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Research Article

SolarGrowNet: Autonomous Greenhouse Monitoring and Control System for Gerbera

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ABSTRACT

This paper presents the development and implementation of an IoT-based solar-powered greenhouse monitoring system designed to optimize plant growth conditions through real-time monitoring and control. The system integrates a variety of sensors to measure critical environmental parameters such as temperature, humidity, soil moisture, air quality, light intensity, and activity. Actuators including fans, water pumps, and lighting systems are employed to maintain optimal conditions based on sensor data. A IoT based low cost computational module utilized as central processing unit, managing data collection and communication between components. Solar panels provide a sustainable and reliable power source, ensuring uninterrupted operation. The collected data is transmitted wirelessly to a user-friendly web application, enabling remote monitoring and control. Experimental results demonstrate the system's effectiveness in maintaining optimal greenhouse conditions, promoting healthier plant growth, and reducing manual intervention. This sustainable approach underscores the potential of integrating renewable energy sources with IoT technologies in agricultural applications.

Keywords: IoT (Internet of Things), Greenhouse Monitoring, Solar-Powered Systems, Environmental Sensors, Real-Time Monitoring, Microcontroller, Automated Control, ThingSpeak

I. INTRODUCTION

Gerbera, scientifically known as *Gerbera jamesonii*, is a popular ornamental plant originating from South Africa, Asia, and South America. It belongs to the *Asteraceae* family and is cultivated worldwide for its bright and vibrant flowers. Gerberas are typically grown through micropropagation, a method that uses a nutrient medium to produce large quantities of plants with consistent characteristics. The plants produce flowers after **7-8 weeks** of planting, and with careful management, they can yield an average of **130-140 flowers per square meter**. Gerberas are usually planted in **September and October**, and are widely valued not only for their aesthetic appeal but also for their environmental benefits, as they produce oxygen and consume CO2, making them ideal plants to keep in bedrooms to enhance sleep quality.

Gerbera flowers come in several varieties, categorized based on their petal arrangement and appearance. The major types include single-flowered, double-flowered, crested double, and full crested double Gerberas. Hybrid varieties are frequently developed to improve traits like flower color, size, and vase life, catering to both the domestic and international markets.

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From maintaining the right temperature, humidity, and light conditions to ensuring proper air circulation, greenhouses enable Gerberas to thrive. Additionally, they play a crucial role during the hardening stage, where plants are gradually acclimatized to outdoor conditions before being transferred from controlled laboratory settings. The hardening process typically lasts around 8 weeks, ensuring the plants are strong enough to survive in natural environments.

India plays a significant role in the global Gerbera industry, exporting 20-25% of its total production along with countries such as the Netherlands, China, Europe, Turkey, and Italy. The Netherlands, exporting over 40% of the world's Gerberas is largest export country. Globally, the top three exporters of Gerbera Flower are Netherlands, India, and China. Most of the Gerbera Flower exports from the World go to the Ukraine, Kazakhstan, and Russia. And most of the Gerbera Flower exports from India go to the Maldives, United Arab Emirates and Oman. Within India, Maharashtra leads Gerbera production, contributing nearly 40% of the total export revenue. Gerbera exports provide substantial economic benefits, with millions of dollars earned annually, contributing significantly to the livelihoods of local farmers and vendors.

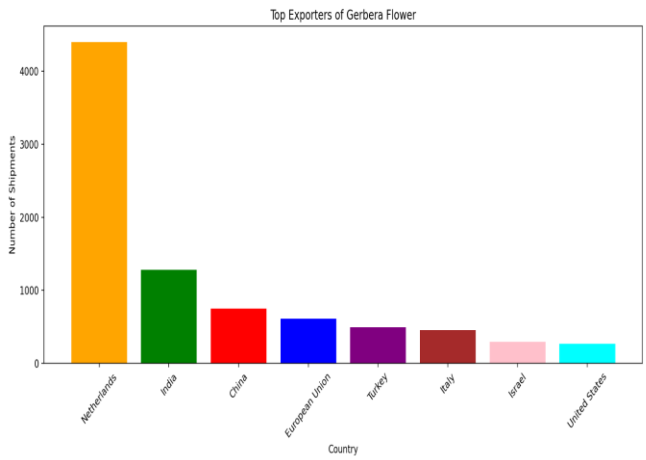

Fig. 1. Graph of Top Exporters of Gerbera Worldwide

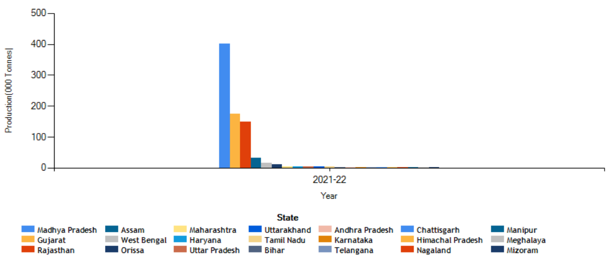

Fig. 2. Graph of Statewise Export of Gerbera

Indian Production of Gerbera

Production(000 Tonnes)

		2021-22	
Sr No.	State	Production	Share(%)
1	Madhya Pradesh	401.52	49.51
2	Gujarat	175.00	21.58
3	Rajasthan	148.70	18.33
4	Assam	31.99	3.94
5	West Bengal	15.37	1.90
6	Orissa	10.85	1.34
7	Maharashtra	4.88	0.60
8	Haryana	4.70	0.58
9	Uttar Pradesh	4.58	0.56
10	Uttarakhand	4.00	0.49
	Page Total	801.59	

Fig. 3. Statewise Production of Gerbera in percentage

In addition to its thriving Gerbera export, India imports most of its greenhouse materials from China, the Netherlands, and Germany. Globally, the top three importers of greenhouse materials are the United States, Russia, and Ukraine. The United States leads with 6,035 shipments, followed by Russia with 1,864 shipments, and Ukraine with 1,492 shipments.

There are many Bio plants across the country, even many of the largest tissue culture facility now available in many cities. They also having large-scale production process and the advanced technologies utilize to maintain the quality of their plants.

Many Indian bio-plants exports to over 35 countries and specializes in tissue culture plants such as Gerbera, Gypsophila, and Phalaenopsis. The facility operates on 17 acres, with five labs producing over 10 crore plants, and utilizes greenhouses equipped with advanced cooling systems, automated shading, and manual irrigation to maintain ideal growing conditions. The hardening process in these greenhouses lasts approximately 8 weeks before the plants are ready for export, with a minimal plant mortality rate of 3% during this stage.

In Indian bio-plants, like many large-scale greenhouse operations, relies heavily, up to 80%, on electricity to maintain optimal growing conditions. Any power outage necessitate the use of diesel-powered generators, which not only increase operational costs but also contribute to pollution. This reliance on imported equipment and diesel generators underscores the challenges faced by such facilities in managing their production expenses and environmental impact. Also, during our visit, it was found that their greenhouse materials and lab equipment were imported too, which are considerably expensive due to additional import taxes. The reliance on imported materials adds to the operational costs, impacting the overall production expenses.

During the visits to many Bioplants' clients, It is observed how the plants are cared for after being received from the greenhouse. The nursery uses drip irrigation, sprinklers, and fans to ensure the plants remain fresh and nourished until they are sold.

This paper focused on an Autonomous Greenhouse Monitoring and Control System, aims to address these challenges by offering a more cost-effective solution that reduces reliance on expensive imports, minimizes pollution and facilitates greater export from the country along with benefit of the local farmers. By utilizing IoT technology for real-time monitoring and environmental control, this system can enhance energy efficiency, reduce operational costs, and limit the environmental footprint. It also represents a significant step toward self-sufficiency in greenhouse management, reducing the need for imported materials and costly backup power systems.

The system's ability to provide affordable and efficient greenhouse solutions can benefit local farmers, vendors, and small greenhouses, empowering them to increase their productivity and income. With automation reducing manual intervention, and sensors optimizing plant growth conditions, this technology can boost Gerbera production while improving the quality of life for those working in the industry.

II. LITERATURE SURVEY

The integration of the Internet of Things (IoT) into greenhouse monitoring and control systems has been explored extensively in recent research. The increasing urbanization and the reduction of available agricultural land have necessitated innovations that can enhance crop production efficiency while minimizing resource use. The literature reveals several approaches and methodologies aimed at optimizing greenhouse conditions through automated and remote monitoring systems.

The Android based Greenhouse Monitoring and Controlling System article presents an monitoring and controlling system designed to address the need for efficient management of greenhouse environments in agricultural settings. The system uses embedded technology to monitor and control indoor humidity and weather conditions affecting plant growth. It employs various sensors (temperature, light, moisture, and humidity) connected to a microcontroller, which communicates with an Android smartphone via Bluetooth. The methodology involves sensors collecting environmental data, the microcontroller processing it, and an Android application providing a user interface for monitoring and control. While innovative, the system's reliance on Bluetooth limits its range to about 10 meters, restricting remote access. Additionally, the paper lacks a detailed evaluation of the system's performance and energy efficiency. Future improvements could include incorporating Wi-Fi or cellular connectivity for extended range, adding more sensors for comprehensive monitoring, and implementing data logging and analysis features for long-term trend analysis.[1]

The research paper title design and prototype development of Internet of Things (IoT) for greenhouse monitoring system presents an IoT based greenhouse monitoring system designed to optimize food crop production. The system utilizes various sensors to collect environmental data such as temperature, humidity, soil temperature, soil moisture, and light intensity. The methodology involves sensors collecting data every minute, which is then transmitted to a Raspberry Pi gateway via Wi-Fi using the MQTT protocol. The gateway stores data in a SQLite database and displays it in real-time through a Node-RED dashboard. The system operates on a local network, allowing for wider area monitoring. Testing over seven days showed a 99.76% success rate in data storage. While innovative, the system lacks automated control features, such as automatic watering based on soil moisture levels. Additionally, the paper does not address scalability for multiple greenhouses or include data analysis features for long-term trend identification. Future developments could include connecting the system to a public network for remote access and implementing predictive analytics for crop management.[2]

The greenhouse monitoring and control using IoT research paper presents a comprehensive IoT-based system for greenhouse monitoring and control, aimed at optimizing plant growth under variable climatic conditions. Utilizing the ESP-WROOM 32 Wi-Fi microcontroller, the system integrates sensors for temperature, humidity, soil moisture, motion detection, and air quality. These sensors transmit data to the cloud, allowing remote monitoring and automated environmental adjustments. However, the paper could benefit from including more advanced machine learning techniques for predictive analysis and integrating renewable energy sources for sustainability. Further work could also explore large-scale applications and more diverse crop types.[3]

The design of intelligent greenhouse control system based on IoT research paper presents an intelligent greenhouse control system based on the Internet of Things (IoT), utilizing LORA wireless technology for real-time data collection and remote management of greenhouse environments. The system collects various environmental parameters such as temperature, humidity, and light intensity, and allows for both automatic and manual control of greenhouse equipment. The final methodology involves the integration of monitoring nodes with a central gateway for data processing and control. However, the paper

be improved by incorporating more advanced predictive analytics and energy-efficient solutions to enhance system sustainability and scalability.[4]

The green house monitoring and controlling using android mobile application research paper outlines a greenhouse monitoring and control system that leverages an Android mobile application to manage humidity levels within a greenhouse. Utilizing an Arduino Uno microcontroller, SHT 11 humidity sensor, and Wi-Fi communication, the system monitors and adjusts environmental conditions by controlling devices like water sprayers and rooftop mechanisms. The methodology involves real-time data transmission from sensors to a server, which then interfaces with an Android app for user control. However, the system is limited by its reliance on basic sensor data without advanced predictive capabilities or integration of other environmental factors, which could enhance its functionality. Adding such features could improve the system's overall efficiency and adaptability.[5]

This automated greenhouse monitoring and Controlling system using sensors and solar power article proposes an automated greenhouse monitoring and controlling system using various sensors, Arduino Uno, and solar power. The system incorporates temup8yperature, humidity, light, and soil moisture sensors to collect environmental data inside the greenhouse. An Arduino Uno microcontroller processes the sensor data and controls actuators like fans and lights to maintain optimal conditions. The system uses a GSM module to send sensor readings to the farmer's mobile phone via SMS. A key feature is the use of solar power with a rechargeable battery to ensure continuous operation. The authors compare their proposed system to recent related works and find it to be cost-effective and efficient in analyzing major environmental parameters. However, the system is limited to monitoring only a few basic parameters. Adding more sensors to measure factors like CO2 levels could provide more comprehensive greenhouse monitoring and control.[6]

This designing an intelligent greenhouse monitoring system based on the IoT paper presents the design of an intelligent greenhouse monitoring system based on Internet of Things (IoT) technology. The authors propose a system that uses wireless sensor networks and IoT to collect real-time environmental data in greenhouses, including temperature, humidity, CO2 levels, and light intensity. A fuzzy adaptive PID control algorithm is developed to regulate the greenhouse environment. The system architecture integrates sensors, Zigbee wireless networks, and cloud computing.

The methodology involves modeling the greenhouse environment mathematically in MATLAB and simulating the fuzzy PID controller. Experimental results show the system can maintain temperature within 16.5-23°C and humidity within 68.2-89.3% RH. The fuzzy PID controller outperformed conventional PID and fuzzy-only approaches.

While comprehensive, the study is limited to simulations and short-term experiments. Longer-term field testing in actual greenhouses would strengthen the findings. The economic feasibility and cost-benefit analysis of implementing such a system at scale is not addressed.[7]

The article monitoring and controlling device for smart greenhouse by using Thinger.io IoT server paper presents an IoT-based smart greenhouse monitoring and control system using the Thinger.io cloud platform. The system aims to create optimal conditions for plant growth by monitoring and controlling environmental factors like temperature, humidity, and light intensity. It utilizes an Arduino UNO for sensor data acquisition and control, a NodeMCU for internet connectivity, and various sensors and actuators. The system allows both automatic and manual control modes, with data viewable remotely via a web interface.

The methodology involves using DHT11 for temperature/humidity sensing, an LDR for light sensing, and controlling fans, pumps and lights based on sensor readings. The NodeMCU connects to Wi-Fi and interfaces with the Thinger.io cloud to enable remote monitoring and control.

While functional, the system is limited in scope, focusing only on basic environmental parameters. It could be enhanced by incorporating additional sensors for factors like soil moisture and CO2 levels. The use of a more robust microcontroller and implementation of data analytics or machine learning algorithms could further optimize the greenhouse environment for specific crops.[8]

Low cost greenhouse monitoring system based on IoT article elaborates a low-cost IoT-based greenhouse monitoring system designed to help small-scale farmers manage environmental conditions efficiently. The system uses an ESP32 microcontroller along with sensors like SEN-0193 for soil moisture and DHT-22 for temperature and humidity, uploading data to Google Firebase for remote monitoring. The final methodology involves using conditional programming to control actuators such as water pumps, fans, and heaters based on sensor data. While the system is affordable and effective for small setups, the paper could have expanded on its limitations, such as the lack of advanced control algorithms (e.g., PID or Fuzzy Logic) and the potential need for additional sensors to monitor other crucial parameters like CO2 levels, which are critical for optimizing plant growth.[9]

In intelligent greenhouse monitoring and automation using Arduino provides a comprehensive review of greenhouse monitoring and automation using Arduino microcontrollers and Internet of Things (IoT) technologies for precision farming. The authors discuss how protected cultivation in greenhouses allows for environmental control to optimize crop growth. They examine various sensors used to monitor parameters like temperature, humidity, and soil moisture, as well as wireless communication protocols like Bluetooth, ZigBee, and Wi-Fi for data transmission. The paper outlines a general IoT greenhouse system architecture involving sensor data acquisition, server processing, cloud storage, and user monitoring/control via internet-connected devices.

The methodology involves reviewing and synthesizing existing literature on Arduino-based monitoring systems, IoT applications in agriculture, and precision farming techniques. Key limitations include the lack of original experimental work or case studies to validate the proposed approaches. The paper could be strengthened by including more quantitative data on the performance and cost-effectiveness of IoT greenhouse systems compared to traditional methods. Additionally, discussion of data security and privacy concerns in IoT agricultural applications is minimal. Overall, the review provides a useful overview of technologies enabling smart greenhouses, but would benefit from more critical analysis of implementation challenges.[10]

IoT-enabled greenhouse systems: optimizing plant growth and efficiency paper describe the integration of IoT technology in greenhouse systems to optimize plant growth and efficiency. The authors propose an advanced greenhouse monitoring and control system using NodeMCU, various sensors (soil moisture, temperature, humidity, light), and MQTT protocol for communication. The methodology involves a comprehensive setup with a Raspberry Pi as the central hub, Node-RED for data processing, and a user-friendly dashboard for remote monitoring and control. The system aims to provide real-time environmental data and automate irrigation based on soil moisture levels. While the project successfully demonstrates the potential of IoT in agriculture, it has limitations in terms of internet dependency and power reliability. Future improvements could include incorporating additional sensors (e.g., nutrient, pH) and exploring energy-efficient solutions to enhance the system's robustness and versatility in various agricultural settings.[11]

Agricultural crop monitoring using IoT paper provides an overview of using Internet of Things (IoT) technology for agricultural crop monitoring. The authors review various systems that utilize wireless sensor networks, microcontrollers, and IoT devices to monitor environmental conditions like soil moisture, temperature, and crop growth. Key approaches include using ZigBee-based wireless sensors, automated irrigation systems, and remote monitoring via web/mobile applications. The final methodology involves deploying sensor nodes in fields to collect data, transmitting it wirelessly to a central system, and providing farmers with real-time information and automated controls. While the paper covers a range of IoT applications in agriculture, it lacks in-depth analysis of data security concerns and scalability challenges for large-scale deployments. Additionally, more discussion on machine learning integration for predictive analytics could enhance the review. Overall, it provides a solid foundation on IoT in agriculture but has room to explore more advanced aspects.[12]

Intelligent greenhouse management system paper proposes an Intelligent Greenhouse Management System using Internet of Things (IoT) technology to monitor and control agricultural conditions. The system aims to improve crop quality and quantity by allowing farm owners to monitor and control their greenhouses remotely via a smartphone application. The authors review various existing systems that use wireless sensor networks and IoT for agricultural monitoring. The final methodology involves deploying sensors for temperature, humidity, soil moisture, and light in a greenhouse, connected to an Arduino microcontroller and WiFi module. The system operates in both automatic and manual modes, allowing for real-time monitoring and control of environmental conditions. While the paper presents a functional prototype, it lacks a detailed analysis of the system's scalability and long-term reliability. Additionally, the research could benefit from a more comprehensive evaluation of energy efficiency and a cost-benefit analysis for practical implementation.[13]

Smart crop cultivation monitoring system by using IoT paper proposes a smart crop cultivation monitoring system using IoT technology to assist farmers in monitoring soil moisture, temperature, and humidity in real-time. The system utilizes NodeMCU ESP8266, various sensors, and cloud computing to collect data and control irrigation. The researchers compared their proposed method against traditional farming and timer-based irrigation in a greenhouse melon cultivation experiment. Results showed the IoT-based system outperformed the other methods in plant growth rate (41.2% better than traditional), productivity (70% higher than traditional), and water savings (20.9% more efficient than traditional). While the system demonstrates clear benefits, it is limited to a single crop type and relatively small-scale implementation. Future work could explore its applicability to diverse crops, larger farm sizes, and integration with other smart farming technologies like predictive analytics or machine learning for optimized crop management.[14]

The IoT based monitoring system in smart agriculture article presents an IoT-based monitoring system for smart agriculture, focusing on improving crop yield by monitoring environmental factors such as temperature and humidity using sensors. The methodology involves using a CC3200 single-chip microcontroller, interfaced with a camera to capture images and send them to the farmer's mobile via Wi-Fi. Despite its effectiveness in providing real-time data and reducing human effort, the paper could enhance its approach by integrating modern irrigation techniques and renewable energy sources, such as solar power, to further improve system efficiency and sustainability.[15]

The Development of an IoT based smart greenhouse research article addresses the critical role of agriculture in ensuring food security and its vulnerability to climate change. The authors propose an IoT-based solution to optimize greenhouse farming by monitoring and controlling environmental factors such as temperature, humidity, soil moisture, and light intensity using sensors like DHT11, resistive moisture sensors, and LDR. Data is managed through cloud-based storage and a mobile application for real-time updates. However, the study's limitation lies in its focus on the technical implementation without detailed analysis of the system's scalability or cost-effectiveness, which could be critical for broader adoption. Further research could explore these aspects to enhance the applicability of the proposed system.[16]

IOT based greenhouse monitoring and controlling system research paper explores the integration of IoT technologies to enhance agricultural productivity through remote monitoring and control of greenhouse environments. The study utilizes sensors for temperature, humidity, soil moisture, and light intensity, managed by a NodeMCU ESP8266 microcontroller, and monitors conditions via the Blynk application. The methodology effectively allows for real-time environmental adjustments, but the system could benefit from scalability improvements, such as integrating multi-controller capabilities for managing multiple greenhouses simultaneously. Further development could also include more advanced data analytics to optimize resource usage and crop yield.[17]

The research article Solar powered greenhouse monitoring using IoT presents a system that integrates IoT and solar energy to automate the monitoring and control of greenhouse environments. The study employs sensors like DHT11 for temperature and humidity, and YL69 for soil moisture, managed by an Arduino microcontroller. The data is stored in a cloud database (ThingSpeak) and can be accessed via a web interface. While the system efficiently automates environmental control, it could be improved by including more comprehensive studies on the interaction between internal and external environmental factors, and the varying needs of different crops. This would enhance the system's adaptability across diverse agricultural conditions.[18]

Smart automated farming system using IoT and solar panel research article explains an automated farming system using IoT and solar power to address various challenges in agriculture. The system incorporates sensors to monitor parameters like soil moisture, humidity, temperature, light intensity, and detect intruders or fires. It uses a Wi-Fi module to transmit real-time data that can be accessed remotely via the internet. The methodology involves developing hardware with various sensors and a microcontroller, creating an IoT interface for monitoring and control, and powering the system with solar energy. Key features include automated irrigation, climate control for sophisticated crops, and alert systems. While comprehensive, the system could benefit from additional sensors like gas detectors. The paper demonstrates the feasibility of the approach through prototype testing, but lacks extensive field trials or economic analysis. Overall, it presents a promising low-cost solution for smart farming, though further validation in real-world conditions would strengthen the findings.[19]

Solar powered smart greenhouse environment monitoring by using IoT paper proposes a solar-powered smart greenhouse monitoring system using IoT technology. The abstract outlines a system that uses sensors to monitor environmental parameters like temperature, humidity, soil moisture, and light intensity in greenhouses. The methodology involves using an ATmega328 microcontroller interfaced with various sensors, an ESP8266 Wi-Fi module for IoT connectivity, and a solar panel for power. The system automatically controls irrigation, cooling fans, and sliding windows based on sensor readings. Data is stored in a cloud database (ThingSpeak) and displayed on a webpage for remote monitoring. While the system offers automated control and remote access, it lacks advanced features like predictive analytics or machine learning algorithms for optimizing plant growth. Additionally, the paper does not discuss scalability for larger greenhouse operations or integration with other smart farming technologies. Further research could explore incorporating artificial intelligence for more precise environmental control and crop management.[20]

III. METHODOLOGY

Many greenhouses uses high amount of electricity which results in increased electricity costs and Generators are used as a back up to supply electricity, causing a lot of air pollution and this factor makes our project stand out from the rest. So, usage of solar energy as a power supply to our greenhouse functioning to reduce such heavy use of electricity, the air pollution and electricity cost. Thus the working on a plant of Gerbera flower species. So, its observed the growth of that plant from the first stage to the last stage, it is observed that different growth parameters like air quality, light source handling, monthly humidity, and temperature level checking.

Stage 1 - Seed Germination

The duration of stage-I with parameters explain in Table 3.1, is around one to two weeks approximately. The parameters are maintain throughout the these period according to Table 3.1 for the seed absorbs water and swells, breaking through its outer shell. The radicle (first root) emerges, followed by the cotyledons. Optimal conditions: a warm, moist environment with good air circulation and indirect light.

Table 3.1 Stage-I Parameters

Parameters	**Value Range**
Temperature	18-25°C (64-77°F) (day) / 16-18°C (61-64°F) (night)
Humidity	65-75%
Soil Moisture	Keep soil slightly moist, not saturated
Light Intensity	25,000-40,000 lux
Air Quality	Well-ventilated, maintain air circulation

Stage 2 - Seedling Stage

The duration of stage-II with parameters explain in Table 3.2, is around four to six weeks approximately. The parameters are maintain throughout the these period according to Table 3.2 to develop small, true leaves to begin develop after the cotyledons. The plant starts to photosynthesize, relying less on stored nutrients and more on sunlight and nutrients from the soil. The root system begins to establish itself.

Table 3.2 Stage-II Parameters

Parameters	**Value Range**
Temperature	18-22°C (64-72°F)
Humidity	70-85%
Soil Moisture	Moist but well-drained
Light Intensity	15,000-25,000 lux (moderate)
Air Quality	Good ventilation, low CO_2

Stage 3 - Vegetative Growth

The duration of stage-III with parameters explain in Table 3.3, is around two to three weeks approximately. The parameters are maintain throughout the these period according to Table 3.3 for the plant focuses on growing more leaves and developing a robust root system. At this stage, Gerbera plants are producing energy, which will later be used for flowering.

Table 3.3 Stage-III Parameters

Parameters	Value Range
Temperature	around 20-25°C or 68-77°F
Humidity	70-85% (reduce slightly from germination)
Soil Moisture	Consistently moist, not waterlogged
Light Intensity	10,000-15,000 lux (low to moderate)
Air Quality	High oxygen, low CO2

Stage 4 - Bud Formation (Reproductive Stage)

The duration of stage-IV with parameters explain in Table 3.4, is around seven to eight weeks approximately. The parameters are maintain throughout the these period according to Table 3.4 for the plants to shifts from vegetative growth to reproductive growth. Flower buds begin to form at the centre of the leaf rosettes.

Table 3.4 Stage-IV Parameters

Parameters	Value Range
Temperature	20-25°C (68-77°F)
Humidity	60-70% (optimal for flowering)
Soil Moisture	Moderately moist, avoid water stress
Light Intensity	35,000-50,000 lux (high)
Air Quality	Good Air circulation, low CO2

Stage 5 - Flowering

The duration of stage-V with parameters explain in Table 3.5, is over the months approximately. The parameters are maintain throughout the these period according to Table 3.5 to open flowers fully, displaying the characteristic vibrant Gerbera daisy blooms. Pollination can occur at this stage, facilitated by insects like bees or manual methods in controlled environments.

Parameters	Value Range
Temperature	20-25°C (68-77°F)
Humidity	55-65% (lower humidity to prevent disease)

Soil Moisture	Moderately moist, well-drained
Light Intensity	30,000-50,000 lux (high)
Air Quality	Maintain clean air, good CO2 balance

Block Diagram

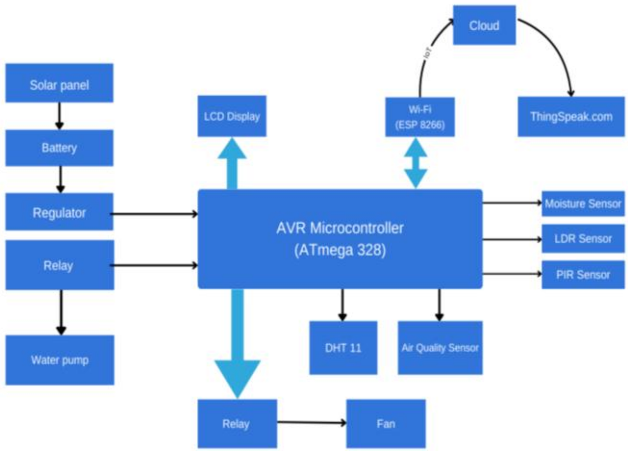

Fig. 4. Proposed Sytem Block Diagram

System Diagram

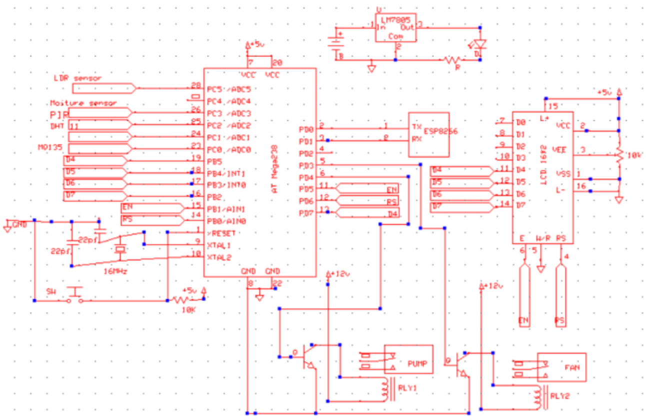

Fig. 5. The IoT based System Diagram

The system operates autonomously, powered by solar energy. The system's components, including the ATmega328 microcontroller and sensors, receive a stable 5V supply regulated by the LM2596S Voltage Regulator. Environmental conditions such as temperature, humidity, light intensity, soil moisture, and air quality are continuously monitored by sensors like the DHT11, LDR, Soil Moisture Sensor, and MQ-135 Air Quality Sensor. The data collected is displayed locally on a LCD screen for real-time monitoring as per shown in Figure 4 and Figure 5 [18][21].

The system automatically controls actuators based on sensor readings. For example, the water pump is activated when the soil moisture level drops below a threshold, ensuring proper irrigation. Similarly, if the temperature exceeds the optimal range, the fan is triggered to maintain a suitable environment. The ESP8266 WIFI module transmits the sensor data to the ThingSpeak IoT platform for remote monitoring, with alerts generated when any parameter crosses predefined thresholds to ensure ideal growing conditions in the greenhouse.

System Implementation Stages

The Printed Circuit Mother Board (PCMB) for the IoT-based Solar-Powered Greenhouse Monitoring and Control System was designed using the ExpressPCB software. The process began by creating the circuit layout, placing components such as the microcontroller, sensors, voltage regulator, and actuators in an organized manner. The software allowed for precise component placement, routing of signal paths, and ensuring minimal signal interference. Design rules were followed to maintain optimal trace widths, spacing, and pad sizes for efficient current handling and ease of soldering.

Once the PCB design was finalized in ExpressPCB, the design file was printed on a specialized toner transfer paper using a laser printer. This toner transfer method was used to create the PCB mask, where the printed design acts as a barrier to protect the copper from being etched away in the following steps. The toner paper was then placed on a copper-clad board, and heat was applied using a household iron to transfer the toner design onto the copper surface.

The next step was etching, where the copper-clad board was submerged in a ferric chloride solution. This solution dissolves the unprotected copper areas, leaving behind the desired copper traces that form the PCB. After etching, the board was cleaned with water to remove any residual chemicals and toner, revealing the final PCB layout as shown in Figure 6.

Finally, the components were placed on the PCB, and soldering was performed to secure them. Using a soldering iron and lead-free solder, each component was carefully mounted onto its respective pad, ensuring solid electrical connections. Special attention was given to solder joint quality, avoiding solder bridges between closely spaced pads. After all components were soldered, the board was tested for continuity and functionality to ensure that it was operating as intended.

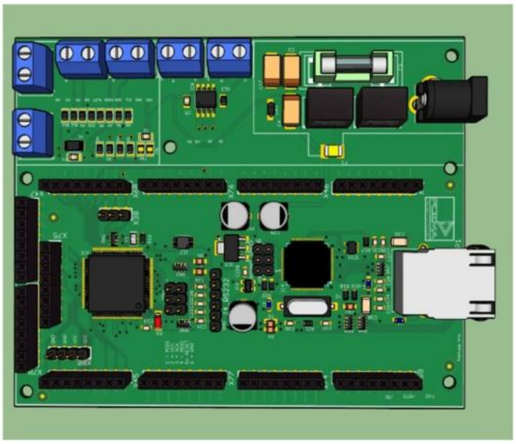

Fig. 6 Component Mounting

Software Setup

The microcontroller for the IoT-based Solar-Powered Greenhouse Monitoring and Control System was programmed using the Arduino IDE to monitor environmental conditions and control actuators accordingly. Sensor data from the DHT11, soil moisture sensor, and MQ-135 air quality sensor were continuously read and compared against predefined threshold values in the code. When sensor readings exceeded or dropped below these thresholds, the system automatically actuated the fan, water pump, or buzzer via relays. For instance, the fan was activated when the temperature exceeded the set limit, while the pump irrigated the plants when soil moisture levels were low.

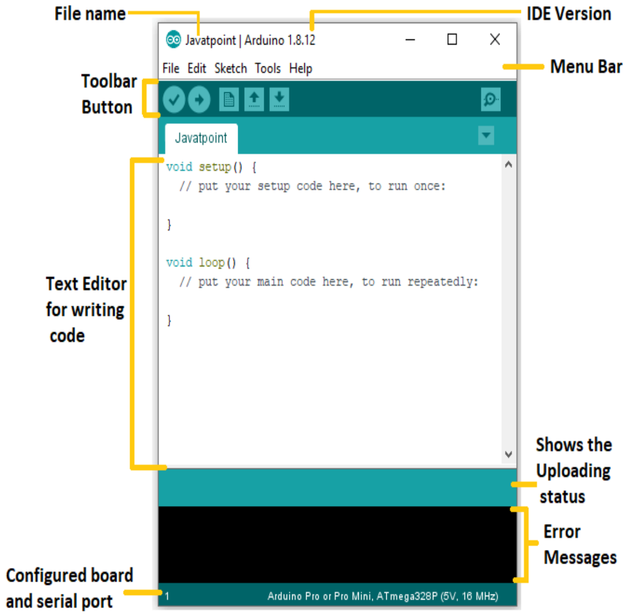

Fig. 6. Arduino IDE

Open Source Cloud Based Data Storage

To enable remote monitoring, one needs to set up a account with open source cloud based data storage, processing and representation system to which the data from the sensor was wirelessly communicated using ESP8266 based low cost mid-range WIFI module shown in Figure 7 and Figure 8. This allowed real-time data logging and monitoring from any internet-connected device, with alerts for any threshold breaches.

Fig. 7. ThingSpeak Dashboard

IV. RESULT AND DISCUSSION

An autonomously working greenhouse prototype, whose battery can be recharged with the help of solar panel. The front of the greenhouse consists of a switch to turn the system ON/OFF, PIR sensor, an LCD display and space for entering.

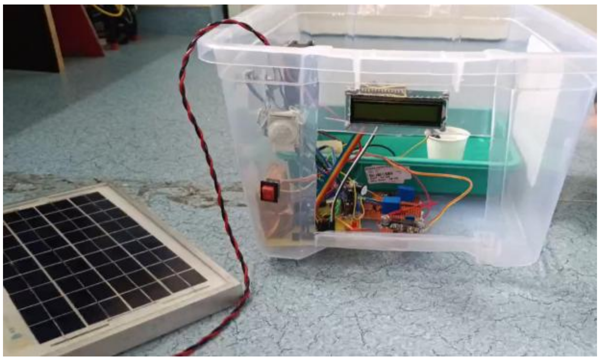

Fig 9. Greenhouse System

The LDR, temperature + humidity sensor, air quality sensor and Fan are mounted on left wall of the system.

The tray signifies the region where the plants will grow and the Fan is intentionally positioned above it, to cool down the temperature around it.

Fig 10 Sensor wall inside the system

The Figure 9 indicated different sensors installed and utilized inside the green house. Control System that includes the circuit and the sensors are placed in the region beside the tray in Figure 10.

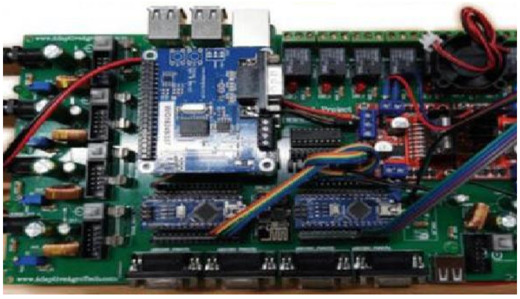

Fig. 11 Complete Circuit Board

After turning ON the system, it shows the project name and introduces the team members of the project on the LCD display.

The circuit diagram as shown in Figure 11 takes input from the sensors constantly and the sensor readings are displayed on the LCD display it consists Air Quality, Light Intensity, Temperature & Humidity and Moisture Level.

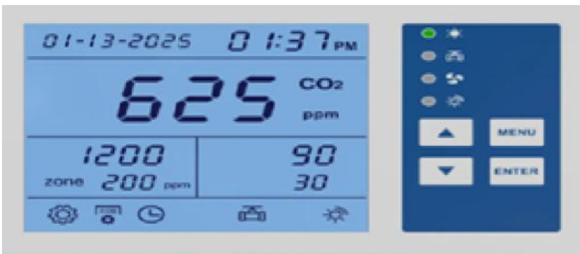

Fig. 12. Various Parameteric Display

As shown in Figure 12. the display section shows al the parameters, as the temperature goes beyond the threshold temperature, which is set to be 35°C, or if the air quality of the air degrades, the Fan turns ON to remove the warm air inside the greenhouse and reduces the temperature & the CO_2 levels in the system as shown in Figure 13.

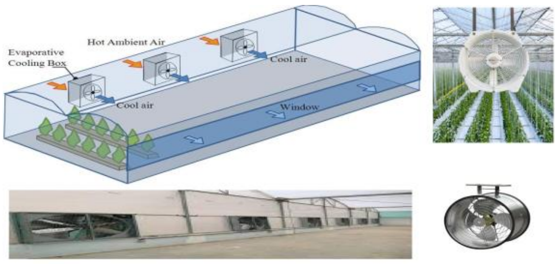

Fig. 13. Fan turning ON

Similarly, if the soil moisture value goes below the threshold value, which is set to 400, the water pump turns ON until the threshold value is restored in the soil.

As the sun starts to set, the nocturnal animals start to roam around in search of food. So, to ensure that it does not cause any damage to the greenhouse or plants, when the value of the light intensity is below 200, the threshold value, the buzzers start to ring and the message gets displayed on the LCD, if any movement is detected within the range of 2 meters of the entry.

All this sensor parameter data is logged on the ThingSpeak Cloud platform and can also be monitored in real-time on website.

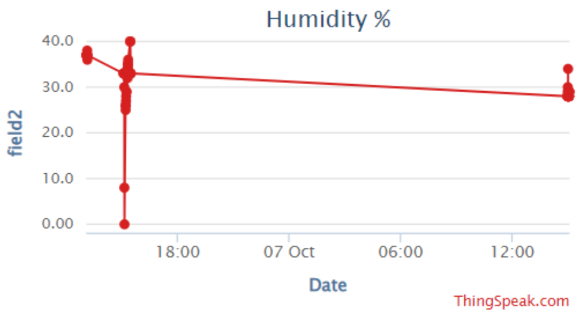

Fig. 8. Graph of humidity

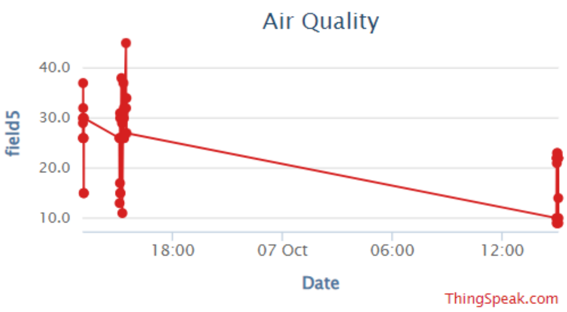

Fig. 9. Graph of Air Quality Level

Thus it is calculated the individual costs of the commercial greenhouse and our system for comparisons.

Cost Component	Quantity	Unit Cost (INR)	Total Cost (INR)
Wired Temperature Control System	5	5,000	25,000
Wired Humidity Control System	5	3,500	17,500
Water Irrigation System (Electric Pump)	5	1,000	5,000
Ventilation Fans (Wired)	5	2,000	10,000
Lighting System	5	1,500	7,500
Air Circulation System	5	2,500	12,500
Total Equipment Cost			**77,500 INR**
Annual Electricity Consumption		**Estimated 10-12 kWh/day, 10 INR/kWh, scaled up**	**109,500 INR/year**
Total First Year Cost		**Equipment + 1-year electricity cost**	**187,000 INR**
Total Recurring Cost		**Annual electricity cost**	**109,500 INR/year**

Fig. 10. Estimate Cost of Commercial Greenhouse

Cost Component	Quantity	Unit Cost (INR)	Total Cost (INR)
AVR Microcontroller (ATmega 328)	2	300	600
Soil Moisture Sensors	20	150	3,000
Solar Panels (100W)	5	5,000	25,000
DHT11 Sensors (Temperature, Humidity)	10	100	1,000
Air Quality Sensors	10	250	2,500
PIR Sensors	10	120	1,200
LDR Sensors	10	50	500
Relays	10	100	1,000
Water Pumps	5	500	2,500
Fans	10	500	5,000
ESP8266 Wi-Fi Modules	5	250	1,250
LM2596 Regulators	5	150	750
LCD Display (16x2)	5	200	1,000
12V Lithium-Ion Batteries (20Ah)	5	2,500	12,500
Total Equipment Cost			**56,800 INR**
Annual Electricity Consumption			**0 INR**
Total First Year Cost			**56,800 INR**
Total Recurring Cost			**Minimal**

Fig. 11. Estimate Cost of SolarGrowNet Greenhouse

Our Autonomous Greenhouse Monitoring and Control System offers an affordable alternative to expensive imported materials and equipment. It enables local farmers, vendors, and small greenhouses to adopt advanced greenhouse technology at a lower cost, improving accessibility and efficiency. The system optimizes the growing conditions through real-time environmental monitoring, ensuring consistent and ideal conditions for Gerbera plants. This leads to higher plant yields and faster growth cycles, significantly boosting Gerbera production across Maharashtra and India.

With enhanced production capacity, Maharashtra's contribution to India's Gerbera export market will increase. This will further solidify India's position as a key global Gerbera exporter, increasing national export revenue.

The system helps farmers produce higher-quality plants with reduced labor costs, increasing their profit margins.

By boosting productivity and export potential, farmers will see improvements in their economic status and quality of life.

Increased plant production and exports will lead to significant growth in Maharashtra's agricultural economy, contributing to the state's overall revenue. The ripple effect will enhance India's agricultural export sector, contributing to the national economy.

The system reduces reliance on electricity, saving significant amounts of energy each year by optimizing environmental controls. By minimizing the use of diesel generators, it also reduces carbon emissions, thus contributing to pollution control and promoting environmental sustainability.

V. CONCLUSION

The IoT-based Solar-Powered Greenhouse Monitoring and Control System successfully automates the monitoring and regulation of essential environmental parameters such as temperature, humidity, soil moisture, air quality, and light intensity. The integration of sensors, actuators, and wireless communication enables real-time data acquisition and control, ensuring optimal conditions for plant growth without the need for constant human intervention. Powered by solar energy, the system is both sustainable and energy-efficient, making it an ideal solution for small to medium-sized greenhouses. With the ability to monitor the greenhouse remotely through the IoT platform, this system provides a practical and cost-effective approach to smart agriculture.

VI. FUTURE SCOPE

Future developments of this system could focus on enhancing its scalability and intelligence. Incorporating machine learning algorithms to predict plant needs based on historical data and environmental trends could further optimize the system's efficiency. Additionally, expanding the range of sensors to include more specific parameters such as CO_2 levels or UV radiation would provide a more comprehensive understanding of plant growth conditions. The system could also be integrated with automated fertilization or pest control mechanisms for more robust agricultural automation. Expanding wireless connectivity options, such as using LoRa or Zigbee, could allow the system to cover larger areas or multiple greenhouses simultaneously. These enhancements would further position the system as a valuable tool in the development of sustainable and automated farming technologies.

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