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Article

Smart Hydroponic Growth Optimisation System with Real–Time Monitoring and Control with Convolutional Neural Network Algorithm Using Machine Learning

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Abstract: This project aims to develop a smart hydroponic plant monitoring system utilising a range of sensors and actuators to enhance the environment for plant growth. The system automatically changes environmental conditions based on real-time data collected from sensors. This makes hydroponic farming more productive and efficient. The Light Dependent Resistor (LDR) detects light intensity, the DHT11 checks the temperature, and the PH sensor checks the quality of the water. Light, temperature, water pH, and nutrition levels are all controlled by actuators such as bulbs, fans, water pumps, and motors. The main goal of this system is to create an automated and efficient method for monitoring hydroponic plants, thereby enabling them to develop more effectively and reducing the need for human intervention. The study also uses deep learning methods to find diseases in spinach leaves, which adds another layer of plant health monitoring to the system. This combination of technology and software makes it easier to run hydroponic farms and also increases their overall efficiency and output. The smart hydroponic plant monitoring system in this project is a paradigm for sustainable farming. It shows how technology can be used to make farming more effective and environmentally benign. This technology aims to enhance hydroponic farming methods by automating the monitoring and adjustment of key growth factors. This will lead to better crop yields and more efficient use of resources.

Keywords: Smart Hydroponic, Real-Time Data, Light Dependent Resistor (LDR), Deep Learning Techniques, Hydroponic Farming Methods, Crop Yields, Crucial Growth, Temperature Sensors, Nutrient Sensors

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1. Introduction

Modern farming has undergone significant changes thanks to new technology, especially smart hydroponic systems, which are crucial for monitoring and tracking key growth factors such as light, temperature, water quality, and fertiliser levels [27]. Farmers can use these systems to create and maintain optimal conditions for plants to flourish, which leads to healthier crops, larger yields, and more environmentally friendly agricultural methods. We designed and constructed a comprehensive hydroponic system for our project, utilising numerous sensors and automated equipment to manage the atmosphere precisely [34]. Light Dependent Resistors (LDR) are used to measure the amount of light in the room so that plants get enough light during their growth cycle.

When the light levels drop below the level needed for photosynthesis, more artificial lighting is automatically turned on to keep the light conditions at their best. This helps plants grow consistently and healthily, even in low-light situations [20]. Temperature sensors are strategically placed to assess the temperature in the area constantly. When the readings show that it is too hot, automated fans are turned on to provide ventilation. This keeps the climate steady and prevents heat stress, which is good for plant growth [42]. It is very important to keep the temperature stable because changes outside of the ideal range might hurt plant metabolism and productivity.

Water quality is another important consideration when growing plants in water [39]. The device has built-in pH sensors that constantly check the acidity or alkalinity of the nutrient solution, which is a significant factor in how well plants take up nutrients [91]. Water pumps turn on automatically when the pH level goes outside of the ideal range. This either adds pH-adjusting solutions or moves the nutrient mixture around, making sure that plants are always in a place where they can easily absorb nutrients. The pH monitoring system and the nutrient sensors work together to determine the concentration of each vital element in the water [26]. The system can change the nutrient solution based on these data to provide plants with the exact amounts they need to grow strong, which stops both deficiencies and toxicities. This level of accuracy ensures that plants receive exactly what they need to grow well without wasting resources, which in turn helps both production and sustainability.

In addition to controlling the environment, our system utilises advanced computer technologies to detect diseases, a crucial aspect of current crop management. High-resolution cameras take close-up pictures of plant leaves[36]. Then, computer systems use image analysis and machine learning methods to find signs of diseases in their early stages. The technology lets you find and fix problems before they get worse, which cuts down on crop losses and the need for chemical treatments. This not only makes the food healthier and better, but it also helps make farming safer and better for the environment [90]. Combining disease detection with environmental monitoring is a comprehensive approach to managing crops. It uses data from many sources to make smart choices that improve efficiency and lower risks.

Embedded systems technology is what makes this kind of hydroponic system work. An embedded system is a controller that a real-time operating system (RTOS) uses to program and control it to do a specific job in a broader mechanical or electrical setup [31]. One of the most important things about embedded systems is that they may work under strict real-time limitations. This means that sensor inputs must be evaluated and actions must be taken without any delays that could hurt the system's performance. They are not computers that work on their own; instead, they are part of bigger systems that include hardware, actuators, and mechanical structures to provide certain functions. Embedded systems are quite common in current technology. About ninety-eight per cent of all microprocessors made in the world are made to be used in embedded applications.

These systems are used in a wide range of fields, including consumer electronics, industrial automation, medical devices, automotive systems, and agricultural technology, like our smart hydroponic arrangement. Typical embedded systems have features that make them better than general-purpose computers [19]. For Example, they use very little power, which is important for continuous operation in remote or resource-constrained environments; they are small enough to fit into many devices; they are tough enough to work reliably in a wide range of temperatures and difficult environmental conditions; and they are cheap enough to be used on a large scale. But there are always trade-offs that come with these benefits. Compared to desktop or server-class equipment, embedded systems usually don't have as much processing power or memory. This makes programming, optimisation, and human interaction more difficult. To make applications for embedded systems, you need unique abilities because the software has to be customised to work as well as possible while yet fulfilling tight performance and reliability standards.

Even with these constraints, adding smart control systems on top of the hardware platform can greatly improve the capabilities of embedded systems [37]. Using existing sensors and the connectivity that networks of embedded units provide, it is possible to put resource management plans into action at both the individual unit and system-wide levels. Smart algorithms can determine the optimal allocation of resources, such as power, bandwidth, and processing time, ensuring each subsystem operates at its peak without compromising overall performance [25]. In the context of our hydroponic system, these features mean that we can change the environment based on sensor readings, past data, and predictive models. For Example, intelligent scheduling can determine the optimal times to turn on lights, deliver nutrients, and adjust the temperature, considering both plant demands and energy conservation.

Another benefit of adding intelligence to the system is that it may enable it to perform more than just basic monitoring and control tasks [40]. For instance, embedded systems can be made to assist predictive maintenance, which uses data from sensors to predict when equipment will break down before it happens. This keeps the equipment from going down and saves money on repairs. In our hydroponic arrangement, this could entail using vibration patterns to predict when a water pump would break or monitoring fan performance to ensure steady air flow. You can also use embedded intelligence to control how much electricity you use more effectively. The system can plan high-energy jobs for times when electricity demand is low or when renewable energy sources like solar panels are making more power than they need [21]. This not only cuts costs for running the business, but it also makes the system more environmentally friendly.

Adding networked embedded systems to farming also makes it possible to monitor and operate things from a distance. This means that farmers can keep an eye on their work from anywhere using an internet-connected device. Our system can provide real-time data to a central dashboard that can be accessed from desktops or mobile devices [28]. This dashboard shows all the important metrics at a glance. When anything unusual happens, such as a rapid decline in nutrition levels or a sudden spike in temperature, alerts can be sent out to get people to act right away. Remote access also makes it easier to work with agricultural specialists, who can look at system data and give advice without having to be there in person. This makes it easier to respond and make decisions.

The disease diagnosis part, which uses machine learning methods, is a good example of how embedded systems and artificial intelligence are becoming more and more compatible [33]. Image processing activities require a significant amount of computing power; however, it is feasible to obtain accurate diagnoses without using high-end computing resources by optimising the algorithms for embedded platforms. By learning from massive sets of labelled photos, these AI models may learn to find a wide spectrum of plant illnesses, even in their early or asymptomatic stages. After being trained, the models can run on embedded hardware, constantly analysing new photos and marking any patterns that look suspicious for future investigation. This feature enhances the farming system's resilience by identifying and addressing potential threats promptly.

In a broader context, the use of smart hydroponic systems with built-in intelligence aligns with the global trend toward precision agriculture, which involves managing farming through technology that monitors, measures, and responds to changes in crops. Precision agriculture seeks to enhance field-level control in agricultural cultivation, resulting in heightened output, diminished environmental impact, and more effective resource utilisation. Farmers can make their farms more sustainable by monitoring and adjusting variables in real time [22]. This allows them to use less water, fertilisers, and pesticides while producing more crops.

Our study demonstrates how sensors, embedded systems, automation, and AI can collaborate to create farming environments that are highly sensitive and adaptable. Each sensor has a specific job: LDRs make sure the illumination is just right, temperature sensors keep the temperature stable, pH sensors make sure nutrients are available, and nutrient sensors make sure the right proportion of critical elements is present [18]. These inputs go into the embedded system, which interprets the data, makes judgments, and turns on the necessary actuators, such as lights, fans, pumps, and valves, to keep the conditions the way you want them. The disease detection module adds another layer of protection, which makes it possible to act quickly when biological dangers arise [41]. The embedded system is like the brain of the whole system. It ensures that all parts work together perfectly, providing the plants with the finest care possible.

In the future, these kinds of systems can be made even more powerful [89]. The system may work with weather forecasting services to predict and get ready for changes in the outside world, and then adapt the indoor climate as needed. You may use machine learning models not only to find diseases but also to guess when plants will grow and when they will be ready to be picked based on past data and current conditions [30]. You may connect energy management systems to make the best use of renewable energy sources, which will make the farm even more sustainable. As wireless sensor networks improve, it will become easier to expand the system to cover larger tasks without increasing complexity. This is because each node can work on its while still adding to the entire data pool.

In conclusion, the creation of our smart hydroponic system demonstrates how embedded technology and intelligent control systems can transform the way we farm today [24]. We have developed a system that not only enhances crop output and quality but also promotes resource efficiency and sustainability through the integration of accurate environmental monitoring, automated control, and advanced disease diagnosis. Embedded systems, despite their inherent limitations, provide a resilient and adaptable framework for developing such applications when augmented with intelligent algorithms and network connectivity (Figure 1). As technology continues to evolve, incorporating these systems into farming will become increasingly crucial for meeting the food needs of a growing global population while also reducing the environmental impact of farming [35]. The transition from conventional agriculture to a smart, data-driven methodology signifies a crucial advancement towards a future in which farming is not only more efficient and lucrative but also more sustainable and ecologically responsible.

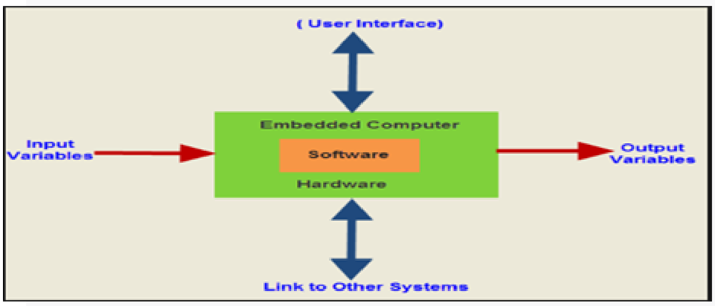

Figure 1. Embedded system.

Electronic Voting Machine's Embedded Computer Sub-Assembly. Figure 2 shows that embedded systems are often used in consumer, industrial, automotive, medical, commercial, and military settings [32]. Telecommunications systems utilise numerous embedded systems, including telephone switches for the network and cell phones for the end user. Dedicated routers and network bridges are used in computer networking to send data.

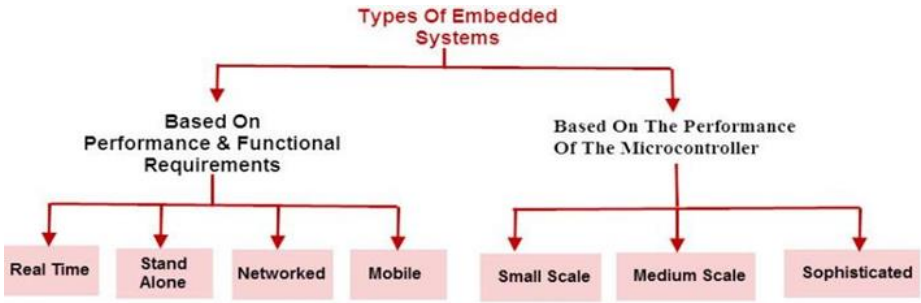

Figure 2. Classification of an embedded system.

Networked thermostats in advanced HVAC systems help keep the temperature more stable and accurate, even when it changes with the time of day or the season [88]. Using wired and wireless networks, home automation may handle things like lights, climate, security, audio and video, and surveillance. Embedded systems can be anything from portable gadgets like digital watches and MP3 players to big fixed installations [23]. They can also be things like traffic lights, factory controllers, and more complex systems like hybrid automobiles, MRI, and avionics. Complexity ranges from minimal to negligible with a single microcontroller.

An embedded system often includes an embedded processor. Embedded systems are used in many items with digital interfaces, such as microwaves, VCRs, and autos. Some embedded systems come with an operating system. Some are quite specialised; thus, the whole logic is put into one program [38]. Some gadgets have these systems built in for a specialised purpose other than general-purpose computing.

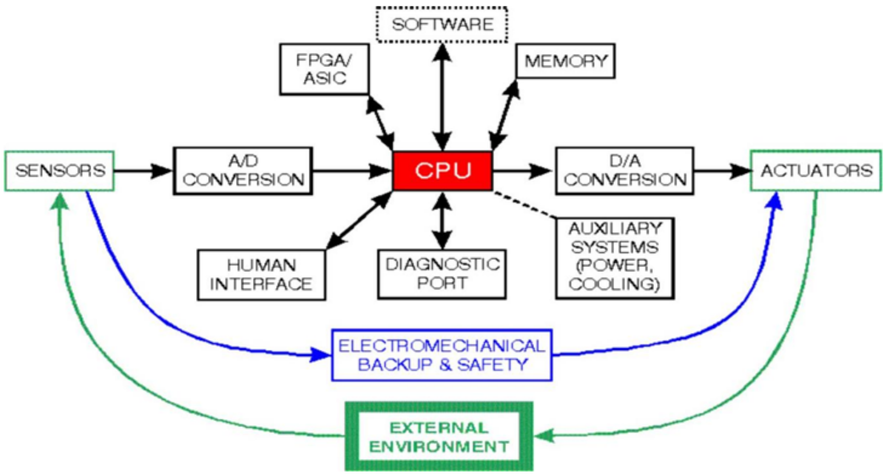

Figure 3. Block diagram of a typical embedded system.

Examples of embedded systems in cars include motor control, cruise control, body safety, engine safety, robotics on an assembly line, car multimedia, car entertainment, e-commerce access, mobile phones, and more [29]. Networking, mobile computing, wireless communications, and other things are all part of embedded systems in telecommunications. Smart cards have built-in systems for banking, phones, and security, see Figure 3.

Literature Review

Plants can grow without soil in hydroponics [7]. Instead, they use water and nutrients. This strategy is ideal for individuals residing in apartments or condos within urban areas. The Internet of Things (IoT) has made it much easier to monitor plants. The goal of this research is to develop an IoT system that enables the monitoring of plants in hydroponics [5]. It employs sensors and a microcontroller to monitor parameters such as pH, colour, water quality, temperature, humidity, and nutrition levels [2]. The information is relayed to a mobile app called Blynk, where users can see what their plants require and make changes, like adding water or fertiliser. This technique is wonderful for growing plants indoors since it makes it easy to keep them healthy.

People all across the world like hydroponics, which is growing plants in water instead of soil, because it saves space and water. It's especially helpful for vertical farming, which uses less dirt and labour [13]. However, indoor hydroponics can be expensive due to the high electricity consumption required to control factors such as sunlight and temperature. The Internet of Things (IoT) can help with smart farming [10]. In this study, we examined the potential of solar cells to save energy and explored how the Internet of Things (IoT) could facilitate smarter farming practices. We used IoT to gather data on how factors such as sunlight, humidity, and water affect the growth of hydroponic plants. Our goal was to uncover trends that would help us take better care of our plants [17].

This paper discusses a clever and cost-effective IoT system that can be used to monitor and regulate hydroponic greenhouses. There are three types of sensor nodes in the system: the main node, which regulates the water pump and examines the quality of the water; the environment nodes, which monitor the greenhouse conditions [4]. And security nodes that can tell when someone is moving [12]. It monitors the temperature, humidity, and water quality to ensure the plants develop well. Greenhouse owners can check these settings from afar using a website for quick monitoring.

In recent years, the farming business has faced challenges, including a shortage of workers and crops that often fail to grow as planned due to adverse weather conditions [15]. At the same time, more people are interested in home vegetable gardens and hydroponic systems because they are worried about chemicals in traditional farming. But many families, especially those with small children or busy schedules, struggle to start and maintain hydroponic systems. This work seeks to tackle these difficulties through the creation of an internet-controlled hydroponic system [1]. The system will be easy to operate and accessible from anywhere, allowing families to cultivate their own safe, pesticide-free vegetables with minimal time and effort [9]. This new idea aims to make hydroponics easier and more comfortable for families, encouraging them to grow their own nutritious and sustainable food at home.

Hydroponic farming is a way to deal with the problem of not having enough land for farming, which can make it harder to grow crops [87]. Precision agriculture poses a challenge in hydroponic farming, particularly for sensitive plants like bok choy and lettuce. To grow well, these sorts of plants need the right amount of water and nutrients every time. The Internet of Things (IoT) is a technology that lets us keep an eye on every part of our lives all the time [16]. One way to keep track of the plants' water and food needs is to check on them periodically. This study presents a monitoring and control system for hydroponic precision agriculture, utilising the Internet of Things (IoT) concept and fuzzy logic.

The Arduino Uno contains a poly fuse that can be reset. This protects your computer's USB ports from shorts and too much current. Most computers have built-in protection, but the fuse adds an extra layer of safety [8]. If you put more than 500 mA into the USB port, the fuse will immediately interrupt the connection until the short or overload is fixed. The Uno PCB is 2.7 inches long and 2.1 inches wide at its widest and longest points. The USB connector and power jack protrude beyond these points [3]. The board has four screw holes that let you attach it to a surface or case. Keep in mind that the space between digital pins 7 and 8 is 160 mil (0.16"), which is not a multiple of the 100-mil space between the other pins [14].

People usually have to turn on and off lights and appliances by hand regularly. However, the procedure for controlling appliances can waste power if people are careless or if something unexpected occurs [6]. To fix this, we may utilise the light-dependent resistor circuit to change the loads based on how bright the light is. A photo resistor or LDR is a device made from a semiconductor material with high resistance [11].

2. Methodology

An LDR is made by putting a light-sensitive substance on an insulating substrate, like ceramic [46]. To achieve the optimal power rating and resistance, the material is arranged in a zigzag configuration. The area zigzag divides the places with metal into two parts.

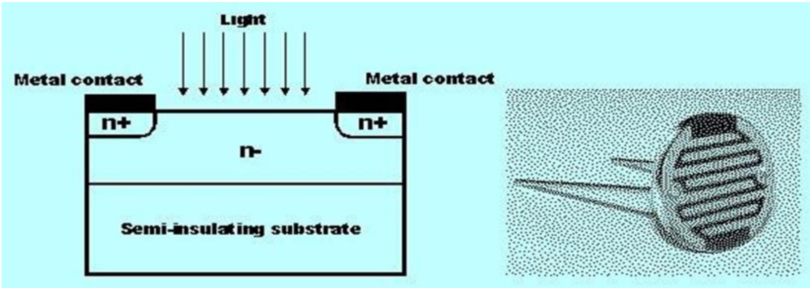

Figure 4. LDR Construction.

The resistance of the Ohmic connections must be as low as possible when they are made on the sides of the region. This ensures that the resistance changes only due to the light effect [45]. Lead and cadmium compounds are not used because they are bad for the environment (Figure 4). Photoconductivity is how an LDR works. This is just an optical phenomenon. The conductivity of the substance goes down when it absorbs light. When light hits the LDR, the electrons in the material's valence band want to move to the conduction band [92]. To have the electrons leap from one band to another (valence to conduction), the photons in the light that hits the material must have more energy than the band gap [50].

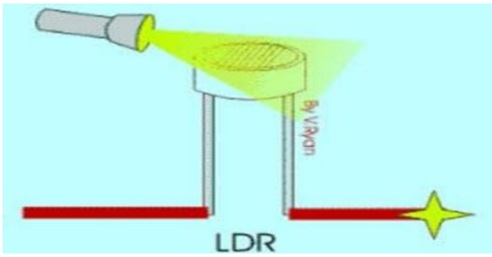

Figure 5. LDR.

So, when light has a lot of energy, more electrons move to the conduction band, which makes a lot of charge carriers [48]. As the effect of this process and the current flow increase, the device's resistance goes down, see Figure 5. The LDR circuit is an electronic circuit made up of an LDR, a relay, a Darlington pair, a diode, and resistors, as shown in the diagram below. The load gets power from a voltage source. A bridge rectifier circuit or a battery provides the LDR circuit with the DC voltage it needs. This circuit turns the AC power into DC power. A step-down transformer in the bridge rectifier circuit lowers the voltage from 230 volts to 12 volts. The diodes are linked together to make a bridge that changes AC voltage to DC voltage. The voltage regulator converts the 12V DC to 6V DC, which then powers the entire circuit [43]. To keep the light sensor circuit running all the time, a 230V AC supply must be kept going for both the bridge rectifier and the load.

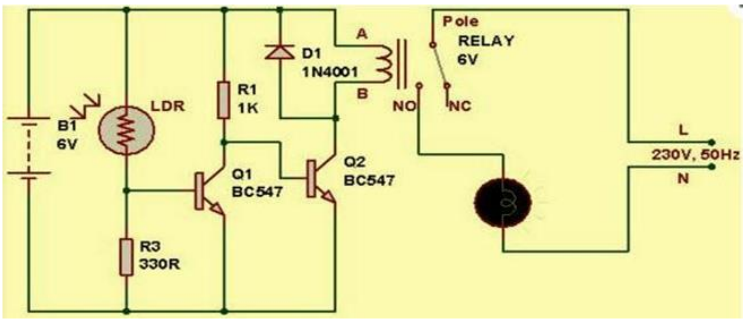

Figure 6. Light-Dependent Resistor Circuit.

This sensor has a low resistance of about 100Ω in the morning [49]. So, as indicated in the light sensor circuit above, the power supply goes through the LDR, the variable resistor and the resistor. This is because the light-dependent resistor (LDR) has less resistance throughout the day or when the light hits it than the rest of the sensor circuit [95]. We are aware of the current concept that current always flows down the path of least resistance, see Figure 6.

So, the relay coil doesn't get enough power to get stronger. So, the light goes out when the sun comes up [51]. The resistance of the LDR also goes up to a high value (20MΩ) at night. Because the resistor has a high resistance, the current flow is minimal or almost nonexistent. The low-resistance lane now lets current flow through it, which raises the base voltage of the Darlington pair to almost 1.4 volts. When the Darlington pair transistor is turned on, the relay coil receives sufficient power to activate, which is why the light switches on at night [47].

Light-dependent resistors are easy to use and cheap. People use these devices to determine if there is light. LDRs are employed as light sensors, and their principal uses are in burglar alarm circuits, alarm locks, streetlights, and light intensity meters [44]. We have discussed one project, the power saving of intensity-controlled lighting using LDR, to help you grasp this idea better.

3. Results and Discussion

The DHT11 is a simple, very cheap digital sensor that measures temperature and humidity [57]. It has a thermistor and a capacitive humidity sensor that measure the air around it and send a digital signal to the data pin (there are no analogue input pins needed). It's easy to use, but you have to be careful about when you gather data [75]. It may provide you with new data every 2 seconds; therefore, when you use the Adafruit library, sensor readings can be up to 2 seconds old. It comes with a 4.7K or 10K resistor that you should use to draw up the data pin to VCC, see Table 1. In the lab, each DHT11 element is carefully calibrated, and it is quite accurate when it comes to calibrating humidity. The OTP memory stores the calibration coefficients as programs [79]. The sensor's internal signal-detecting algorithm uses this memory [61]. The single-wire serial interface makes it straightforward and quick to connect systems. Because it is compact, uses little power, and can send signals up to 20 meters, it is the finest choice for a wide range of uses, even the most demanding ones. The part comes in a 4-pin single-row pin box [68].

Table 1. Pin Identification and Configuration.

No:	Pin Name	Description
		For DHT11 Sensor
1	VCC	Power supply 3.5V to 5.5V
2	Data	Outputs both Temperature and Humidity through serial Data

3	NC	No Connection, and hence, it is not used
4	Ground	Connected to the ground of the circuit

A pH meter tells you how many hydrogen ions are in a solution, and pH indicator paper changes colour depending on how acidic or basic a solution is [84]. The pH scale goes from 0 to 14, with seven being neutral. Acidic solutions have a pH below 7, whereas solutions that are alkaline have a pH above 7 [62].

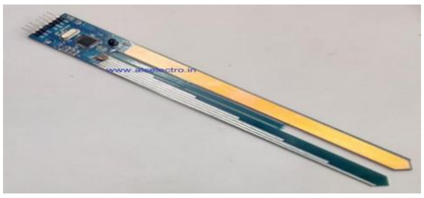

Figure 7. PH meter.

The pH meter tells you how many hydrogen ions are in a solution, and the pH indicator paper changes colour depending on how acidic or basic a solution is [63]. You can use pH to determine how acidic or basic something is. It can also be used to find out how acidic or basic a water supply is Figure 7.

Table 2. Pin Function.

1	VCC	Power supply 3.5V to 5.5V
2	Ground	Connected to the ground of the circuit
3	TX	Connected to the RX of the board
4	RX	Connected to the TX of the board

Water level sensors can tell how high liquids, other fluids, and fluidised solids are, such as slurries, granular materials, and powders that have an upper free surface [58]. Because of gravity, substances that flow become almost horizontal in their containers or other physical boundaries [56]. Most bulk solids, on the other hand, pile up at an angle of repose to a peak, see Table 2. The thing that needs to be measured can be in a container or its natural state. You can measure the level in either continuous or point values. Continuous-level sensors assess levels within a set range and determine the amount of material present in a specific spot [74].

Point-level sensors, on the other hand, tell you if the chemical is above or below the sensing point. In general, the latter finds values that are too high or too low [67]. Numerous physical and application factors go into choosing the best level monitoring system for business and industrial activities. The parameters for choosing include the physical: phase (liquid, solid, or slurry), temperature, pressure or vacuum, chemistry, dielectric constant of medium, density (specific gravity) of medium, agitation (activity), acoustical or electrical noise, vibration, mechanical shock, and the size and shape of the tank or bin [80]. Also, the application restrictions that matter include the price, accuracy, appearance, reaction rate, ease of calibration or programming, physical size and mounting of the instrument, and the ability to monitor or regulate continuous or discrete (point) levels [59]. In short, level sensors are very significant sensors that are used in many different consumer and industrial settings. Level sensors, like other types of sensors, can be made or bought utilising many different sensing techniques. Choosing the right sort of sensor for the job is quite crucial [76].

Figure 8. Water Level Sensor.

The ESP8266 Wi-Fi Module is a self-contained system on a chip (SOC) that has a built-in TCP/IP protocol stack. It lets any microcontroller connect to your Wi-Fi network. The ESP8266 may either run an application or take care of all Wi-Fi networking tasks for another application processor [55]. The ESP8266 has a 32-bit processor that can only understand 16-bit instructions. This is Harvard architecture, which means that the memory for instructions and data is not connected. The ESP8266 contains a die program Read-Only Memory (ROM) that has some library code and a boot loader for the first stage [93]. Wi-Fi modules or Wi-Fi microcontrollers broadcast and receive data over Wi-Fi, see Figure 8.

They can also take orders over Wi-Fi [73]. Wi-Fi modules enable devices to communicate with each other. Most of the time, they are employed in the Internet of Things [81]. Microcontrollers may connect to a Wi-Fi network and make simple TCP/IP connections using this little module. It operates at a voltage of 3V and can withstand a maximum of about 3.6V. A Serial Port makes it easy to connect to a microcontroller board [64]. Many breakout boards are built on the ESP8266 Wi-Fi Module, such as the ESP8266 NodeMCU V3. Because it is small, it is most useful for projects that don't need any help. It can be used as a standalone program or as a tool for enslaved individuals. If a microcontroller host controls the ESP8266 Wi-Fi, it can be used as a Wi-Fi adapter for any microcontroller that uses UART or SPI [69]. The module has the same functions as a microcontroller and a Wi-Fi network when it is used on its own.

A programming language is a group of functions that work together to do a certain job. Most people are familiar with application software that enables them to perform tasks on their computers [85]. Embedded software, on the other hand, is typically harder to see but just as hard to understand. Embedded software has set hardware needs and abilities, and adding third-party hardware or software is rigorously restricted. Application software does not have these restrictions. At the time of production, embedded software must include all necessary device drivers [52]. These drivers are built for the specific hardware. The software relies heavily on the CPU and the chips that were chosen. Most embedded software engineers know how to read schematics and data sheets for parts to figure out how to use registers and communication systems [77]. It is helpful to be able to switch between decimal, hexadecimal, and binary, as well as to employ bit manipulation. People don't use web apps very often, yet they can send XML files and other output to a computer to show [94].

There are usually no file systems with directories or SQL databases [82]. A cross-compiler is needed for software development. It operates on a computer but creates code that can be run on the target device [60]. To debug, you need to use an in-circuit emulator, JTAG, or SWD. Often, software developers can see the entire kernel (OS) source code. The amount of storage memory and RAM might be very different. Some systems have a CPU that runs at 8 MHz, 16 KB of Flash, and 4 KB of RAM. Other systems can compete with modern computers. [8] Because of these space needs, more work is done in C or embedded C++ than in C++. People don't often utilize interpreted languages like BASIC (even though compiled BASIC may be used with Parallax Propeller) and Java (Java ME Embedded 8.3[9] is available, for Example, for ARM Cortex-M4, Cortex-M7 microcontrollers, and earlier ARM11 microcontrollers used in Raspberry Pi and Intel Galileo Gen. 2). MicroPython is an implementation of the interpreted Python 3 language that is specifically designed for usage with microcontrollers, such as 32-bit ARM-based (such the BBC micro: bit) and 16-bit PIC microcontrollers [70]. Processors need to be able to talk to each other and other parts of the system. I²C, SPI, serial ports, and USB are among the most used protocols, along with direct memory access, see Figure 9.

This program shows you how to use structure inside structure in C using regular variables [72]. In this software, the "student_college_detail" structure is declared inside the "student_detail" structure. Both structure variables. Please note that the two-dot (.) operator is used to access members of the "student_college_detail" structure, while members of the "student" structure are normal variables [65]. A single dot (.) operator lets you get to "Detail" structures.

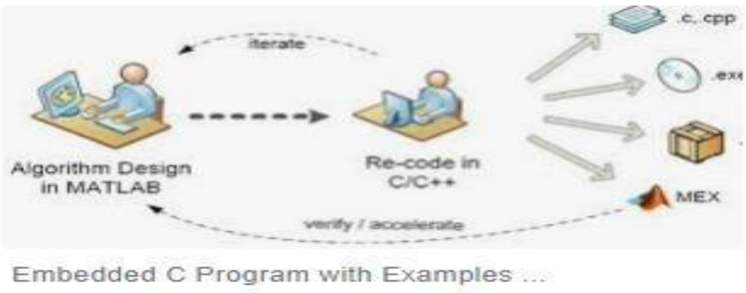

Figure 9. Embedded C program with Example.

A keyword is a word that has a special meaning to the compiler (for Example, a C compiler is software that turns programs written in C into machine code). Visual Studio Code (VS Code) has been really helpful in making our smart hydroponic plant monitoring system [66]. It has been a smooth and effective integrated development environment (IDE) for our team. The integrated terminal has made it easy for us to work with both the front and back ends of the system, which has made it easy to make changes and fix problems quickly [86]. VS Code's support for many languages has been really helpful. We use Python for backend logic, JavaScript for frontend interfaces, and specialised libraries for machine learning [53]. The inclusion of Git into VS Code has made version control and collaborative development easier by letting us stage, commit, push, and pull changes right from the IDE (Figure 10).

Also, the huge marketplace of extensions has helped us change our environment with tools like IntelliSense for code completion, GitLens for better Git features, and the Python extension for bespoke Python development [71]. Breakpoints and step-through debugging are two examples of debugging tools that have been very helpful in quickly finding and fixing problems [83]. The Live Share addon has made it easier for team members to work together in real time, which is very important while working from home. Finally, using tasks and runners to automate jobs has made our workflow more efficient by automating repetitive operations and developing processes [54]. In short, adding Visual Studio Code has significantly enhanced our project's success by increasing productivity, improving code management, facilitating collaboration, and enhancing the overall development process for our smart hydroponic plant monitoring system [78].

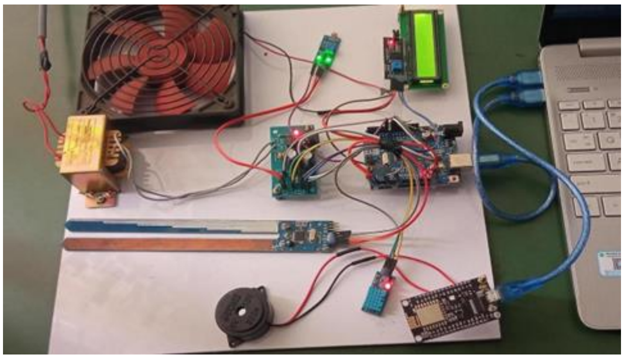

Figure 10. Hardware Result.

4. Conclusion

In conclusion, our smart hydroponic plant monitoring system represents a significant advancement in farming technology. By seamlessly connecting sensors and actuators, we've created an autonomous environment that enables us to make precise adjustments to improve the conditions for plant development. The system keeps an eye on and reacts to light, temperature, water quality, and nutrient levels in real time. This makes sure that plants have the best conditions for healthy growth. We've also added advanced disease identification using deep learning, which lets us act quickly to stop crop losses.

The combination of technology and software in this system allows for precise control, which makes plants grow better and makes farming more efficient. We're moving toward sustainable and automated agriculture by giving farmers the tools to care for their plants automatically. Our method enhances plant growth, optimises resource use, and effectively controls diseases. This means that farming will be more sustainable and productive in the future.

This project built a sophisticated hydroponic plant monitoring system that offers numerous benefits. It helps plants grow effectively by monitoring factors such as light, temperature, water quality, and nutrients. This is highly useful for large hydroponic farms where it would be hard to inspect everything by hand. It also saves water and nutrients, which makes hydroponic farming more sustainable. The device can even detect infections early in spinach leaves, preventing significant crop losses. Farmers can use the system from anywhere, change settings, and receive alerts on their phones. This is perfect for farmers with multiple farms or those who travel frequently.

The system also helps save energy by adjusting how lights, fans, and water pumps work depending on real-time data. This not only saves electricity, but it also reduces farmers' expenditures. Also, using deep learning to find diseases makes it possible to enhance the accuracy of disease recognition over time, which helps safeguard crops from infections. Also, the technology makes workers more productive by reducing the need for human monitoring and intervention. Farm workers can be assigned to more specific jobs, which will make the farm more productive as a whole. Finally, the system's ability to log data lets farmers look at past trends and make smart choices about how to manage their crops.

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