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Smart-Hydroponic-Based Framework for Saffron Cultivation: A Precision Smart Agriculture Perspective

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Abstract: Saffron, one of the most expensive crops on earth, having a vast domain of applications, has the potential to boost the economy of India. The cultivation of saffron has been immensely affected in the past few years due to the changing climate. Despite the use of different artificial methods for cultivation, hydroponic approaches using the IoT prove to give the best results. The presented study consists of potential artificial approaches used for cultivation and the selection of hydroponics as the best approach out of these based on different parameters. This paper also provides a comparative analysis of six present hydroponic approaches. The research work on different factors of saffron, such as the parameters responsible for growth, reasons for the decline in growth, and different agronomical variables, has been shown graphically. A smart hydroponic system for saffron cultivation has been proposed using the NFT (nutrient film technique) and renewable sources of energy.

Keywords: IoT; saffron; NFT; hydroponics; WSN

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1. Introduction

Agriculture is considered to be the backbone of the Indian economy, contributing to about 18 percent of the Gross Domestic Product (GDP) and 43 percent of the geographical area [1]. With the drastically increasing population, the world population is supposed to reach 9.8 billion by the year 2050, with its maximum impact being on developing nations such as India [2,3]. Agriculture, being the primary source of food, requires a great deal of evolution and technology [2,4]. Hence there is a great need for maximizing the economic potential of agriculture. This can be achieved by improving the cultivation of economically potent crops like saffron.

Saffron is the most expensive crop throughout the world and can be helped to boost the economy of a country to a great extent. Available data shows that the economies of nations such as Afghanistan and Italy have been immensely benefited by saffron cultivation [5,6]. The largest and the best quality saffron-producing area, Herat, has generated more than USD 2.6 billion by increasing the land under saffron cultivation by 21 percent to 6200 hectares [6,7]. The world production of Saffron is estimated to be more than 200 metric tons annually [5,8]. The chief producers of the crop are Iran, Afghanistan, India, Spain, Italy, and Greece [5,9]. However, some countries are experiencing a sudden decline in the production of the crop such as Spain, Italy, Greece, and India [8]. This makes Iran one of the lead producers of the crop, estimated to provide 90 percent of the world's saffron production [8]. The yield and quality of the crop can be increased by monitoring the environmental conditions, which can be easily achieved by using Internet of Things (IoT) sensors [10].

The IoT may be defined as a vast network which allows any things and people to be connected anytime, anywhere, using a service [11,12]. In the last few years, the number of devices encompassing the Internet of Things (IoT) has increased from 0.9 billion things in the year 2008 to 50 billion by the end of the year 2020, making it a part of every application in existence [11,13–15]. The IoT is also used in various smart agriculture solutions. One of the most common methods used for the artificial cultivation of crops is hydroponics [16]. It may be defined as a hydroculture technique that does not rely on soil for cultivation [17]. In this method, nutrient solutions rich in micro and macronutrients are provided to the plant through water [16,17]. Different kinds of hydroponic techniques are present such as the nutrient film technique (NFT), thin-film, drip irrigation, the ebb and flow system, and the continual-flow system, which will be discussed in detail in the later sections [16,18]. There has been a trending decline in the cultivation of saffron due to numerous factors. The production of saffron has decreased to 5.91 tons in 2019, from 9.85 MT in 2011 [19–24]. Saffron is a highly laborious crop, requiring lots of meticulous work and manual operations. The drying of the stigmas also has to be conducted at low temperatures (below 55 °C) to maintain all the benefits [25–27]. Not keeping the basal part of the stigmas intact is what leads to quality compromise. Due to the lack of proper storage houses adjacent to the farms, the crop is not stored as per scientific norms in cool, dark, and dry places, hence leading to adulteration [27–29].

As per the reports from the Agriculture and Revenue Department of Jammu and Kashmir (J and K), India, there is no greater increase in the production of saffron [19]. Comparing the data from the past 10 years, the production can be plotted graphically as shown in Figure 1 [19,22–24].

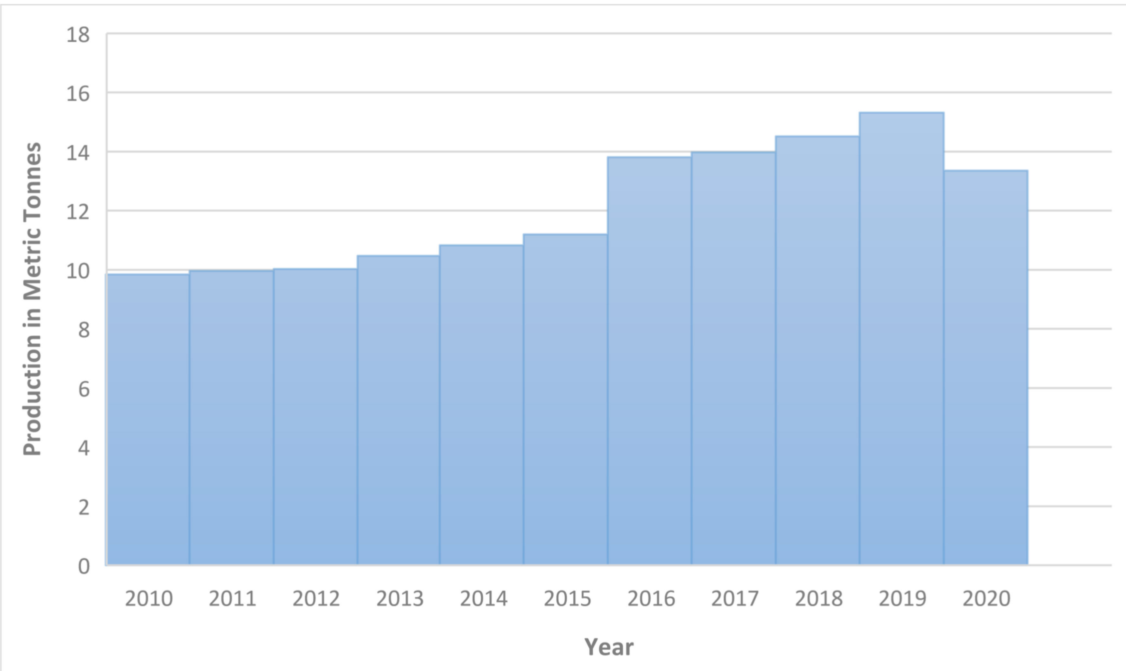

Figure 1. Saffron Production over the years in J and K, India.

The world-wide production of saffron is 200 MT, out of which Iran used to contribute approximately 178 tons [8]. The greater the export, the more the economy of the nation can be benefited. It can be clearly seen in Figure 2 that there is a great need to increase the production and export of saffron so that it can provide greater economic benefits. As shown in Figure 2, the leading producers, and exporters of saffron are Iran, Spain, Afghanistan, Greece, Italy, and India [19,22–24]. The major contributions of this paper are as follows:

- Providing a detailed summary of saffron cultivation and reasons for the decline in yield.
- Comparative analysis of different hydroponic approaches.
- Different artificial approaches used for the cultivation of saffron.
- Smart Hydroponic system for saffron cultivation.

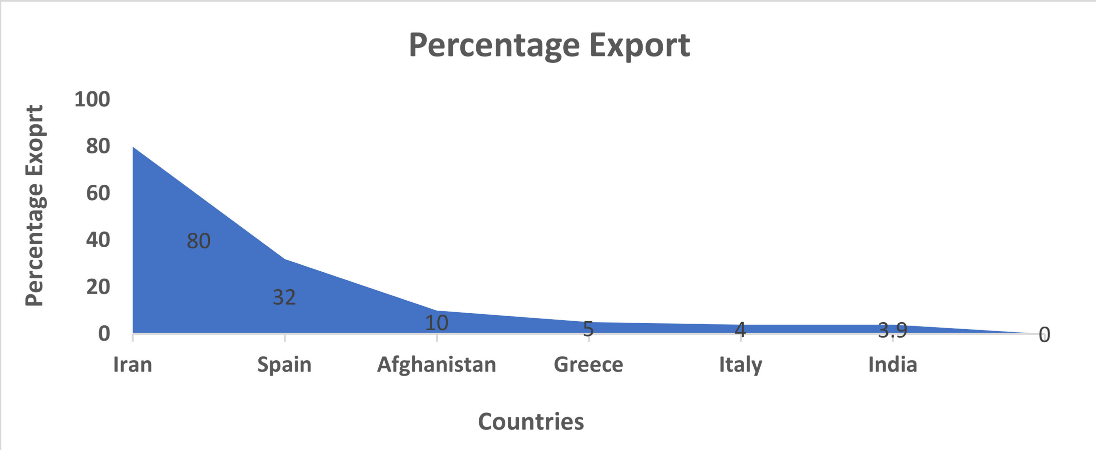

Figure 2. Percentage export of saffron by different countries.

The structuring of contributions in this paper is presented as follows: Section 2 presents various approaches used for saffron cultivation using the IoT and provides a summary of the findings. Section 3 illustrates the research methodology used to select papers from various databases and the process adopted to select the best quality papers. Section 4 outlines important aspects that address various considerations for saffron cultivation using the IoT. Section 5 proposes a smart hydroponic system approach used for saffron cultivation. Section 6 discusses the future scope of the developed hydroponic system with a conclusion.

2. Literature Review

Most of the issues arising in traditional farming methods such as more time consumption, deficiency of nutrients in soil, more space consumption, and the huge manpower requirement, can be easily addressed using artificial methods of cultivation [30]. The IoT, along with other technologies such as Big Data, Machine Learning, and Robotics, can be used in the development of various smart farming techniques which can be helpful in addressing all the issues of traditional crop cultivation [31,32]. Hydroculture is the technique of cultivating plants without using soil as a medium [33]. It is classified into several subtypes, as given in Figure 3 [33–35]. Hydroculture involves growing plants in any medium other than soil, such as clay pebbles, rockwool, or aquatic medium [34]. Various other types of hydroculture techniques, such as aeroponics, involve the use of air as a medium of growth for plants by suspending them in mid-air, while aquaponics involves the use of a complete ecosystem so that the output from aquatic animals can contribute to plant growth. The issue in the use of both of these systems is the cost, space consumption, suitability for selective crops, and one-point failure leading to a complete malfunction of the system [36,37].

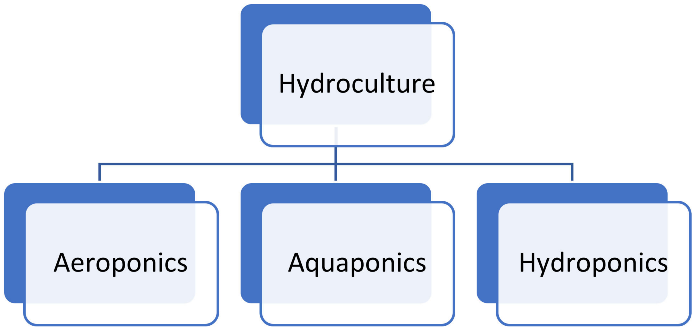

Figure 3. Different Hydroculture Systems.

2.1. Aeroponics

Aeroponics refers to the artificial soilless method of plant cultivation in which plant roots are kept hanging in the air and the nutrients are provided to the plant using sprays through nozzles, either continuously or after fixed intervals [38]. This technique has been widely used in the research of plant physiology and growing plants by NASA; however, it is not as commonly used as hydroponics [38,39]. This method is mostly suited for small vegetable crops, such as cucumber, tomatoes, lettuce, herbs, and medicinal plants, where the roots serve as the end product [39]. The method requires a specially designed room for installation and the maintenance cost is huge [40,41].

Kerns et al., proposed an automated indoor cultivation system using aeroponics using Arduino and different sensors. This system is well-suited for indoor farming in urban areas. Webservices and continuous data monitoring are the important factors controlling this system. The system is user-friendly, without many complex operating procedures [42].

Francis et al., proposed an IoT-based aeroponic system that is pest- and disease-free for healthier plant growth. Various sensors for measuring and controlling temperature, pH, and humidity have been used. The system is placed in an indoor location and the light for photosynthesis is obtained by using LEDs. The nutrient-rich mist is sprayed using a spray jet. Sensor data is continuously collected after regular intervals and monitored. Data from each sensor is collected and analyzed individually [43].

Salazar et al., also proposed an IoT-based aeroponic system with automated irrigation. This system is designed for the arugula plant. Different irrigation cycles are generated by using software-based electronic circuits which work by generating irrigation cycles after fixed intervals in Simulink (MATLAB). Using this approach, the time taken to obtain the yield was considerably reduced to five weeks [44].

Jamhari et al., designed an indoor IoT system for six vegetable plants in an aeroponic environment. The reason for using an aeroponic system was reduced water usage. The system was automatically monitored using the IoT. ADHT11 temperature sensor was connected to a microprocessor and a Wi-Fi module and used for monitoring and maintaining a temperature of 25–30 °C, which is ideal for vegetable growth. Humidity and light intensity were also continuously monitored in the system [45].

Mangaiyarkarasi et al., also reviewed the use of an aeroponic system for the cultivation of horticulture crops such as saffron. The essential nutrients are supplied to the air-suspended roots using spray filming techniques. Light penetration and algae growth is avoided by using a sealed box to promote faster root growth. The nutrient spray duration is also calculated for crops such as tomatoes, cucumber, saffron, lettuce, peas, and onions, etc. [46].

Fallahi et al., also cultivated saffron in a soilless medium using aeroponics. The corms used for plantation were obtained from non-flowering small mother corms in a controlled environment. The impact of the use of corms from a controlled environment was used to study the effect on the yield. The water-holding capacity and nutrient absorption of the roots were increased by using superabsorbent. The new corms obtained after growth had increased weight and mass. Some of the limitations of this method were the production of contractile roots and the drying of aerial parts [47].

Razavizadeh et al., have studied the quality parameters, i.e. crocin, safranal, and picrocrocin, of saffron grown in an aeroponic environment using plant acoustic frequency technology (PAFT) and liquid chromatography and treated corms for growing with high-frequency sound waves. The aeroponic growth chamber monitored and controlled all the factors such as relative humidity, temperature, and light. The results from the experiment concluded that some metabolites show a positive effect on the quality of the saffron [48].

Ebrahimi et al., studied parameters such as the weight, apocarotenoid, safranal, and picrocrocin content of the corms used for sowing on the yield and quality of saffron produced from it in an aeroponic environment. The mother corms were divided into three categories with weights in increasing order. It was observed that there was an increase in the safranal, picrocrocin, apocarotenoid, and the number of flowers per plant with the increase in the weight of the mother corms up to 16 g [49].

Salas et al., aimed to study the aeroponic cultivation of saffron and the features of the nutrient solution used. The cultivation of the plant was carried out at Almeria University using 15 L pots, and the soil replacement medium used was perlite. The parameters studied included the shoot length, corm yield, and nutrient solution concentration in the plants. It was observed that a nutrient intake increase resulted in an increase in production [50].

Eldridge et al., studied the cultivation of saffron in both aeroponic and hydroponic environments and identified the future research areas and research gaps in the aeroponic environment. It was found out in the study that no-matter aeroponics serves as an important vertical farming method, leading to productivity gains and less space consumption, but this generalization is limited to certain crops, mostly vegetables and smaller herbs. In the case of saffron, aeroponic cultivation leads to an increase in corm production and unaltered yield, but an improvement in the quality of petals and an increase in production of flowering patterns have not been reported. It has been concluded that the use of the aeroponic method for root crop cultivation should be conducted only after analyzing the crop variety and parameters related to root morphology and anatomy, such as photoperiod cycles, recycling of roots, microbial impact on roots etc. [51].

The comparison of the above models as per their performance can be seen in Table 1.

Table 1. Comparison of existing aeroponic models.

Ref.	Nature of System	Parameters Used	Advantages	Drawbacks
[42]	Automated aeroponics system using the IoT for smart farming.	Temperature, pH, humidity.	User friendly; no complex operating procedures. Well-suited for indoor farming.	Not fully automated. Costly.
[43]	IoT-based automated aeroponics system.	Temperature, pH, humidity.	Controls temperature and humidity effectively.	Lack of synchronization among all the units. Lacks remote data monitoring.
[44]	Arugula plant cultivation using aeroponic culture with an automated irrigation system.	Temperature, light, pH.	Time taken to obtain the yield was reduced to five weeks.	Showed decrease in leaf and root size.
[45]	IoT system for aeroponic chamber with temperature monitoring.	Humidity, light intensity.	Reduced water consumption. Covers variety of crops.	Parameters such as temperature not considered.
[46]	Aeroponics system for production of horticultural crops.	Light penetration, algae growth.	Water efficient; involves low mineral consumption.	Less space for root expansion.

Table 1. *Cont.*

Ref.	Nature of System	Parameters Used	Advantages	Drawbacks
[47]	Evaluation the possibility of saffron transplanting and corm production in aeroponics.	Corm size.	Increased corm size.	Production of contractile roots;drying of aerial parts.
[48]	Quantification of safranal and other pigments in saffron stigmas using PAFT.	Crocin, safranal, and picrocrocin.	Novel approach to improve saffron quality.	More research in determining the duration of exposure and other factors.
[49]	Effect of corm weight on the yield, growth, pigments and production of corms in saffron aeroponic cultivation.	Weight, apocarotenoid, safranal, and picrocrocin.	Resulted in increase in the weight of mother corms upto 16 g.	No increase in corm size beyond a limit.
[50]	Optimal strength of the nutrient solution for aeroponic cultivation of saffron.	Shoot length, corm yield, and nutrient solution concentration.	Impact of nutrient solution on yield and quality studied.	Components of nutrient solution based on different crops not analyzed.
[51]	Getting to the roots of aeroponic indoor farming.	Root morphology, photoperiod cycles, recycling of roots, microbial impact.	Covers in-depth study on use and conditions for using aeroponic.	Lacks study on important cash crops such as saffron.

2.2. Aquaponics

Aquaponics refers to the combination of animal culture and plant cultivation for the mutual relationship of both. This symbiotic relationship results in water conditioning for aquatic life and oxygenated water recirculation for plants [52,53]. Researchers have designed aeroponic systems based on the monitoring and controlling of different parameters which have been compared in Table 2, highlighting their advantages and limitations.

Table 2. Comparison of existing Aquaponic models.

Ref.	Nature of System	Parameters Used	Advantages	Drawbacks
[54]	Smart aquaponic system based on Internet of Things.	Acidity, water level, temperature.	User friendly and real-time results.	Throughput index lag; decreasing packet loss and delay.
[55]	Towards automated aquaponics: a review on monitoring, IoT, and smart systems.	Temperature, pH, moisture, alkalinity, dissolved oxygen, water hardness, relative humidity, and nitrification.	In-depth technical knowledge about automation and use of IoT in aquaponic systems.	Not implemented yet.
[56]	Smart aquaponics design using Internet of Things technology.	Temperature, light, pH.	Good for small scale applications.	Not implemented for scalable networks.
[57]	Smart aquaponic with monitoring and control system based on the IoT.	Temperature, humidity, soil moisture.	Automatic and manual modes of operation.	Average manual control speed is 5 s.

Ulum et al., proposed a smart aquaponics system using the IoT in which water is allowed to flow after regular intervals. Various parameters such as acidity, water level, temperature, and the feed used for fishes were monitored in real time using a mobile-based application. All the data was collected on the Ubuntu cloud for future use. The sensors used to control the pH, temperature, and other parameters worked fine and gave real-time results [54].

Yanes et al., proposed an automated aquaponic system with efficient use of water and minimal use of pesticides and fertilizers, making use of the Green IoT. The paper also provides a systematic literature review of different sensors used in an aquaponic environment. The system focuses on monitoring and controlling different parameters such as temperature, pH, moisture, alkalinity, dissolved oxygen, water hardness, relative humidity, and nitrification, etc. The system focuses on analyzing each parameter responsible for growth. The paper gave in-depth technical knowledge about automation and the use of the IoT in such systems [55].

Hardyanto et al., proposed a smart aquaponic approach using the IoT in which plants filter out the water for aquatic animals and plants derive nutrition from aquatic animal extracts. The system contains actuators and sensors which monitor and control the chamber using mobile phones. The results of this system show that it is a great fit for small-scale applications [56].

Vernandhes et al., designed a smart aquaponics system that monitors and controls temperature, humidity, soil moisture, etc. using the IoT. The system has two modes of working, automatic and manual, and the average manual control speed is five seconds [57].

2.3. Hydroponics

Hydroponics involves the use of water as a medium for the cultivation of crops. The IoT can be used in hydroponics to control and monitor different agronomical variables, creating a smart environment for the cultivation of saffron. The network of sensors used in the IoT can continuously monitor and control crop health and growth. All the essential macro and micronutrients required for the saffron crop, such as Ca, N, Mg, S, K, P and Cu, Fe, B, Mn, Ni, respectively, are passed to the plant through channels or other mediums [58]. Agronomical variables for growth can be both monitored and controlled by farmers using application interfaces directly connected to the cloud storing real-time data. It also results in the improved quality of crops and eliminates the damage caused by parasites and rodents on crops by the use of controlled environments [59]. Based on the type of medium, hydroponic techniques are classified into several categories as shown in Figure 4 [35].

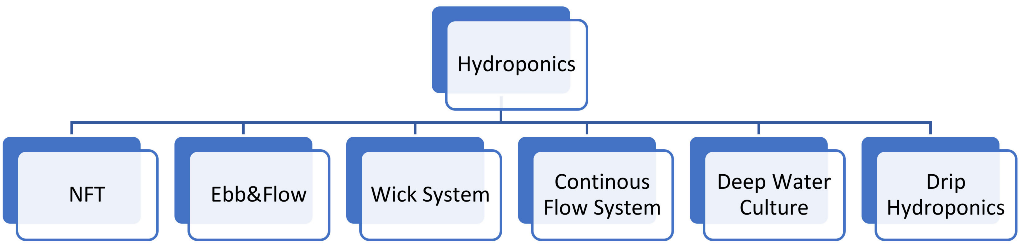

Figure 4. Different Hydroponic Approaches.

The NFT refers to the use of a small channel or tube for the continuous circulation of a nutrient solution through the array of plants. It is an electricity-based system with channels placed at an angle so that nutrients can be moved to higher segments also to facilitate nutrient movement [60–64].

The ebb and flow system uses the concept of flood and drains for the movement of nutrients. An air pump is used to deliver oxygen and nutrients to the roots of plants in cycles and, with the help of a timer, the excessive water is removed for the system to dry out. However, there is a lot of effort involved in the removal of damaged and leftover plants due to the widespread roots of the plants covering the whole tray, hence making it suitable only for the cultivation of small plants [35,62,64].

Drip or trickle hydroponics is an active system that makes use of emitters sprinkling nutrient-rich solution at a very slow speed. It is mostly adopted for commercial hydroponic setups due to the controlled nutrient supply. This system is suitable for the cultivation of larger plants such as onions, melons, strawberries, cucumbers, and peas. The disadvantage of the system lies in its complexity for a small project [62–64].

The wick system is based on the capillary action of roots, and the nutrients from the reservoir reach the plants through wicks. It involves components such as an air pump, reservoir, wick, growing medium, and the plant. It is very easy to set up and requires minimal maintenance. It is suitable for smaller plants such as herbs that do not require much water [62,64].

The continuous flow system also recycles and reuses nutrient-rich water for plant growth. The nutrient solution is continuously passed through a pipe to let the plants absorb the required water for growth [64,65].

Deep/direct water culture is one of the effective hydroponic systems which involves continuous reimbursement of plant roots in a nutrient and oxygen-rich solution. The quantity of water required for this is large in order to maintain nutrient stability. This system requires an air stone and air pump to continuously run to prevent oxygen deficit and the waterlogging of roots. This system is best for the growth of herbs and small plants such as tomatoes, peppers, and lettuces which do not require flowering. This system can be used in scenarios where a maximum yield is the goal, as it accelerates the plant growth rate by double. The limitations of this approach are the possibility of a complete failure due to the failure of the air pump leading to the oxygen starvation of all the plants and the difficulty of maintaining the nutrient concentration of solution [64,66].

Different researchers have designed hydroponic systems based on the monitoring and controlling of different parameters which have been compared in Table 3, highlighting their advantages and limitations.

Table 3. Comparison of existing hydroponic models.

Ref.	Nature of System	Parameters Used	Advantages	Drawbacks
[17]	Automation system hydroponic using smart solar power plant unit.	Temperature, humidity, and pH.	Controls temperature and humidity effectively.	No proper pH monitoring. Lacks proper measurement of nutrients in nutrient tank.
[35]	Hydroponic growth of saffron (ebb and flow vertical system)	Temperature, humidity, oxygen concentration.	Detailed analysis of all the hydroponic approaches present.	Not implemented.
[66]	Hydroponic forcing of saffron.	Light intensity, temperature.	Increased crop yield.	Costly. Flowering in selective plants.
[67]	Saffron by vegetative growth.	All.	The sizes of flowers and stigmas were considerably improved.	Lack of use of technologies. Good flowering in limited plants.
[68]	Growth of saffron in aeroponics and hydroponics.	Temperature, humidity, and pH.	Increased yield. Good quality. Implemented in real time.	Development of contractile roots. Plants not able to get full nutrients due to short roots.
[69]	Internet of Things application for hydroponics plant-monitoring system.	pH, temperature, liquid level, light intensity.	Uses renewable sources of energy.	Considers only a few parameters of growth. Focusses only on monitoring agronomical parameters.

Table 3. *Cont.*

Ref.	Nature of System	Parameters Used	Advantages	Drawbacks
[70]	Smart farm hydroponics system using wireless sensor networks and the Internet of Things.	Temperature, humidity, pH.	Provides monitoring and control of parameters for growth.	Not implemented yet.
[71]	Internet of Things for planting in a smart-farm-hydroponics style.	Temperature, humidity.	Covers vast scope of the IoT in agricultural domains.	Not implemented yet.

The hydroponic system developed by Jurnal et al. [17] aims at improving the energy efficiency of the system. The system is designed to use solar energy for running the hydroponic system. Moreover, the system focuses on controlling and monitoring the parameters of growth in a hydroponic chamber. The prototype designed can control and monitor only a few parameters, such as temperature, humidity, and pH, and is not specifically designed for saffron.

Khan et al. [35] proposed a home-based hydroponic system using ebb and flow for the cultivation of saffron. The authors have come up with a comparison based on the performance and cost of various present hydroponic approaches. The proposed system uses ebb tables, a water controlling system, a fertilizer system, and a ventilation system.

Schroeder et al. [66] used a growth chamber for saffron cultivation by using four different environments, namely organic layer, pin tray, control group, and hydroponic system environments. The vertical hydroponic system developed consisted of LED lighting and temperature regulators. The saffron plants were first cultivated in the field until flowering and then transferred to the growth chamber. Though the crop yield increased, the system incurred high costs. It was also not implemented using the IoT to give better results. Moreover, the authors stated that flowering did not occur in all the plants.

Fallahi et al. [67] explain in their paper that saffron cultivation was increased by using the concept of transplanting the corms which flowered earlier to provide better results. The observations from the experiment indicated that the sizes of the flowers and stigmas were considerably improved.

Souret et al. [68], in their paper, studied saffron cultivation in various environments such as natural, hydroponic, and aeroponics. It was found that the aeroponic and hydroponic approaches yielded better results as compared to the natural. However, the quality of the saffron remained the same in all three cultures. However, there was a reduction in root size in the aeroponic and the hydroponic cultures, which can harm the nutrient and water uptake. Moreover, there was the development of contractile roots, which plays a role in corm lowering.

Hidyanti et al. [69] have designed a hydroponic system as a solution to the decreasing Indonesian agricultural land. The designed hydroponic system focuses on growth parameters such as pH, temperature, liquid level, and light intensity. There is the use of renewable solar energy for power supply. Various monitoring tools were used for analysis.

Boonnam et al. [70] have designed a hydroponic system by using the IoT and a wireless sensor network (WSN). Various important parameters such as light, humidity, and temperature were controlled by using this system. The data obtained from the sensors was continuously sent to the cloud for storage and future use. The parameters were controlled by using a mobile application.

Wongkoon et al. [71] have designed a model using the concept of the greenhouse using WSN. The paper focuses on many areas of agriculture requiring the use of the IoT, such as market availability, geospatial information, and weather prediction, but lacks a real-time implementation of the same.

There are various points of difference between the three hydroponic systems discussed above, which can be shown in tabular form [35,62,64–66]. Tables 4 and 5 present various points of difference between these three hydroponic systems, which can be shown as:

Table 4. Comparison of NFT, ebb and flow, and drip.

NFT	Ebb and Flow	Drip
Nutrient solution is passed through the plants making a film.	Uses flood and drain to deliver nutrients and oxygen to plants.	Continuous nutrient supply using emitters for each plant in different pots.
Water saving.	Uses a lot of water.	Limited water usage.
Single-point failure if pump fails.	Single-point failure.	No single-point failure.
Suitable for medium plants.	Suitable for plants requiring a lot of water for growth such as spinach and lettuce.	Suitable for large gardens having different plants.
Expensive and complex only at beginning.	Complex management due to smaller distance between plants.	Cost friendly and low maintenance for larger projects.

Table 5. Comparison of wick, continuous flow and deep culture.

Wick	Continuous Flow	Deep Culture
Passing nutrient solution to roots using wicks based on capillary action.	Continuous passing of nutrient solution through roots after fixed intervals.	Continuous immersing of plant roots in nutrient solution.
Consumes very little water.	Consumes more water than wick system.	Consumes a lot of water.
No single-point failure.	Single-point failure.	Difficult to maintain nutrient concentration in solution. Single-point failure if air pump or air stone fails.
Ideal for smaller plants with low water requirements.	Ideal for plants having water requirements in intervals.	Suitable for plants requiring lot of water for growth.
Economical.	Costly.	Costly.

2.4. Discussion

The use of any hydroponic technique out of the six listed above depends on several factors, such as root anatomy, plant structure, water requirement, and suitability in a particular environment [51,71]. Considering the water consumption, cost, and anatomical factors of saffron related to root morphology studied from the literature, NFT was considered to be the best practice for the growth of saffron hydroponically [66–69,72]. The most famous hydroculture approach being followed is hydroponics, due to its low cost and having a majority of benefits [36,37,51,72]. Aeroponics is best suited for plants that are small and not propagated by using roots. Tomatoes, lettuce, herbs, celery, and leafy greens are some of the plants cultivated by using aeroponics [38,44,72]. On the other hand, aquaponics is best suited for plants having shallow roots, such as sweet corn, beets, onion, cucumbers, and radishes. Plants that need an uninterrupted water supply are an excellent choice to be grown in such medium [R, S]. Saffron is a plant with a short height, moderate water requirement, and is propagated using roots, hence an excellent choice for cultivating it in an artificial environment is hydroponics [20,22,23,73]. Hydroponics is also widely used and preferred due to its low cost, low water consumption, improved yield, and quality [36,37,73].

3. Research Methodology

In this section, we present a systematic literature review (SLR) method for categorizing various artificial approaches used for saffron cultivation using the IoT for current research. The following studied string words are used to determine important synonyms and keywords of the approaches:

- ("Saffron" OR "Cultivation" OR "IoT" OR "Saffron Cultivation" OR "Hydroponics") We created some technical questions (TQ) based on the scope of the precision farming in saffron cultivation using the SLR method:
- TQ1: What are the primary reasons for saffron decline?

- TQ2: Which existing artificial techniques are used for saffron production?
- TQ3: Which agronomical variables are considered for increasing the yield?

To refine the key research, the addition and removal techniques are employed as paper screening in the final paper selection. Due to the tremendous potential of Web of Science journals, research articles that are indexed in the Web of Science and ISI proceedings with the peer-reviewed process are considered for saffron cultivation in the IoT. Some of the paper's drawbacks are as follows: (1) non-English research articles are not considered in the SLR method and (2) low-quality conferences with fewer than four pages are not considered in the SLR method. Finally, we chose 100 papers to respond to our technical queries. Scientific publishers such as Google Scholar, IEEE, Elsevier, Springer, ACM, and Wiley publish a wide range of research studies each year, as seen in Figure 5. Figure 6 depicts the addition and rejection flowchart for the final selection.

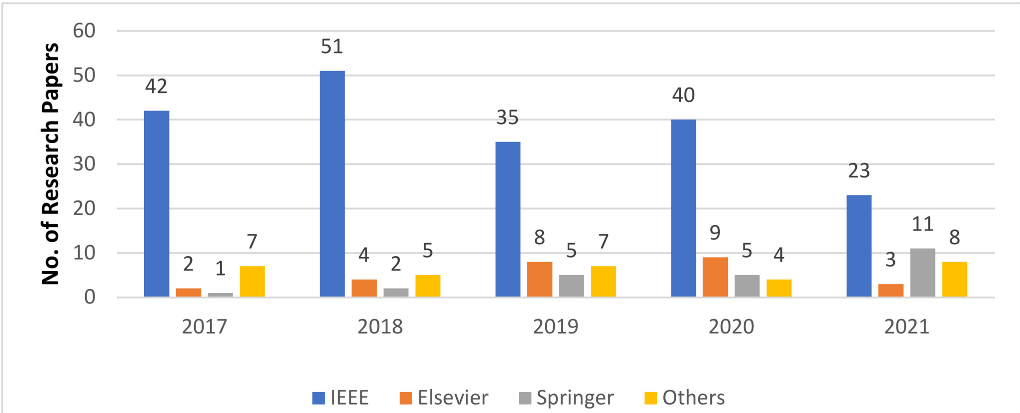

Figure 5. Yearlyresearch paper publications by publishers.

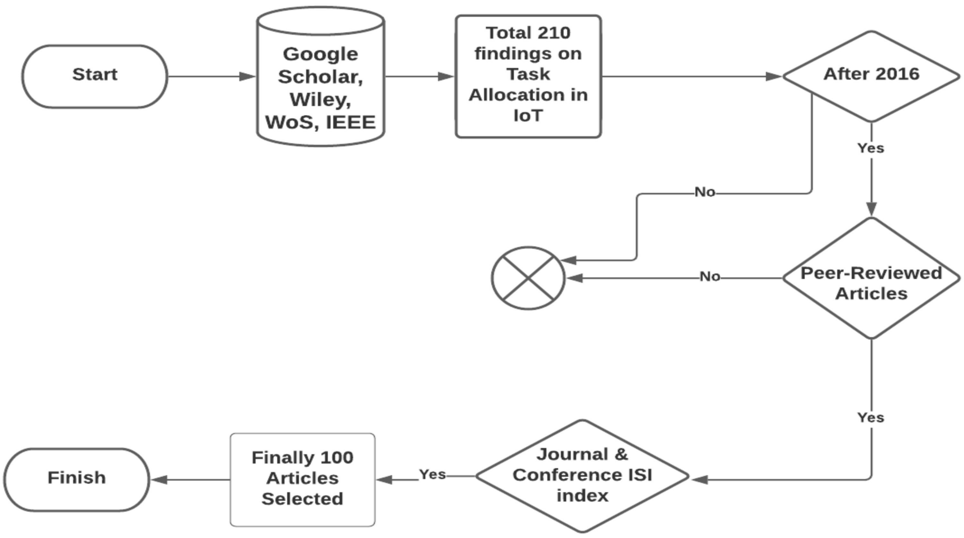

Figure 6. Paper selection procedure.

4. Summary and Discussion

This section shows an analytical examination of the critical factors identified by different researchers and used for saffron cultivation, such as reasons for the decline, artificial techniques used, and agronomical variables considered. The analytical examination and reports are based on the existing TQs in Section 3:

- TQ1: What are the primary reasons for saffron decline?

Figure 7 represents a statistical comparison of various issues related to the saffron decline. In this, we consider five different issues. The non-availability of good quality corms has the highest percentage with 37%, followed by nutrient-deficient soil with 20%, and a lack of efficient post-harvest practices with 18%.

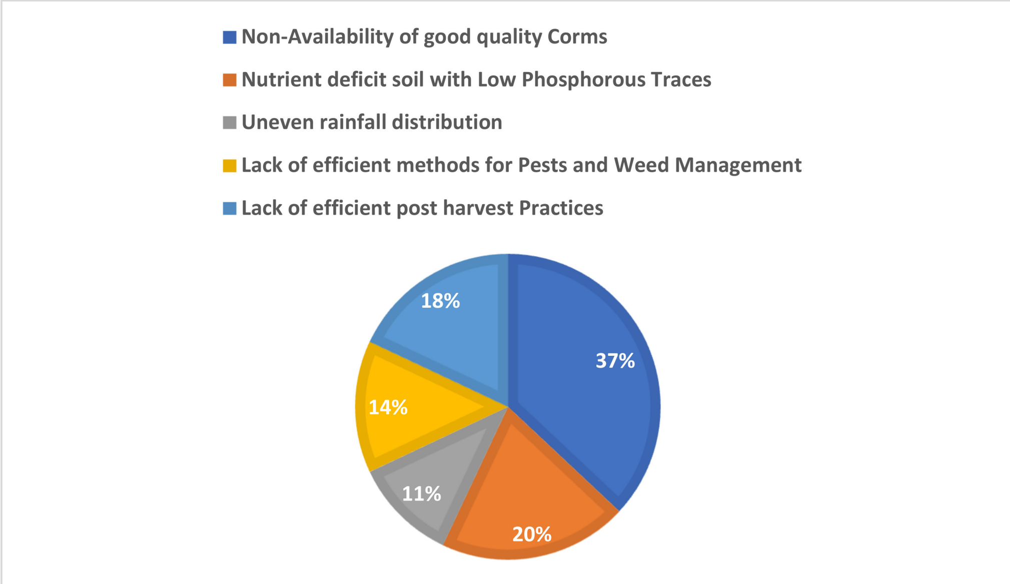

Figure 7. Reasons for saffron decline.

- TQ2: Which existing artificial techniques are used for saffron production?

Figure 8 represents a statistical comparison of various artificial approaches used for saffron cultivation. For this analysis, we considered 22 different research papers studying the use of the IoT for artificial techniques. Out of those, 11 papers were dedicated to hydroponics models, 9 papers to aeroponics, and only 4 papers to aquaponics approach.

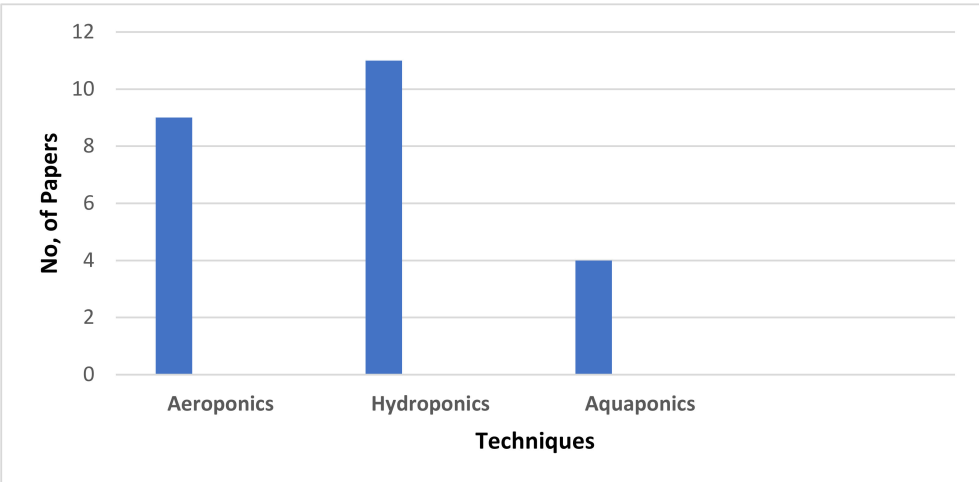

Figure 8. Artificial techniques used for saffron cultivation.

- TQ3: Which agronomical variables are considered for increasing the yield?

In Figure 9, the analytical report on agronomical variables depicts that the temperature parameter is used most in increasing the yield of the saffron with 27%, followed by corm size with 21%, and rainfall with 19%.

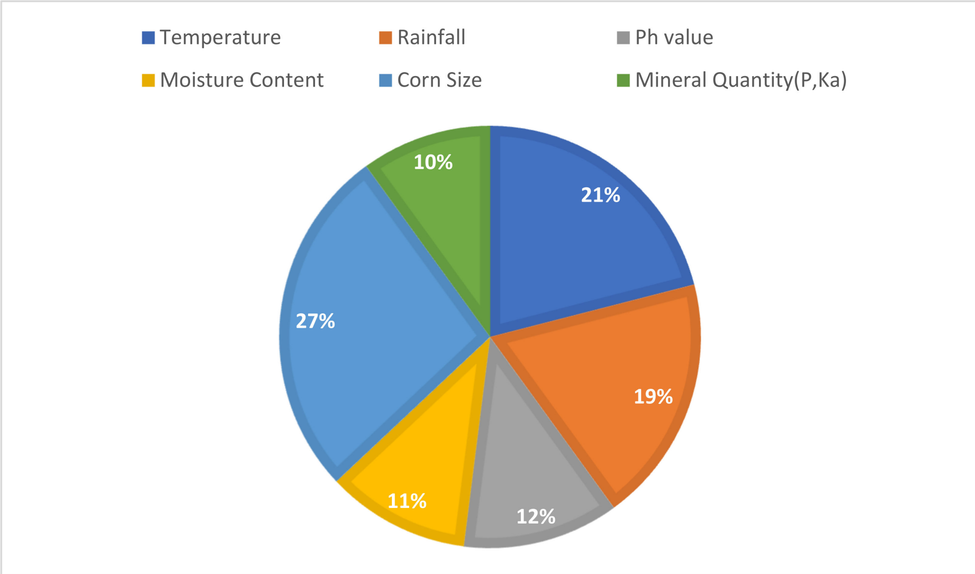

Figure 9. Agronomical variables of saffron as per the priority.

5. Smart Hydroponic System for Saffron Cultivation

The smart hydroponic system as shown in Figure 10 has been proposed after studying all the existing hydroponic systems and analyzing their features and drawbacks. It aims to enhance saffron yield and quality in an artificial medium by using cost-effective and renewable energy sources [17]. The proposed system aims to use renewable sources of energy such as solar and water so that it can work in places with a scarcity of electricity. The hydroponic approach used is NFT due to its reliability and water-recycling capabilities.

The system consists of a smart power supply source, nutrient solution tank, growth chamber, smart corm basket, user interface, and cloud data storage for analysis and future use.

Once the power supply mode is selected automatically, the sensors in the nutrient tank are activated. Different parameters related to the nutrient solution, such as pH, turbidity, temperature, and the concentration of minerals, are continuously sent to the growth chamber, monitored, and shared on the user device as well as the cloud for future use and controlling the parameters. The water stream, rich in the micro and macronutrients required for saffron cultivation, is continuously circulated through the growth chamber. The corms are selected based on their mass and size by the smart basket, which is equipped with load sensors, to maximize the saffron yield and enhance the quality. The corms with weights<2gare discarded as they do not flower at all. Only the corms having weights and diameters>10g are planted [20]. The best quality corms are planted after passing them through a fungicide solution to protect them from fungal infections [22]. The nutrient solution tank is equipped with various sensors, an air pump, and an air stone. The air pump passes the nutrient solution continuously through the growth chamber while the air stone is used to keep the presence of oxygen high in the solution provided. Ultrasonic sensors are used to calculate the desired space between two saffron plants in the growth chamber for plantation [20]. The final stage of cultivation occurs after the flowering of plants and the separation of stigmas from other parts. The obtained stigmas can be dried with 30 percent moisture remaining to maximize the value of the obtained crop.

The working of the system and the process of communication between different units can be clearly explained using a block diagram as shown in Figure 11.

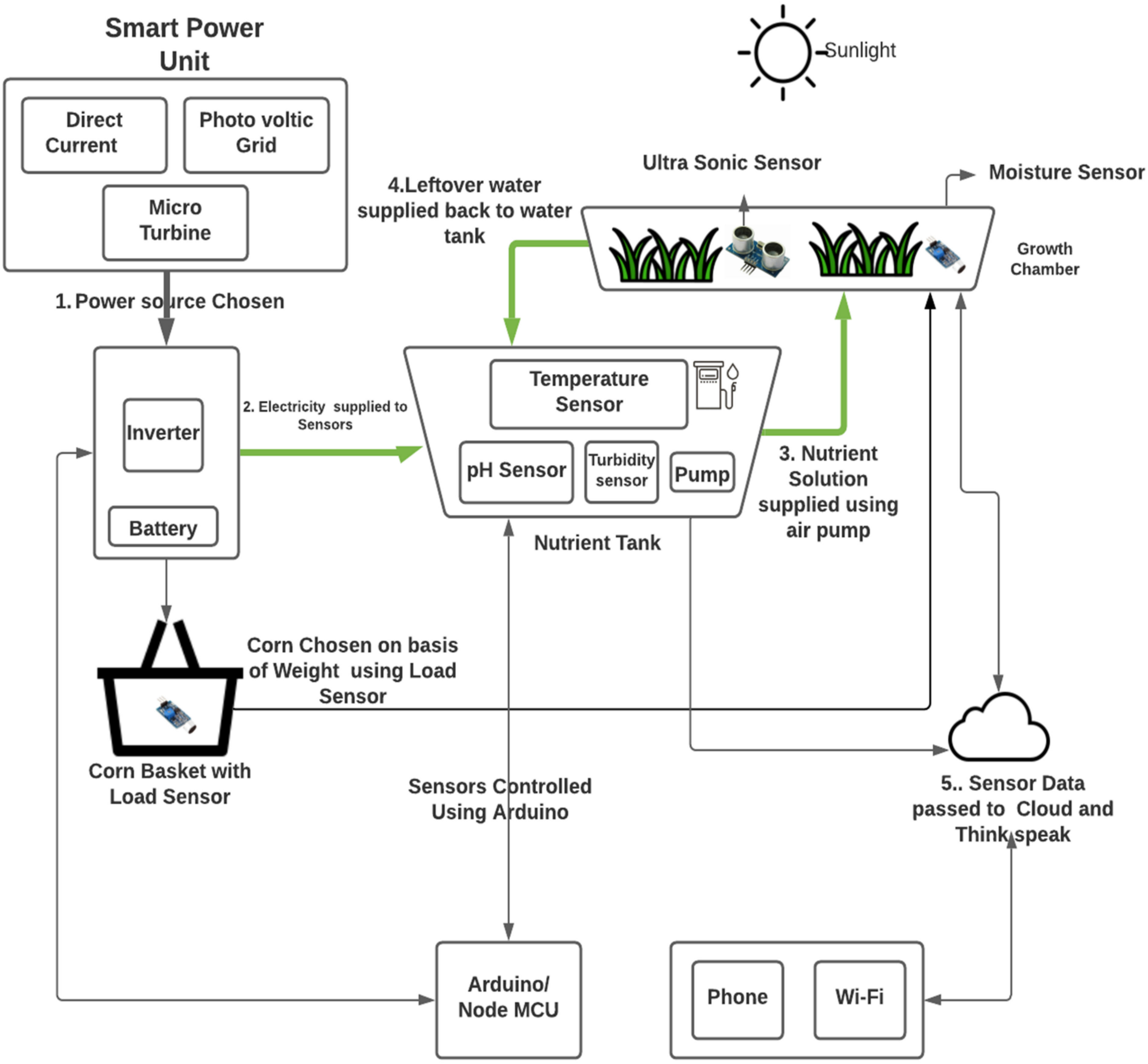

Figure 10. Layout of the smart hydroponic system for saffron cultivation.

The system consists of three components:

Power Unit: Due to the high energy consumption by various sensor devices, there is a great need for the use of renewable sources of energy such as solar energy, wind energy, and hydro energy. This will make the designed hydroponic system more sustainable and cost friendly. The power unit of the system consists of an array of photovoltaic cells, microturbines, a power supply, voltage sensors, controller, relays, and a battery for the storage of energy, so that the system is equipped with all the options of energy consumption and the user can switch between the alternatives using relays and switches. The photovoltaic cell array is used to convert solar energy to electricity, while microturbines help in the generation of hydroelectricity. In case of the absence of both, the power supply can also be used to supply the electricity used. The battery, which will be used for the storage of energy, will be a lithium battery depending on the size of the system, used devices, and the number of sensors deployed, which enables the hydroponic system to run for hours in case of a power failure. The inverter is used for converting DC to AC.

Sensor Unit: It consists of an array of sensors that have been used depending on the controlling and monitoring of various agronomical variables of saffron. The turbidity sensor is used to check the cleanliness of the nutrient solution and detect the presence of any unwanted waste materials in the nutrient solution tank. Gas sensors help to measure the oxygen levels in the growth chamber so that the plants don't suffer a lack of oxygen. Pressure sensors and flow sensors guide the user regarding the flow of the nutrient solution through the growth chamber. Other sensors used include temperature, pH, light, humidity, and load sensors. Load sensors are used to identify the corms suitable in size and mass for cultivation.

Processing and Analyzing Unit: All the sensor data is shared with the microcontroller and Node MCU for analysis. All the parameters of growth can be monitored and controlled by Arduino and Node MCU. Node MCU is an open-source platform that replaces complex application programming interfaces (API) and uses the ESP8266 Wi-Fi module. The ESP8288 module, being very small in size, can sense the data from various sensor nodes wirelessly without any failures [72]. This unit is also connected to the graphical user interface and the Thing Speak platform, which is an online platform for data aggregation and visualization. It provides instant access to the user, and the user can take corresponding actions using mobile apps through their smartphones. The IoT protocols used for the data transfer within the network are CoAP (Constrained Application Protocol) and STOMP (Simple Text Oriented Messaging Protocol). CoAP and STOMP can be used for data transfer in different applications, such as smart healthcare and smart education, due to the security offered wirelessly using other technologies such as artificial intelligence and fuzzy logic [73–86].

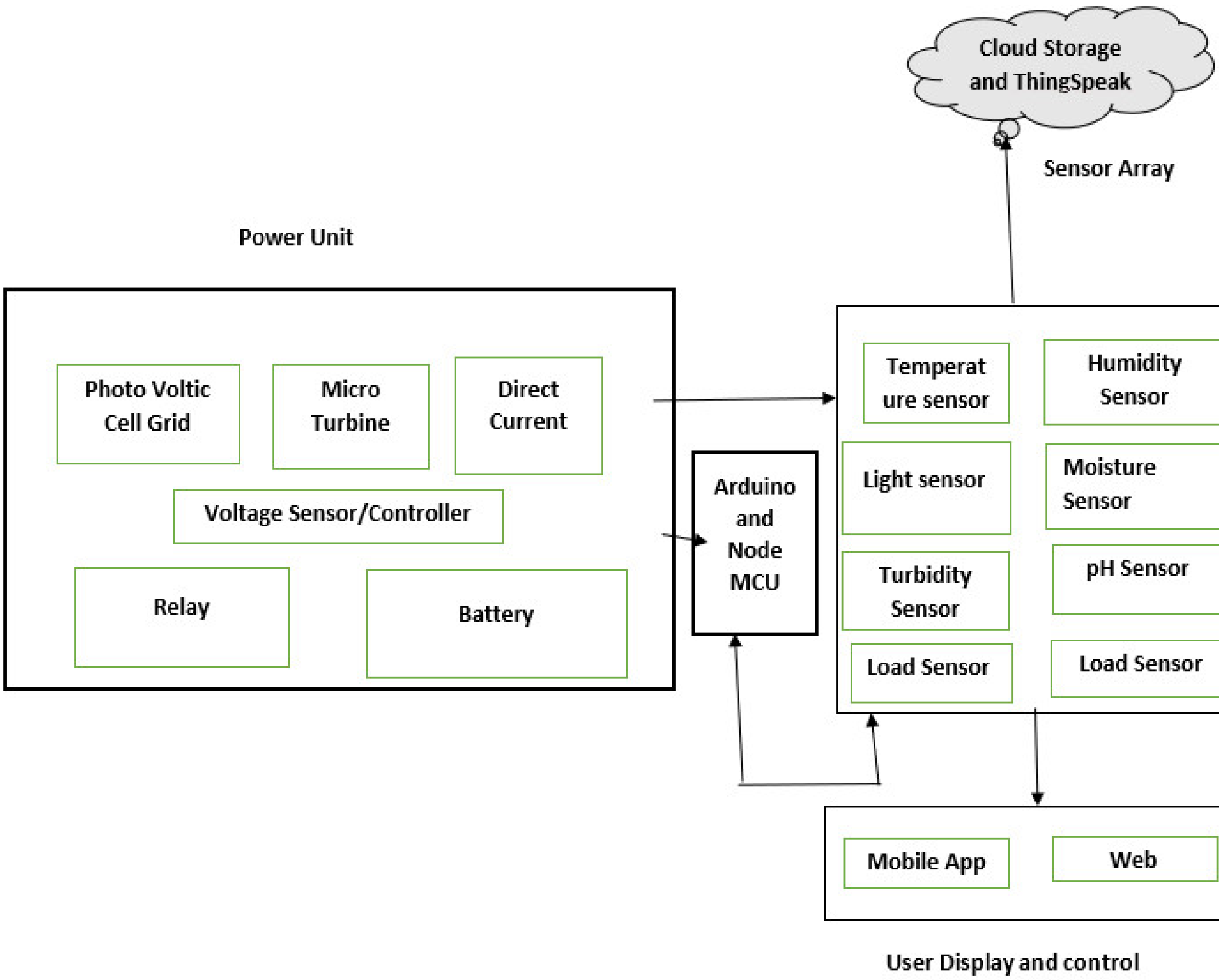

Figure 11. Block diagram of the proposed hydroponic system.

6. Conclusions

This paper focuses on providing a systematic literature review of all the artificial approaches which can be used for saffron cultivation. Various artificial approaches for saffron cultivation were reviewed in general but with a focus primarily on hydroponic approaches. Important issues and the suitability of different approaches in hydroponics were also highlighted along with the major agronomical variables required for saffron growth. Different IoT-based hydroponic models developed by different researchers in this area were studied. The proposed smart hydroponic system for saffron cultivation was also presented. As per the literature review, it was observed that major reasons for the decline in saffron cultivation include the absence of good quality corms, water deficiency, undetected nutrient deficiency, and fungal diseases. It was observed that there was not much research carried out on the use of smart sensors and devices for improving saffron cultivation conditions. Out of various IoT-based models using aeroponics, aquaponics, and hydroponics for the cultivation of saffron,22 models were found to be eligible for comparative study. It was also found that, out of 100 research articles studied, only 25 entirely focused on saffron cultivation. The future scope of this paper will be the implementation of the proposed system.

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