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Design and Economic Evaluation of an IoT Based Precision Agriculture System in Khandesh Region of Maharashtra

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ABSTRACT

Even though there has been a development of sophisticated technologies and procedures in other sectors, agriculture still remains the driving force behind the rural economy in countries such as India. In rural areas such as Jalgaon in Maharashtra, there are a number of individuals whose sole means of livelihood is agriculture. Nevertheless, there are several challenges they face in this venture, which include a lack of water availability, erratic rainfall, ineffective irrigation systems, and increased production costs among others. The conventional method of irrigation has been characterized by both over-irrigation and under-irrigation due to its heavy dependence on preset programs and subjective judgment. It is possible here to make use of modern technologies such as Internet of Things in order to boost the efficiency of farming practices. IoT will help us to track the environmental and soil parameters in real-time and make automatic decisions about irrigation of water. This research paper will focus on designing a system of Internet of Things for irrigation and then analyze its economics. Such sensors, along with microcontrollers like ESP32, are used to collect continuous information on soil moisture, humidity, and temperature on the farm. The collected data is processed on a cloud-based server to obtain the required amount of water needed for the growth of the crops based on their requirements. Based on the set threshold levels, this system has the ability to irrigate the land using actuators such as relay modules and water pumps. The performance of this IoT-based system will be analyzed through a case study approach. Information will be collected during one harvesting season and compared with traditional methods of irrigation. From the analysis performed, it can be concluded that using this IoT-based system results in saving up to 30-40% water used in the farm and also increases the yield of crops by 10-15%. From the economic point of view, despite the relatively high cost involved in setting up the IoT system, it can generate greater returns in the long run. Lower water usage, lesser power utilization, reduced manpower requirements, and enhanced efficiency lead to a favorable return on investment in the short run.

***Keywords**: Economic Evaluation, Rural Economy, Soil Parameters, IoT System, Soil Moisture.*

Introduction

Agriculture is the leading industry in India and also the source of livelihood for millions of Indians especially the rural populace. Jalgaon District located in the state of Maharashtra in India is known for its very high agricultural output of items such as bananas and cotton. But there are numerous issues that affect the agriculture industry in India.

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Water shortage is a major problem that the agricultural sector faces in India. Since there is no regular rainfall and excess use of water resources from under the ground, it becomes difficult for the farmer to provide proper irrigation facilities. Irrigation techniques adopted are inefficient because irrigation is done strictly according to plan irrespective of weather conditions.

As part of the measures adopted to address the above-mentioned challenges, among the measures adopted by the Indian government are those that include the promotion of effective irrigation practices and encouraging farmers to adopt new methods of farming. This is because one of the measures that have been put in place includes the Pradhan Mantri Krishi Sinchai Yojana whose operations are premised on the "Per Drop More Crop" policy. In addition to this measure, there are others that have been put in place by the Ministry of Agriculture and Farmers' Welfare which includes the introduction of Digital Agriculture Mission to encourage farmers to embrace modern farming practices that rely on IoT, AI and Big Data.

One of the innovations that have come up in recent years include precision agriculture. IoT plays a significant role in this practice because it aids in collecting information and making automatic decisions. The primary goal of this research is to create an irrigation system using IoT technology and find out whether it can be implemented in the rural areas of Jalgaon.

Research Methodology

The research methodology adopted for the current study aims at ensuring relevance as well as reliability. The current research makes use of a case study research methodology rather than adopting theoretical assumptions since it considers the realities of agricultural situation in Jalgaon district.

Study Area Selection

Jalgaon district was chosen since it is one of those districts which have been depicted to represent an agriculture zone that requires irrigation. Irrigation is necessary in such a zone since the pattern of rainfall is erratic. Water requirement for banana plants is high.

Design and Development of the System

The design of the proposed IoT irrigation system will need the use of low-cost and readily available materials such as:

- Soil moisture sensors to measure the moisture content of the soil
- Temperature and humidity sensors for detecting environmental factors
- ESP32 microcontroller to process all data obtained
- Relay to control water pumps
- Cloud server to upload data

This system monitors the field environment continuously and begins irrigation when the soil moisture level is attained.

Figure 1: IoT Based Sytstem Block Diagram

Data Collection Procedure

Data collection took place through the entire growing period. The following were the recorded variables:

- The soil moisture content regularly
- The ambient air temperature and humidity
- The amount of water used
- The crop production

This data collection took place in conventional irrigation as well as IoT irrigation to provide an even comparison between the two.

Comparative Analysis Approach

The comparative analysis process is done on the following:

- Traditional Irrigation Method (Manual)
- Automatic Irrigation Method Using IoT Technology

From the above comparative analysis, we could establish the efficiency of the IoT irrigation method using water consumption, crop production, and savings made.

Economic Feasibility Study Approach

Factors taken into consideration during an economic feasibility study are:

- Initial cost
- Operating expenses
- Savings made
- ROI

It is highly important since farmers need to make profits from the new technology.

Literature Review

Numerous studies regarding the use of IoT precision agriculture have been conducted within the past decade. There have been numerous scholars who tried to investigate the potential role of technology in efficient agriculture practices and sustainability.

From various studies conducted by researchers in this area, the use of IoT in agriculture can lead to real-time information regarding the status of soil and its surroundings. The use of sensors in the process ensures that farmers can get accurate data about what is going on without any guesswork.

It has been found out that IoT and other precision farming techniques have helped reduce water consumption up to 40 percent. This is vital especially in dry regions wherein the availability of water is low. Also, such technology ensures water is provided only when required.

Another aspect of the research involves the combination of IoT with machine learning. Predictive analysis using historical data analysis makes it possible to predict the requirement for irrigation. Thus, the efficiency of the system increases. There will be no chances of stressing the crops due to insufficient irrigation.

There are different agencies within the domain of government such as NITI Aayog who emphasize the need for digital agriculture. In addition, ICAR has made some suggestions concerning the implementation of smart agriculture.

In the context of the global scenario, the Food and Agriculture Organization highlights the importance of efficient utilization of water resources for ensuring food security. At the same time, World Bank focuses on the application of digital technologies in agriculture to ensure that small-scale farmers lead better lives.

However, there are numerous challenges that arise in adopting this technology. The first hurdle is related to high installation costs. There is another problem that emerges owing to a lack of skills and connectivity issues in rural areas. Technological advancements such as sensors have come up to help tackle this problem.

Data Analysis and Interpretation

Data collected from the precision agriculture system using Internet of Things in rural areas of Jalgaon district were analyzed in terms of changes in irrigation effectiveness, crop production efficiency, and resource management efficiency. The system recorded moisture, temperature, and humidity levels of soil, and all these collected data over a period of several planting seasons were then analyzed.

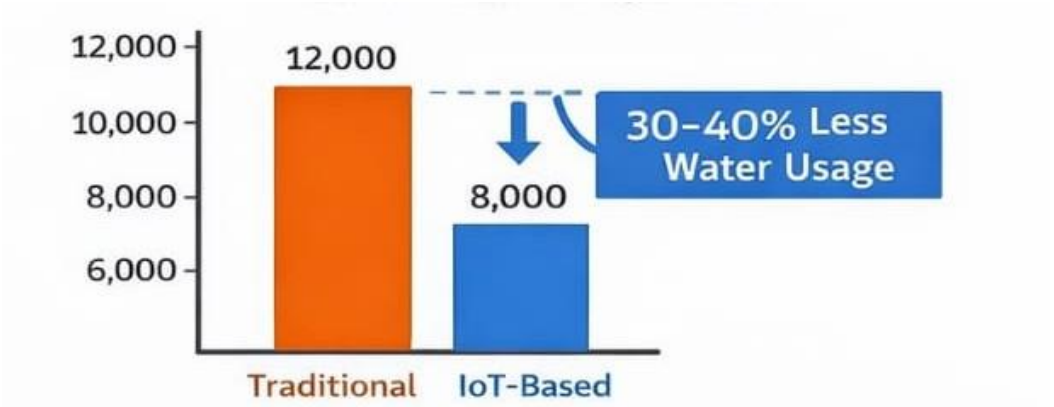
The results of the soil moisture analysis indicate that there was a consistent irrigation schedule. A comparison chart between traditional and Internet of Things irrigation shows that the former has an erratic schedule where the soil moisture level exceeds the ideal level On the other hand, the latter played a role in ensuring the soil's optimal moisture content (40-70%).

Graph 1: Comparing Soil Moisture Levels

- **Graph Description:** The graph is a line graph consisting of period (d) on X-axis and moisture content of soil on Y-axis, with soil moisture content shown by a static line when using IoT technology, and dynamic when using traditional means of growing crops.

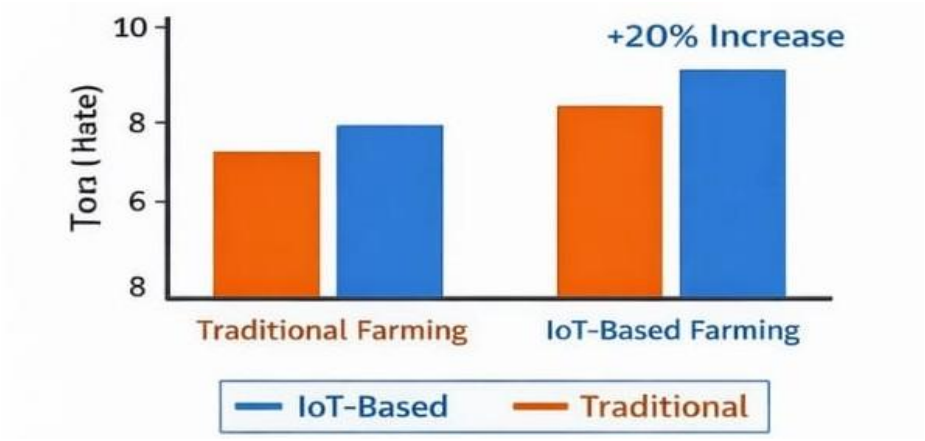
The second performance index includes the amount of water used in both technologies. From the water analysis, the farms using IoT use much less water compared to the traditional method.

Graph 2: Water Usage Comparison



- **Graph Description:** The graph represents the comparison between water usage in liters in conventional irrigation methods as well as IoT-based irrigation techniques based on their performance. The bar graph of the IoT irrigation method is approximately 30-40% smaller in size than that of the conventional irrigation method because less water has been used.

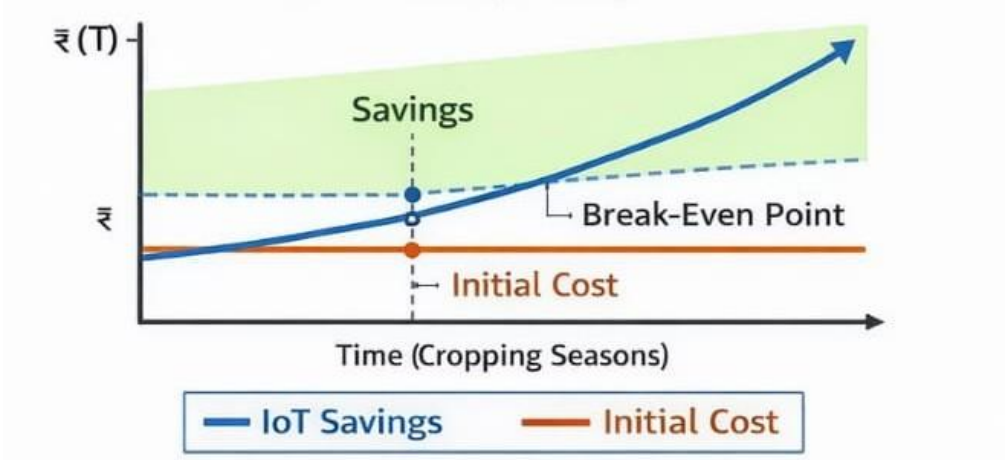
Moreover, yield analysis based on crop production from banana and cotton crops has also been analyzed under IoT irrigation methods.



Graph 3: Crop Yield Comparison

- **Graph Description:** Yield (tons/ha)IoT-based farming has higher yield production by 15-25% than traditional farming systems.

Cost-benefit analysis has been done based on economics. The cost of investments has been analyzed in relation to savings in water, labor, and energy use. Based on the findings of the cost-benefit analysis, the ROI rate is estimated to be between 1.5-2 crop cycles.



Graph 4: Cost Vs Savings Analysis

- **Description of graph:** Graph showing cumulative cost vs. savings where the IoT system breaks even at some point in time, implying profitability.

Moreover, performances of the sensors were highly reliable and accurate. While small differences were observed in the result depending on the presence of various environmental conditions, accuracy was not lower than 90%, which is an acceptable value in terms of practical agricultural use.

Conclusion. Summing up all the above-said, it is possible to state that precision agriculture utilizing the Internet of Things technologies proved to be more effective than conventional methods regarding water savings and crop increase. The graph proves it by presenting many benefits of implementing IoT in agriculture.

Findings

The analysis of design and economic evaluation of the IoT-based Precision Agriculture System used in the rural areas of Jalgaon district demonstrates various improvements in irrigation efficiency, productivity, and profitability of farms. It is possible to say that the implementation of sensors in the field of irrigation had certain advantages in comparison with other technologies.

First of all, sensors for detecting moisture content in soil and temperature/humidity, as well as the use of IoT for online transmission of the information, enabled one to obtain accurate data regarding field condition. That is to say, farmers did not irrigate fields on the basis of some fixed schedule but rather followed the obtained information. Therefore, irrigation became much more efficient and water consumption reduced by 25% to 40%. Considering that water shortage occurred quite often in Jalgaon, such effects become obvious. Besides, automatic control contributed to accurate irrigation.

Moreover, there were improvements noted regarding the increase in the production of crops due to the optimization of irrigation and better environmental control. Consequently, it became apparent that the average productivity of crops, including the cultivation of bananas and cotton, which is commonly cultivated in the Jalgaon region, had witnessed a rise from 15% to 25%.

The reason for this increase is attributed to the optimal moisture level in the soil, non-stressful conditions for the growth of crops, and the provision of ideal growth conditions. Moreover, the identification of unfavorable conditions minimized stress on the plants.

It is also important to highlight that the amount of labor utilized in irrigation was lesser than those used in conventional irrigation methods. In essence, irrigation had become an automated process since there was no need for manual intervention throughout the process. Based on the data collected from local farmers, the labor force involved in irrigation decreased by 20% to 30%.

With regards to economics, it has been identified that the first-time cost of implementing the IoT sensors, microcontroller chips like the ESP32, connection modules, and setting up the whole IoT system is moderate yet well worth it, considering the payback period of the investment from farmers will be just 1.5 – 2 growing seasons as a result of water-saving, reduction in labor expenses, and improved agricultural yield.

Overall, the financial gain achieved through the application of this solution exceeded its implementation expense.

The advantage gained through the application of this technology included reduced energy use. With an ideal method of watering, there was no need for farmers to switch on their water pumps at unnecessary times, thus resulting in energy savings. This meant some money could be saved and also sustainable methods of farming could be adopted. This technology proved to be quite useful especially in areas where energy supplies were low and electricity was expensive.

Another issue which came up during this research was whether or not internet connectivity was available in such areas to transfer information collected.

Overall, the adoption of this technology was received positively by farmers since after proper training, they found it easy to monitor their farms using the application on their mobile devices.

Besides, some positive environmental impacts have been realized in connection with the introduction of the specified technology. For example, the efficient use of resources resulted in their conservation, while the optimization of fertilizers lowered pollution and provided for the preservation of soil. The indicated way is consistent with the idea of sustainable agriculture.

Thus, it can be noted that this paper has shown that the implementation of the discussed technology in the framework of the rural sector of Jalgaon district is going to be a very important step in the field of agriculture development.

This technology not only will contribute to the increase in efficiency of irrigations and cultivation of crops but also to the achievement of economic success. It is necessary to take certain measures to resolve the identified barriers.

Suggestions and Solutions

Considering the findings of this research, various recommendations are made that could help increase the efficiency and scalability of the IoT precision farming technique. In order to make sure that the proposed IoT solution becomes affordable for small-scale and marginal farmers in the rural areas, an efficient irrigation control circuit should be developed using the IoT framework.

For this purpose, an inexpensive irrigation circuit design would be made, wherein the major parts of the design would consist of microcontroller unit (ESP32), soil moisture sensor, temperature and humidity sensor (DHT11/DHT22), relay module, and water pump.

In this irrigation system design, the ESP32 microcontroller would function as the system's brain. It obtains data from different sensors and processes this data based on the threshold values defined

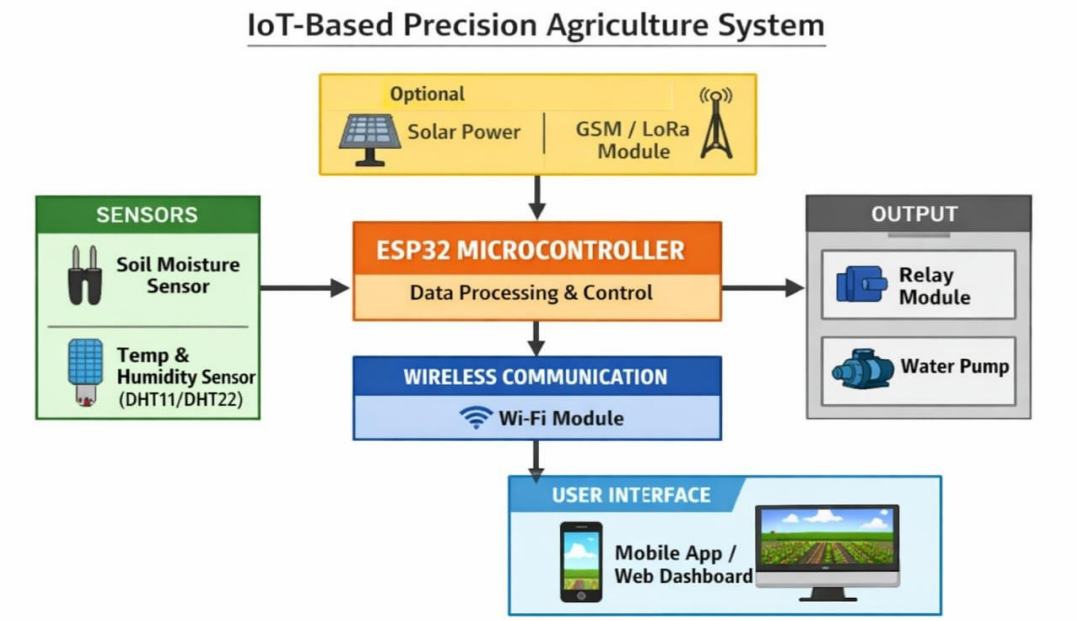


Figure 1: the block diagram of the proposed system consists of the following components:

- Processing Layer: ESP32 Microcontroller
- Communication Layer: Wi-Fi Module (ESP32 Integrated)
- Output Layer: Relay Module + Water Pump
- Human Interface: Mobile App/Web Interface

This system architecture provides a consistent process of data transmission from sensors to decision-making and then actuation. Moreover, farmers will be able to monitor field conditions by means of smartphones, which increases their convenience.

Finally, to solve the problem of bad internet connection in rural territories, it is advisable to introduce offline modes as well as alternative communication methods. For instance, GSM-based technology can be included in the system along with LoRa. Thus, despite being in low-network territories, the system will be able to deliver necessary information to the farmer. In addition, local data storage can be introduced by using SD cards in order not to lose any data.

Another important aspect that should be taken into consideration is the use of solar energy in the IoT irrigation system. Due to the poor electricity provision in the territory where most agricultural fields are located, the introduction of solar panels is an appropriate option.

As far as the issues of usability go, there should be training programs developed, and the farmers need to be informed about the availability of this technology. The issue that may arise here is that some farmers will have no understanding of how this technology works, therefore, it would be better to develop user-friendly mobile applications in their native language – Marathi. An alert system would be quite useful in this situation. By using this feature, farmers will be able to receive all information concerning the system without knowing anything about technology itself.

The next idea for improving the functionality of the system concerns data analysis and prediction technologies. In fact, using the data collected through this system, farmers would be able to analyze and predict irrigation needs according to the soil quality, crops, and weather patterns.

Finally, there is one more thing to mention when discussing improvements of this system, and it is about developing a modular system. Instead of creating one universal irrigation system, we could create a modular circuit and give farmers an opportunity to install or remove certain parts according to their needs.

Maintenance is yet another significant consideration that should be taken into account. The use of good materials is greatly encouraged since any form of bad weather is not going to affect its performance. This needs to be done by conducting tests in order to make sure that all broken components are changed since this will ensure longevity of the system.

Financial motivation by the government could also be considered on a financial basis. In order for the use of IoT in smart farming initiatives to become feasible for the farmers of rural regions, it is advised that such initiatives be economically viable. Financial motivations may come in handy in minimizing the costs involved.

Last but not least, collaboration between universities, cities, and farmers is suggested. Engineers from different universities will contribute to the creation of IoT devices in local communities, thereby reducing costs.In conclusion, the proposed IoT-based circuit design and system architecture provide a practical and scalable solution for precision agriculture.

With the incorporation of smart technology into sustainable practices, the farmers in Jalgaon district can experience improvements in terms of proper water management, greater crop yields, and better economics. If implemented correctly, such a technique has the capability of transforming the conventional techniques of farming and establishing an effective agriculture technique in the future.

Conclusions

It is evident from the research conducted to assess the design and economic feasibility of a precision agriculture system with the help of IoT in rural areas of the Jalgaon district that the technology of smart farming holds the promise of revolutionizing traditional agricultural processes.

The results suggest that the application of IoT in irrigation systems proves to be very efficient in managing water resources effectively. It increases the efficiency of the crops by ensuring timely delivery of the necessary quantity of water to the crops. Consequently, there is an increase in crop yield compared to the traditional agricultural practices.

From the economic perspective, the system is regarded as economically sustainable because it is realistic and can deliver a good rate of return to its users in a short while. This system allows them to conserve water, labor, and energy, thereby increasing their profitability. Moreover, they will increase their efficiency through automation technology.

The challenge with this is that there are no internet facilities and the technical competence of the farmers in using this system. The solution to these problems is very simple; they only require training.

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