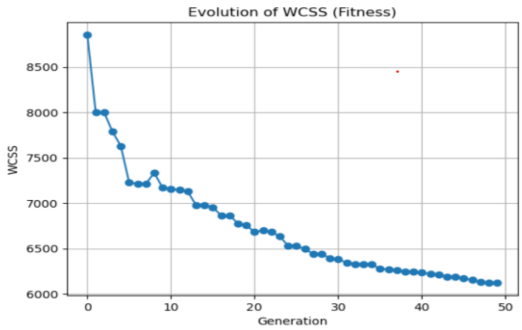

Figure 6: Evolution of WCSS (Fitness)

the Figure 7, the data is segmented into groups consisting of similar values of distance and/or proximity. When the points that have the same color are well clustered it means that the algorithm has provided a correct partitioning of the data set. The coordinates of the clusters denote that the algorithm accomplishes the identification of the right points that represent each cluster.

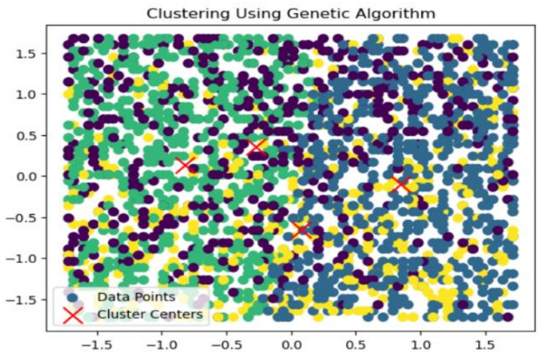

Figure 7: Clustering Using GA

5.5 Discussion

The findings of the study do confirm the concept of combined use of IoT and GA to address the issues of population growth by boosting the production yield of crops in agriculture. The main advantages of the proposed system include:

- Real-time monitoring: IoT monitors and recognizes the environmental features and hence, aspects that include the initiation of the irrigation cycle can be reversed immediately.
- Individualization and optimization: The genetic algorithm also give the best irrigation plans that help in using less water but increases productivity.
- Sustainability: This makes the conservation of the environment and the economy for the longer-term because it tries to ensure that water usage is optimized and canopy yield is improved upon.

However, some limitations were noted:

Initial setup cost: However, smart sensors or controllers for IoT applications need a massive initial setup and integration costs.

Model dependence on data quality: And this can be concluded that if the input data is accurate enough and is of good quality, the model high performance was observed during the experiment.

5.6 Comparative Analysis

This section conducts a comparison between traditional approaches and the proposed Genetic Algorithm supported by Internet of Things (GA + IoT) for smart irrigation management based on vital criteria such as water consumption efficiency alongside improved agricultural productivity alongside data requirements and cost.

5.6.1 Comparison with conventional irrigation management methods

The water distribution methods of flood irrigation together with scheduled irrigation depend on pre-established technological schedules and basic crop water calculation methods. Even though these techniques remain prominently used across water management systems they still contain various weaknesses that reduce overall water resource management efficiency because they cannot interpret quick climate changes or genuine plant requirements [27].

The most prominent disadvantages of traditional methods

1- A large waste of water consumption due to excessive or insufficient irrigation

2-The system fails to adjust properly to unexpected environmental shift patterns between extreme heat and dry soil conditions.

3- Adverse impact on productivity due to misuse of water for a negative impact on crop productivity.

Compared with the proposed method (GA + IoT):

1-The implementation of dynamic soil and climate condition-based adaptation allows farmers to reduce water use by 30% .

2-Farmers could reach a 20% higher agricultural productivity by delivering perfect growing conditions for their crop fields.

3-Immediate response to environmental changes through the use of IoT sensors and real-time data analysis.

5.6.2 Comparison with other smart technologies

The improvement of irrigation efficiency through various artificial intelligence-based and data analytic methods includes deep learning (LSTM RNN) and reinforcement learning together with classification methods including K-Means and Decision Trees.

Analysis of the most important limitations of these techniques:

1-The classification methods K-Means and Decision Trees utilize cluster partitioning for data organization while offering no dynamic adaptation approach for environmental condition changes [28].

2-Deep learning (LSTM RNN) depends mostly on past data thus causing limited efficiency when faced with conditions beyond its training scope [29].

3-The adaptive qualities of (reinforcement learning) are high but its extensive training requirements coupled with big data needs make it impractical for real agricultural use [30].

Compared with the proposed method (GA + IoT):

1-The genetic algorithm maintains equilibrium between how quickly algorithms adapt and how precisely they execute irrigation processes without depending on extensive historical information.

2-Implementation with the genetic algorithm occurs more easily and economically than artificial intelligence techniques containing deep learning methods.

3- The real-time collection of data from IoT sensors produces enhanced decisions while improving handling of instant system alterations

The following table shows a comparison between the proposed method and other methods.

Table 1: Comparison between the proposed method and other methods.

Method	Water efficiency	Improve productivity	Adapting to changing conditions	Cost
Traditional irrigation	weak (big waste)	Low	No air conditioning	Low cost
K-Means و Decision Trees	Limited (non-dynamic)	Medium	poor adaptation	Medium Cost
Deep Learning (LSTM RNN)	Good	High	Weak in immediate adaptation	Very high
Reinforcement Learning	Excellent	very high	Good adaptation	Very high
IoT & GA-Based	30% improvement in	20% increase in	Dynamically adapts to	Moderate cost

Clustering	water efficiency	productivity	conditions	and easy to apply

The proposed combination of GA + IoT serves as an efficient smart irrigation management solution because it delivers superior water consumption efficiency than traditional approaches with results similar to advanced AI systems yet operates at lower expenses and provides flexible control. Several essential elements make the proposed method stand out as the superior solution.

1-The water consumption under this method drops 30% below traditional approaches.

2-Improving agricultural productivity by 20% through precise control of environmental factors.

3- The system has an immediate capability to react to climate conditions and soil quality for maintaining sustainable water management operations.

The proposed approach demonstrates superior capabilities because it functions effectively in real agricultural areas at reasonable financial costs.

Conclusion

In conclusion, the use of IoT technologies together with genetic algorithms can be considered as the potential solution that allows increasing the efficiency of water supply and the productivity of agricultural production in greenhouses. A great aspiration illustrated by this research is the potential of IoT sensors to gather real-time information so as to develop dynamic irrigation systems that can change to the current climactic condition. In contrast to the conventional methods of watering crops which normally entails a fixed timetable or routine control changes, the genetic algorithm-based technique designs optimal irrigation methods in every successive day so that water usage is optimal. Such findings clearly identify increased efficiency of water usage and crop production proving the applicability of smart technologies for intelligent irrigation. This method can also improve crop production and also promotes conservation of water resource especially in areas of low water availability. The development provided by this study underlines future research directions in precision agriculture and helps to create new opportunities for growth in both agriculture as well as in the preservation of the environment. Further research could then try to fine-tune the algorithm, add more variables, and extend the system practicality across various agro-ecological regions to enhance more efficient use of resources to improve yields.

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