**Automating Hydroponics**

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***Abstract*—In recent years, advancements in Internet of Things (IoT) and sensor technologies have greatly influenced the agricultural sector. These innovations have introduced more efficient, automated systems that can monitor and manage farming processes with greater precision. Traditional farming methods, particularly in urban areas, often involve the heavy use of pesticides, which not only pose serious health risks to consumers but also degrade the quality of arable land. While organic farming offers a healthier alternative, it is not always a feasible option due to its high costs and resource-intensive nature. As a result, hydroponics has emerged as a promising solution for sustainable agriculture. Hydroponics is a soil-less method of growing plants, using nutrient-rich water solutions to provide plants with essential minerals. Combined with our newly designed system, it offers an efficient and sustainable alternative to conventional farming methods. This research presents a smart hydroponic system powered by IoT technology, allowing for precise control of key environmental factors. The proposed system utilizes various sensors, including ultrasonic sensors for monitoring water levels and temperature sensors to regulate the environmental conditions. These sensors work together to automate the flow of nutrients, ensuring that the plants receive the optimal amount of water and nutrients for their growth. The system is designed to prioritize the maintenance of ideal temperature, water levels, and pH balance key factors that directly influence plant growth and health. By automating these processes, the system reduces the need for human intervention, offering a reliable and scalable solution for year-round crop production. This smart hydroponic system meets the growing global demand for sustainable agricultural practices, providing a viable alternative to both traditional and organic farming techniques, and ensuring consistent, efficient crop growth with minimal human input.**

***Keywords*—Hydroponics, Arduino, pH Sensor, Electrical Conductivity, Automated Agriculture.**

I. INTRODUCTION

Internet of Things (IoT) and sensor technology have revolutionized the agricultural industry, promoting greater efficiency and sustainability in farming practices. These technological advancements have led to the development of automated systems capable of monitoring and managing agricultural processes with precision. Traditional farming methods are increasingly struggling to meet growing food demands due to climate change, shrinking resources, and inherent inefficiencies. As a result, adopting smart agricultural solutions has become essential for improving productivity and sustainability. Conventional agriculture, particularly in urban environments, often depends on the excessive use of chemical pesticides and fertilizers. While these chemicals may enhance short-term yields, they pose significant health hazards to consumers and damage the environment by contaminating soil and water, reducing biodiversity, and disrupting ecosystems. Although organic farming offers a safer alternative, it is expensive and resource-heavy, making it less feasible for widespread implementation.

Hydroponics is an advanced method of cultivating plants without relying on soil, instead using nutrient-rich water solutions to supply

plants with the essential minerals they need for growth. In this system, plants are grown in controlled environments where crucial factors such as light, temperature, humidity, and nutrient concentration are meticulously regulated to optimize plant health and accelerate growth rates. This precise control allows for higher yields in a shorter period compared to traditional farming methods. One of the key advantages of hydroponics is its exceptional water efficiency. The system recycles water, reducing consumption by up to 90% compared to conventional soil-based agriculture, making it particularly advantageous in regions facing water scarcity or drought conditions. Additionally, hydroponics drastically reduces the need for chemical pesticides and herbicides, as the enclosed environment minimizes exposure to pests, weeds, and diseases, promoting healthier plant growth with minimal environmental impact.

Hydroponic systems are highly adaptable and can be implemented in diverse settings, ranging from high-tech greenhouses and vertical farming setups to urban rooftops and indoor farms. This versatility makes it possible to grow food in areas where traditional farming is not feasible due to a lack of arable land or adverse climatic conditions. Furthermore, hydroponics supports year-round cultivation, regardless of season or weather, ensuring a steady and reliable food supply. As the global population continues to grow, putting pressure on land and resources, the need for more sustainable and efficient agricultural practices is becoming increasingly urgent. Hydroponics presents a promising solution, offering a more sustainable alternative to conventional farming methods by using fewer resources while producing higher yields, contributing to global food security and environmental sustainability.

Hydroponics, a modern farming technique that grows plants without soil, has emerged as an eco-friendly and effective solution to these problems. Hydroponic systems utilize nutrient-rich water to supply plants with essential minerals, allowing for faster growth with minimal water usage in controlled environments. This method is especially valuable in urban areas, where space for traditional farming is limited, and can be employed in rooftop farms, greenhouses, or vertical farming setups.

The integration of IoT technology has become a driving force behind the success of hydroponic systems. IoT enables the automation of critical processes such as nutrient delivery, water circulation, and environmental control. Sensors continuously measure vital factors like temperature, humidity, water levels, and pH, enabling the system to make real-time adjustments to optimize plant growth conditions. This level of automation ensures that plants receive precisely the right amount of water, nutrients, and light for each stage of growth. This research explores an advanced IoT-powered hydroponic system centered around the Arduino Uno microcontroller. The Arduino Uno is a versatile, cost-effective tool popular in both DIY and professional projects, especially in agricultural automation. The system incorporates various sensors, including the ultrasonic sensor to monitor water levels, the LM35 temperature sensor to regulate environmental conditions, and SE515 pH sensors to maintain ideal nutrient solution acidity. With the help of the ESP8266 Wi-Fi module, this setup allows remote monitoring and control from any connected device, such as smartphones or computers. The designed hydroponic system focuses on optimizing plant growth by automating key processes

like nutrient low, water management, and temperature control. Through the use of logic-based programming, the Arduino Uno can autonomously manage the system, turning on water pumps when nutrient levels are low or adjusting fans to maintain optimal temperatures. This automation reduces the need for manual intervention, making the system an efficient and scalable solution for both small-scale urban farming and large commercial operations.

Hydroponics, though often considered a modern farming technique, has deep historical roots. The current form of hydroponics began to take shape in the 1930s when Dr. William Frederick Gericke of the University of California promoted it as a method for commercial crop production. Dr. Gericke’s pioneering work laid the foundation for the hydroponic systems we use today, which have evolved into widely recognized sustainable agricultural solutions. His early advancements showed the potential of growing plants without soil, relying instead on nutrient-enriched water to nourish crops.

As we entered the 21st century, the introduction of Internet of Things (IoT) technology fundamentally transformed hydroponic systems, greatly enhancing their efficiency and expanding their capabilities. In traditional hydroponic setups, tasks like monitoring water levels, adjusting nutrient concentrations, and overseeing plant health required manual attention, which increased labour demands and limited precision. However, with the emergence of IoT and automation, hydroponics evolved significantly. By integrating devices like the Arduino Uno microcontroller and various real-time sensors, modern hydroponic systems now allow farmers to remotely monitor and adjust conditions with ease. This shift has not only streamlined the process but also reduced the need for constant manual intervention, enabling farmers to achieve higher precision in controlling their systems.

One notable example of hydroponic innovation is NASA’s research on space-based hydroponic systems. Designed to provide astronauts with fresh produce during long-term space missions, this project demonstrated hydroponics’ remarkable potential in extreme and resource-limited environments. The system’s success underscored hydroponics as a viable method for sustainable food production in otherwise uninhabitable conditions.

In the United Kingdom, "Project Eden" further exemplifies the innovative application of hydroponics. By combining vertical farming with IoT and machine learning, Project Eden creates a finely tuned environment for urban farming, optimizing growth conditions to maximize yield and resource efficiency. In the United States, New Jersey’s Aero Farms has taken a similar approach, employing an IoT-enabled closed-loop water system in its hydroponic farms. This system reduces water usage by 95% compared to conventional methods while enhancing plant health. These examples showcase how hydroponics, especially when integrated with IoT, has become a powerful tool for addressing global challenges such as food security, resource scarcity, and environmental sustainability.

Together, these advancements highlight the evolution of hydroponics into a highly adaptable and efficient agricultural practice, capable of supporting food production in diverse environments and promoting sustainable solutions in response to modern challenges.

In this context, the Arduino Uno plays a vital role in automating hydroponic systems by serving as the central controller for sensor data and automated functions. Known for its ease of use and compatibility, the Arduino Uno processes data from sensors like the ultrasonic sensor (which measures water levels), the LM35 temperature sensor (which monitors ambient temperature), and pH sensors (which track water acidity). When the sensors detect values outside optimal ranges, the Arduino Uno triggers corrective actions such as adjusting water levels, adding nutrients, or turning on fans for temperature regulation. The system’s Wi-Fi connectivity, powered by the ESP8266 module, enables remote monitoring through smartphones or computers, allowing for real-time farm management and scalable operations with minimal human intervention.

II. LITERATURE SURVEY

In [1] An automated nutrient flow management system for hydroponic plants is developed using an Arduino Uno microcontroller, operated through a smartphone. The system controls nutrient flow using if-else logic and tracks water levels with an HC-SR04 ultrasonic sensor, while temperature is measured using an LM35 sensor. The Arduino processes the data and displays it on an LCD screen, with the ESP8266 Wi-Fi module sending real-time updates to the user’s Android smartphone.

In [2] The design and implementation of a smart hydroponics system using IoT addresses rising food demand and promotes sustainable farming. Built with NodeMcu, Node Red, MQTT, and sensors, the system monitors environmental conditions via the cloud and includes a bot for supply chain management and notifications. Tested in different environments, the system showed improved performance. Future plans involve integrating AI for crop optimization and developing a more user-friendly interface without technical complexities.

In [3] India’s growing health-consciousness demands healthier food options, but urban vegetables are often contaminated with pesticides, and organic farming is expensive. Hydroponics, along with the proposed system, offers a sustainable farming alternative by ensuring faster plant growth in a controlled environment. This system monitors and controls key parameters with actuators, reducing the need for manual farming tasks. Remote monitoring allows year-round cultivation of plants and vegetables, showing that properly managed hydroponic systems enhance growth rates and reduce human dependency.

In [4] The Titan Smartponics project aims to improve hydroponics by creating an automated, cost-effective system for indoor plant growth that requires minimal human interaction. Unlike conventional hydroponic systems, it controls all key parameters such as air temperature, humidity, and water temperature, in addition to EC and pH levels. Using microcontrollers, sensors, and IoT technology, the system monitors and adjusts conditions for optimal plant growth. It offers a more affordable solution compared to current automated systems on the market, providing complete control of the growing environment.

In [5] The project involved studying the chemical and climatological needs of plants, identifying key factors affecting productivity, and selecting appropriate sensors. Using recyclable PVC pipes and a Raspberry Pi with sensors for pH, conductivity, temperature, and humidity, the system was designed to optimize plant growth and produce high-quality vegetables.

In [6] Hydroponic planting media is gaining traction due to its space efficiency, using water instead of soil and thus needing less land. Despite its benefits, hydroponic farming demands consistent monitoring of nutrients, pH, and water levels. This study introduces an Arduino-based system for automating these tasks, using fuzzy logic to handle vague concepts like temperature. Testing with kale demonstrated high success rates: 100% for water level, 80% for nutrient control, and 75% for pH, averaging an 85% effectiveness over two weeks.

In [7] Hydroponics, a method for growing plants in nutrient-rich water without soil, is favoured for its resource efficiency and year-round crop production. However, managing greenhouse conditions like temperature and humidity can be challenging, and manual monitoring is time-consuming. This paper introduces a fully automated IoT-based hydroponic system using an ESP32 microcontroller and sensors to streamline greenhouse farming and automate essential tasks.

In [8] Agriculture in India faces issues like limited land and chemical use, while there is rising demand for healthy, chemical-free food. This IoT-based system enables organic plant growth in controlled spaces such as terraces or balconies, maximizing plant density in small areas. It provides an efficient solution for urban dwellers, home gardeners, and commercial growers to cultivate fresh vegetables.

In [9] Smart farming is the future of agriculture, enhancing crop quality by making farms smarter through IoT and data analytics. This work presents a smart hydroponics system that automates crop growth using a Bayesian Network (BN) model. Sensors monitor key parameters like light, pH, conductivity, and humidity, with the BN predicting optimal settings for automated control. Results show reduced fluctuations in sensor values and an 84.53% prediction accuracy. Crop yields under automatic control were 66.67% higher than those under manual control, demonstrating the system's effectiveness.

In [10] An autonomous system for monitoring and controlling pH in hydroponics to optimize nutrient availability for plant growth has been developed. Using sensors for temperature, pH, and dissolved oxygen, data were processed via a Raspberry Pi and displayed in Grafana. If pH values exceeded the optimal range, peristaltic pumps automatically adjusted the solution. The system successfully maintained pH within the desired range, enhancing nutrient absorption and plant growth.

In [11] A Fully Automatic Hydroponics system monitors and regulates temperature, humidity, pH, and EC levels. Utilizing a PIC16F877A microcontroller, along with four pumps and a fan, it efficiently manages nutrient solutions, water, and environmental conditions. This system automates the process, enhancing crop yield, reducing water consumption, and requiring less space compared to traditional soil-based farming. Analysis demonstrates hydroponics as a more effective method, offering higher yields and improved water efficiency.

In [12] Hydroponics is a soil-free method of growing plants that depends on key factors like pH, nutrient concentration, and Electrical Conductivity (EC) for healthy growth. This study introduces an algorithm to automate the monitoring and control of pH and EC in hydroponic systems, factoring in water types and tank volumes using sensors and an app for efficient management.

In [13] Advancements in AI and IoT have revolutionized agriculture, boosting automation, offering recommendations, and optimizing monitoring for better results. Hydroponics, ideal for urban farming, enables efficient space use by delivering nutrients directly to plant roots. Our AI-IoT integrated system recommends crops, monitors plant conditions, and suggests adjustments, with the Random Forest model achieving 97.5% accuracy in recommendations using data from the Indian Chamber of Food and Agriculture.

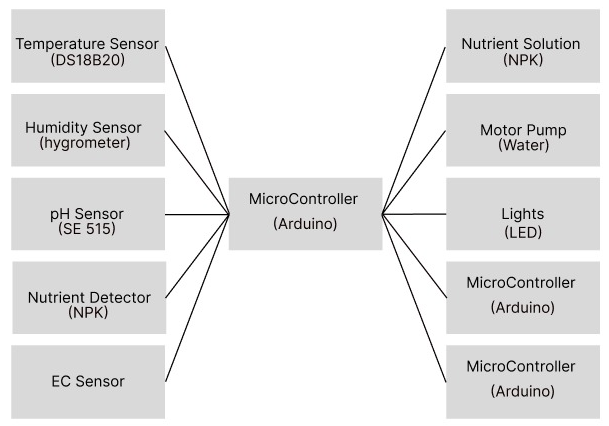
In [14] Hydroponic farming addresses the issue of limited arable land, allowing precise cultivation of flowers and vegetables in controlled settings with reduced energy use. It also serves as a means of treating partially treated wastewater, as plants can absorb nutrients and contaminants. This method offers economic advantages to farmers by supporting sustainable, high-quality crop production and allows for year-round growing in greenhouses, independent of water availability or seasonal factors.

In [15] Urban farming, increasingly popular for meeting food needs in cities, often utilizes hydroponics, a soil-free method suitable for urban settings. However, hydroponic farming requires consistent monitoring and adjustment of environmental conditions and nutrient circulation. This paper presents an IoT-enabled hydroponic system using sensors, an Arduino, and a Raspberry Pi to monitor and control key parameters like temperature, humidity, pH, and TDS. With Node-RED and MQTT on the Raspberry Pi, users can view plant conditions via a web browser, while the system automates nutrient and water delivery for optimal plant growth.

III. SYSTEM DESIGN AND METHODOLOGY

A. SYSTEM OVERVIEW

This IoT-based hydroponic system (Figure 1) automates key aspects of managing a hydroponic farm, utilizing a network of IoT sensors and actuators to continuously monitor and adjust critical environmental factors. These factors include temperature, humidity, water pH, and nutrient levels, all of which are essential for optimal plant growth. At the core of this system is the Arduino microcontroller, which serves as a central hub for collecting real-time data from sensors and coordinating the responses of actuators. The system’s primary focus is on maintaining appropriate nutrient levels, especially ensuring the right balance of nitrogen, potassium, and phosphorus (NPK), which are fundamental for healthy plant development. Through automation, this system enhances efficiency and accuracy in managing a hydroponic environment, reducing the need for manual intervention.



**Fig 1.** Block diagram of automating hydroponics

B. HARDWARE COMPONENTS

**Microcontroller (Arduino):** As illustrated in Figure X, the Arduino serves as the system's brain. It interprets sensor data and controls actuators such as water pumps, lights, and nutrition dispensers accordingly.

**Temperature Sensor (DH11):** It keeps an eye on the outside temperature and makes sure the system is ready to respond if it deviates from the ideal range.

**Humidity Sensor (Hygrometer):** This device gauges the humidity in the area surrounding the plants. Using the sensor's data, the system can modify ventilation or misting.

**The pH Sensor (SE 515):** It keeps an eye on the nutrient solution's pH levels to make sure the health of the plants is not being jeopardized.

**Nutrient Detector (NPK):** Measures potassium (K), phosphorus (P), and nitrogen (N) concentrations. The system replenishes these nutrients as needed.

**EC Sensor:** Determines the solution's electrical conductivity, which indicates the amount of dissolved nutrients in the water.

C. ACTUATORS

The microcontroller regulates the actuators, which are shown in Figure 1, to maintain the hydroponic environment.

**Nutrient Solution (NPK):** Based on data from the NPK sensor, this solution replenishes the system with nutrients as needed.

**Water-controlling motor pump:** regulates water flow to keep plants properly hydrated.

**LED lights:** These are a great way to mimic sunlight, which is necessary for indoor growth and can be adjusted to maximize photosynthesis.

D. SYSTEM WORKFLOW

**Data Collection:** As shown in Figure X, sensors gather information from the growing environment on a regular basis.

**Data processing:** To ascertain if the circumstances satisfy the intended thresholds, the Arduino processes the data.

**Control Actions:** Based on sensor data, actuators are activated to modify the environment (e.g., turning on the pump or delivering nutrients).

**Feedback Loop:** Constant modifications are made to the system in response to changes in sensor readings.

E. CIRCUIT DESIGN

An Arduino microcontroller is connected to a number of sensors and actuators as part of the circuit design for the Internet of Things-based automated hydroponic system. Vital indicators like temperature, humidity, pH, electrical conductivity (EC), and nutrient levels (NPK) are tracked by the sensors. The actuators, which include nutrient solution pumps, lights (LEDs), and water pumps, are activated in response to sensor readings in order to sustain ideal growth conditions.

Taking in information from the sensors and managing the actuators, the Arduino microcontroller functions as the central processing unit. With the Wi-Fi module (ESP8266), which allows for real-time adjustments based on the hydroponic system's environmental conditions, remote monitoring and control are made possible via a cloud platform.

It is possible to see how the sensors, actuators, and Arduino microcontroller are connected in the circuit design diagram. After processing the input and turning on the appropriate actuators, the Arduino receives feedback from each sensor. The system's design guarantees that it will run effectively and independently while preserving the ideal ratio of light, nutrients, and water for plant development.

Figure 2, displays the comprehensive circuit schematic.

IV. RESULT AND DISCUSSION

A. SOFTWARE IMPLEMENTATION

The automated hydroponics system operates with software hosted on an Arduino microcontroller, which enables seamless communication with a diverse array of sensors and actuators. This setup is essential for monitoring plant health and growth, as the system constantly collects and processes environmental data to optimize growing conditions. The C code powering this system is written and deployed using the Arduino IDE, enabling control of various sensors, including temperature, moisture, simulated pH, NPK (nitrogen, phosphorus, potassium), and electrical conductivity (EC) sensors. These sensors are connected to the microcontroller, which regularly retrieves readings essential for efficient plant management. After gathering data, the microcontroller compares each sensor reading against preset thresholds to determine the necessary actions. For instance, if the temperature exceeds 25°C, the system activates a cooling fan to regulate the environment. Similarly, when moisture levels fall below a certain point, a water pump is triggered to maintain adequate hydration for the plant roots. Actuators, such as the cooling fan and water pump, are controlled through the digital output pins of the microcontroller, where specific output pins are set to HIGH to activate relays for each device. To prevent the pump from toggling on and off unpredictably, a cooldown delay of 30 seconds is implemented. Additionally, sensor readings are continuously transmitted to a cloud server via the MQTT protocol, allowing remote access and enabling the collection of historical data. This stored data is subsequently used as input for a machine learning model, as discussed in Paper 2, to further analyse and explore predictive insights, enhancing the system's potential for refined decision-making and future optimization.

**Algorithm:**

temperature\_count = 0

moisture\_count = 0

ph\_count = 0

ec\_count = 0

npk\_count = 0

Start 30-minute sensor data checks

Read temperature, moisture, pH, EC, and NPK values

If temperature > 25°C:

temperature\_count = temperature\_count + 1

Activate cooling fan

If moisture < preset level:

moisture\_count = moisture\_count + 1

Activate water pump

If pH out of range:

ph\_count = ph\_count + 1

Log pH adjustment

If EC out of range:

ec\_count = ec\_count + 1

Adjust nutrient solution

If NPK levels < required threshold:

npk\_count = npk\_count + 1

Add nutrients

Send data to MQTT server

This sample of code illustrates the reasoning used in the automated hydroponics system to continuously monitor key environmental parameters for 30 minutes. Important parameters that have a big influence on plant health are monitored here, including temperature, moisture content, pH, electrical conductivity (EC), and nutrient levels (NPK). Through consistent monitoring and evaluation of these parameters, the system can guarantee the best possible growing conditions for the plants. For example, it automatically turns on cooling systems when the temperature rises above 25 °C and turns on the water pump when the moisture content drops below a predetermined level Finally, by improving the automated hydroponics system's efficacy and efficiency, this integrated approach supports sustainable farming methods.

B. HARDWARE IMPLEMENTATION

The hardware implementation of the automated hydroponic system is structured around an **Arduino microcontroller**, which serves as the central processing unit. This section outlines the key components, their roles, and the integration of various sensors and actuators within the system.

**1. Arduino Microcontroller**

The **Arduino** serves as the core of the system, facilitating sensor data collection and actuator control. An **Arduino Nano** or **Arduino Uno** (Figure 2) is commonly used due to its compact size, ease of programming, and sufficient I/O pins for connecting various components. The Arduino is responsible for processing the input from sensors, executing control algorithms, and managing the system's operations.



**Fig 2.** Arduino UNO

**2. Wi-Fi Module**

A **Wi-Fi module** (e.g., ESP8266) is integrated to enable remote monitoring and control of the hydroponic system. This module allows the Arduino to connect to a local network or the internet, facilitating data transmission to a cloud service or a user interface for real-time monitoring. The Wi-Fi module is connected to the Arduino via serial communication, enabling data exchange between the two.

**3. DHT11 Temperature Sensor**

The **DHT11 temperature** (Figure 3) **and humidity sensor** is utilized to monitor the environmental conditions within the hydroponic system. This sensor provides accurate readings of both temperature and humidity, which are critical for optimal plant growth. The DHT11 is connected to a digital pin on the Arduino, and its readings are periodically collected and processed to maintain suitable conditions.



**Fig 3.** DHT11 Temperature Sensor

**4. pH Sensor**

The pH sensor (Figure 4) is critical for monitoring the acidity of the nutrient solution, as an optimal pH level is essential for plants to absorb nutrients effectively. If the pH level deviates too much, plants may struggle with nutrient uptake, impacting their growth. By connecting the pH sensor to the Arduino’s analog input pins, the system can continuously monitor acidity levels in real time. This allows for timely adjustments to maintain the pH within the ideal range, ensuring healthy plant development.



**Fig 4.** pH Sensor

**5. NPK Sensor**

The **NPK sensor** (Figure 5) (measuring nitrogen, phosphorus, and potassium levels) is employed to assess the nutrient concentration in the hydroponic solution. By providing real-time feedback on nutrient levels, the NPK sensor allows for precise adjustments to be made to the nutrient solution, optimizing plant growth. It is also connected to an analog input pin on the Arduino for data acquisition.



**Fig 5.** NPK Sensor

**6. EC Sensor**

The **Electrical Conductivity (EC) sensor** (Figure 6)  is used to measure the concentration of dissolved salts in the nutrient solution. This measurement is crucial for understanding the nutrient strength available to the plants. Like the pH and NPK sensors, the EC sensor connects to an analog input pin on the Arduino enabling continuous monitoring of the nutrient solution's conductivity.



**Fig 6.** EC Sensor

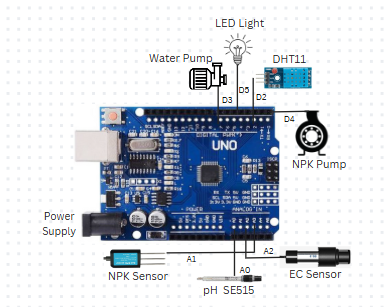
**7. Actuators**

The system incorporates several actuators to automate various processes:

* **Water Pump**: A water pump is used to circulate the nutrient solution within the hydroponic system. The pump is controlled by a relay connected to the Arduino, allowing it to be activated or deactivated based on sensor readings and predefined thresholds.
* **Nutrient Solution Control**: Actuators such as solenoid valves may be employed to dispense precise amounts of nutrient solution into the water, ensuring optimal nutrient delivery to the plants.
* **Lights:** The light spectrum required for plant photosynthesis is provided by integrated grow lights. Depending on the time of day or particular stages of growth, the Arduino regulates the lighting schedule.
* **Cooling Fan:** To control the temperature in the growing environment, a cooling fan is used. The Arduino keeps an eye on the DHT11 sensor's temperature readings and turns on the fan when needed to keep things at their best.

**8. Circuit Design and Assembly**

To ensure accurate connections and reliable functionality, integrating these components demands meticulous circuit design. The actuators, which require specific current and voltage levels to operate effectively, are managed through relay modules or transistor circuits. These components act as intermediaries, allowing the system to handle higher power requirements without damaging the Arduino. Meanwhile, sensors are connected to the Arduino’s analog and digital pins, enabling precise data collection and real-time monitoring. This careful configuration ensures that each component communicates correctly with the microcontroller, allowing for smooth operation of the entire system as in Figure 7.



**Fig 7.** Circuit Diagram of Automating Hydroponics

V. CONCLUSION

In conclusion, this research demonstrates how integrating IoT technology with hydroponic systems can significantly enhance agricultural efficiency and sustainability. The automated hydroponic system, centered around the Arduino microcontroller and powered by various sensors, offers precise control over key environmental factors essential for plant growth. Traditional farming methods, particularly in urban areas, often rely on pesticides and resource-heavy practices, which can harm the environment and pose health risks.

The smart hydroponic system incorporates essential sensors, including DHT11 for temperature and humidity, SE 515 for pH, NPK sensors for nutrient concentration, and an EC sensor for electrical conductivity. These sensors work in tandem to monitor the growing environment in real-time, with the Arduino processing data and triggering actuators as needed. This dynamic setup allows the system to autonomously maintain ideal conditions for plant health, such as controlling water levels, nutrient delivery, and temperature. Additionally, the inclusion of the ESP8266 Wi-Fi module enables remote monitoring, allowing users to oversee system performance and environmental parameters from any internet-connected device.

By automating these essential processes, the hydroponic system not only reduces manual labour but also ensures consistent crop production throughout the year, regardless of seasonal variations. This feature is particularly valuable in urban settings, where traditional agriculture is limited by space and environmental factors. The use of LED lights to simulate sunlight further enhances the system’s flexibility, making indoor farming feasible even in densely populated urban areas. This adaptability supports sustainable, localized food production, offering a viable solution for urban populations with limited access to fresh produce.

In summary, the proposed IoT-enabled hydroponic system represents a significant leap forward in sustainable agriculture by enhancing resource efficiency, boosting productivity, and minimizing environmental impact. Integrating IoT technology automates vital tasks such as monitoring and adjusting nutrient levels, temperature, and humidity, ensuring optimal growing conditions with minimal human intervention. The data gathered by IoT sensors enables continuous system improvements, making hydroponics a smart, adaptable choice for modern agriculture. As the global need for sustainable food production increases, IoT-powered hydroponic systems can play a transformative role in securing food supplies and advancing environmental conservation. This research underscores how IoT advancements make hydroponics a scalable, sustainable agricultural method. With further innovations, hydroponic systems are poised to become a widely accepted solution, providing a reliable, eco-friendly method to meet food production needs in diverse environments, from densely populated cities to regions with limited water resources.

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