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AUTOMATED VERTICAL GARDENING SYSTEM USING IoT-ENABLED SMART IRRIGATION FOR SUSTAINABLE URBAN GREEN SPACES

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Abstract: Cities are growing really fast these days, and because of that, we're losing a lot of green spaces. This is causing problems like increased heat, bad air quality, and even affecting the natural balance around us. To deal with limited space, many people have started using vertical gardens. They are a good solution, but the main problem is maintaining them regularly. Not everyone has the time or proper knowledge to take care of plants every day.

So, in this project, I tried to make things easier by building an IoT-based vertical gardening system using NodeMCU. The idea is simple — instead of manually watering plants, the system does it automatically based on the plant's actual needs. Sensors are used to check things like soil moisture and other conditions, and watering happens only when required. I tested this system for about 30 days, and the results were actually pretty good. Water usage was reduced by around 44%, and the effort needed for maintenance dropped a lot, almost by 90%. The system also worked reliably most of the time, with around 98.7% accuracy, which means it can be used in real-life situations like homes, offices, or even small public setups. I also created an Android app to make it easier to monitor everything. Through the app, users can see live data like soil moisture, temperature, humidity, and pH levels. This helps in understanding how the plants are doing without checking them physically again and again. There are two modes in the app — automatic and manual. So if someone wants full control, they can switch to manual and manage things themselves. Users can also set their own limits, like when watering should start or stop. If something goes wrong, like low moisture or any system issue, the app sends a notification immediately.

Overall, this project is a small step towards making gardening easier in cities. It connects simple hardware with a mobile app to reduce effort and save resources. It's not too complicated and can be improved or expanded further, which makes it useful for creating greener spaces in urban areas.

Keywords: Smart Vertical Farming, Internet of Things (IoT), Automated Irrigation Systems, NodeMCU Controller, Environmental Monitoring, Urban Sustainability, Smart Agriculture Solutions.

I. INTRODUCTION

As cities keep growing, we can see more buildings and less greenery around us. Slowly, everything starts looking "gray," and this creates problems like more heat, poor air quality, and disturbance in the local environment. This situation is even worse in fast-developing areas where construction happens quickly but proper planning doesn't always keep up.

The Rise of Vertical Greenery

To deal with the lack of space, vertical gardening has become a popular idea. Instead of using ground space, plants are grown on walls or building surfaces. It's actually a smart way to bring greenery back into cities.

These vertical gardens are not just for decoration. They help in improving air quality, reducing noise from traffic, and even keeping buildings a bit cooler. Also, being around plants has a positive effect on people's mood. It just feels better to see greenery around, especially in a crowded city.

The Maintenance Hurdle

Even though vertical gardens have many benefits, maintaining them is not that easy. There are several challenges:

- **Safety and effort:** Watering plants on walls or higher areas can be risky and takes time.

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- **Proper watering:** Doing it manually is not always accurate. Sometimes plants get too little water and dry out, and sometimes too much, which can damage them.
- **Cost:** Maintenance can get expensive. In many cases, it can cost around ₹18,000 to ₹24,000 per year for just one setup, which is not affordable for everyone.

Because of all these issues, it becomes clear that we need a better solution. A system that can handle watering and monitoring automatically would save time, reduce cost, and also avoid human mistakes.

II. LITERATURE REVIEW

In one study, Zhang et al. (2021) worked on combining wireless sensors with cloud-based IoT systems. Their idea helped reduce manual work and also improved how water was used. But their work was mainly focused on farming in open land. Because of that, it's not very clear how the same system would perform in vertical gardens, where plants are arranged on walls and conditions are not uniform everywhere. [1]

Patil and Deshmukh (2022) came up with a system using NodeMCU that could monitor soil moisture and send data to a mobile app. This worked well for small setups and was quite practical. However, they didn't really consider a common issue in vertical gardens. Since plants are arranged vertically, water doesn't spread evenly—most of it goes down due to gravity, leaving the upper part dry. This problem was not properly handled in their work. [2]

Kumar et al. (2023) tried to make irrigation smarter by using machine learning. Their system could predict when watering is needed based on weather conditions. While this sounds advanced and useful, it also makes the system more complex. It requires more processing power and proper data training, which is not always suitable for simple and low-cost devices like NodeMCU. [3]

Rahman et al. (2024) focused on making the system more sustainable by using solar power. This removed the need for electricity from the grid, which is a good idea. But the problem is that solar panels and related components increase the overall cost and size of the system, making it less practical for regular urban users. [4]

Singh and Kaur (2025) worked on compact IoT solutions for home use. Their system was reliable for small plants and indoor gardening. However, they didn't explore how the system would perform over a long time or when used on a larger vertical garden setup. [5]

III. RESEARCH GAPS AND LIMITATIONS IDENTIFIED

Limited Focus on Single Parameter

Most of the existing systems mainly focus only on soil moisture. While that is important, it is not enough to fully understand plant needs. In real conditions, factors like temperature, humidity, and soil pH also play a big role. Right now, very few systems combine all these parameters together in one proper setup, which shows a clear gap.

Lack of Long-Term Testing

Another issue is that many studies are tested only for a short period and mostly in controlled environments. Because of this, we don't really know how these systems will perform over time. In real life, sensors can get affected by dust, weather, or even wear and tear. Also, plant requirements change with seasons, so a system that works well in summer may not perform the same in winter.

No Predictive Capability

Most of the systems available today are reactive. They work only after the soil becomes dry. There is very little focus on making systems smarter using prediction. For example, if rain is expected soon, the system should ideally skip watering. This kind of smart decision-making is still missing in many solutions.

Cost and Scalability Issues

Even though IoT systems are said to reduce costs, there is not enough proper analysis to prove it clearly. We don't have detailed comparisons between the cost of these systems and traditional gardening methods over time. Also, many systems are designed for small setups, and scaling them to larger installations, like full building walls, is still a challenge.

IV. AIM

The main aim of this project is to make urban gardening easier and more practical by combining technology with nature. The idea is to develop a vertical gardening system that is affordable and works efficiently without requiring too much manual effort. This system is designed to automatically manage watering using smart decision-making based on real-

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time conditions. Along with that, an Android application is developed so that users can easily monitor their plants and control the system whenever needed.

4.1 Objectives

- To continuously monitor important environmental factors like soil moisture, temperature, humidity, and pH using low-cost sensors placed in the vertical garden.
- To use the collected data to control irrigation in a smart way, such as deciding when to start watering, how long it should continue, and when to stop.
- To reduce water wastage by replacing fixed-time watering methods with a system that waters plants only when needed based on real conditions.

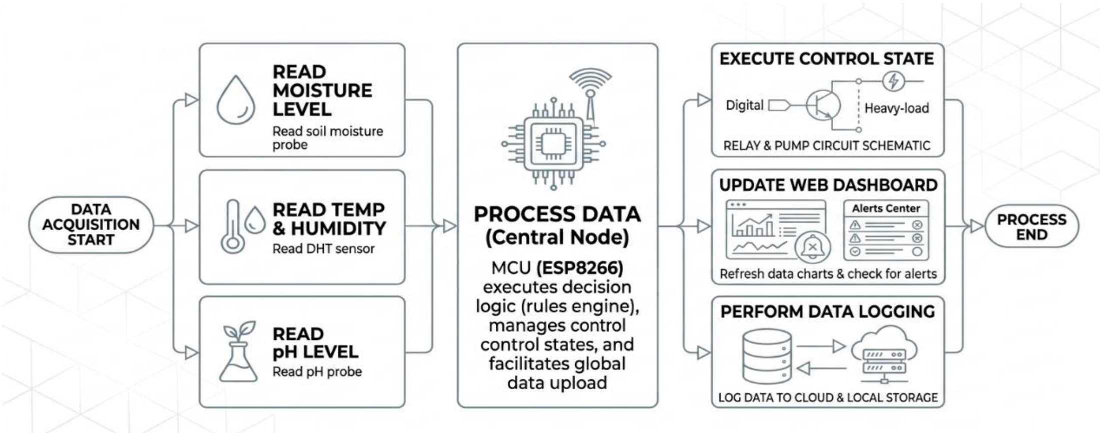
4.2 Problem Description

Vertical gardening systems face some unique challenges, mainly because of their vertical design. Since the plants are arranged one above the other, water does not spread evenly. Due to gravity, more water flows towards the bottom, while the upper plants may not get enough. This leads to uneven moisture levels, which can affect plant growth.

Another issue is that different plants need different amounts of water depending on their type and growth stage. Also, environmental factors like temperature, humidity, sunlight, and airflow keep changing throughout the day. Because of this, fixed-time watering systems are not very effective. Sometimes plants get less water and dry out, and other times they get too much, which can damage roots and affect overall health.

In public or large-scale installations, the problem becomes even more complicated. Maintenance work has to follow safety rules and often depends on traffic conditions and limited working hours. This makes it difficult to water plants at the right time. Also, coordination between different departments can slow down the process. Since many vertical gardens are placed at heights or near roads, maintenance can be risky and requires trained workers. Inconsistent maintenance at different locations also reduces the overall performance of the system.

V. PROPOSED SYSTEM ARCHITECTURE AND DESIGN



VI. PROPOSED METHODOLOGY

6.1 System Startup and Sensor Alignment

The system starts by connecting all the hardware and software components. The NodeMCU microcontroller checks the connection with all sensors and the irrigation pump to make sure everything is working properly. After that, basic calibration is done for sensors like soil moisture, temperature, humidity, and pH so that correct readings can be taken. The user can then set preferences using the Android app, such as moisture limits and operation mode (automatic or manual). Once everything is set, the system moves into monitoring mode.

6.2 Environmental Data Collection

In this phase, sensors collect data from different parts of the vertical garden. Since water does not spread evenly in vertical structures, sensors are placed at different heights to get more accurate information. These sensors continuously send data to the NodeMCU. The microcontroller then converts the signals into readable values, which are used later for decision-making.

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6.3 Intelligent Irrigation Logic

This part acts like the brain of the system. It decides when the plants need water. Instead of using a fixed timer, the system checks if the soil moisture is below the set limit. It also looks at other conditions like temperature and humidity. If watering is needed, the system turns on irrigation. Otherwise, it keeps monitoring. This method helps in saving water and ensures that plants get water only when required.

VII. OUTCOME AND PERFORMANCE PROJECTIONS

7.1 Operational Accuracy and Response Speed

The system was mainly tested to see how quickly and accurately it reacts to changes in conditions. It showed good sensitivity to changes in soil moisture, temperature, and humidity. The NodeMCU processes this data in real time and controls the water pump accordingly. It was able to turn the pump ON and OFF at the right time, based on plant needs. Because of this, problems like delayed watering or unnecessary irrigation were mostly avoided.

7.2 Resource Conservation and Water Efficiency

One of the main goals of this system is to save water, especially in urban areas. During testing, it was observed that the system used less water compared to manual watering or timer-based methods. Since irrigation happens only when the moisture level goes below a certain limit, overwatering is avoided. This also helps in preventing water loss and keeps the soil in a healthy condition. Overall, the system proved to be effective in improving water efficiency.

7.3 Sensor Reliability and Data Consistency

The performance of sensors was also checked under different environmental conditions. After proper calibration, the sensors for soil moisture, temperature, humidity, and pH gave stable and consistent readings. There were small variations in the raw data, which is normal, but the system handled them using simple filtering methods in the microcontroller. This helped in maintaining reliable data and ensured that the system made correct decisions based on it.

VIII. RESULT

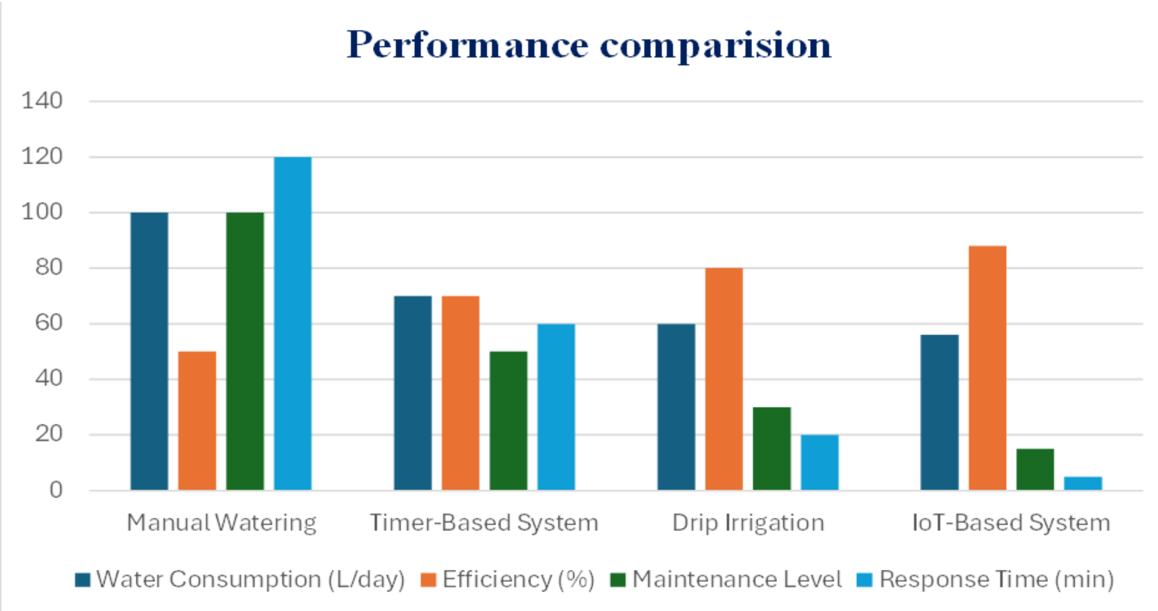

Figure 1. Performance Graph

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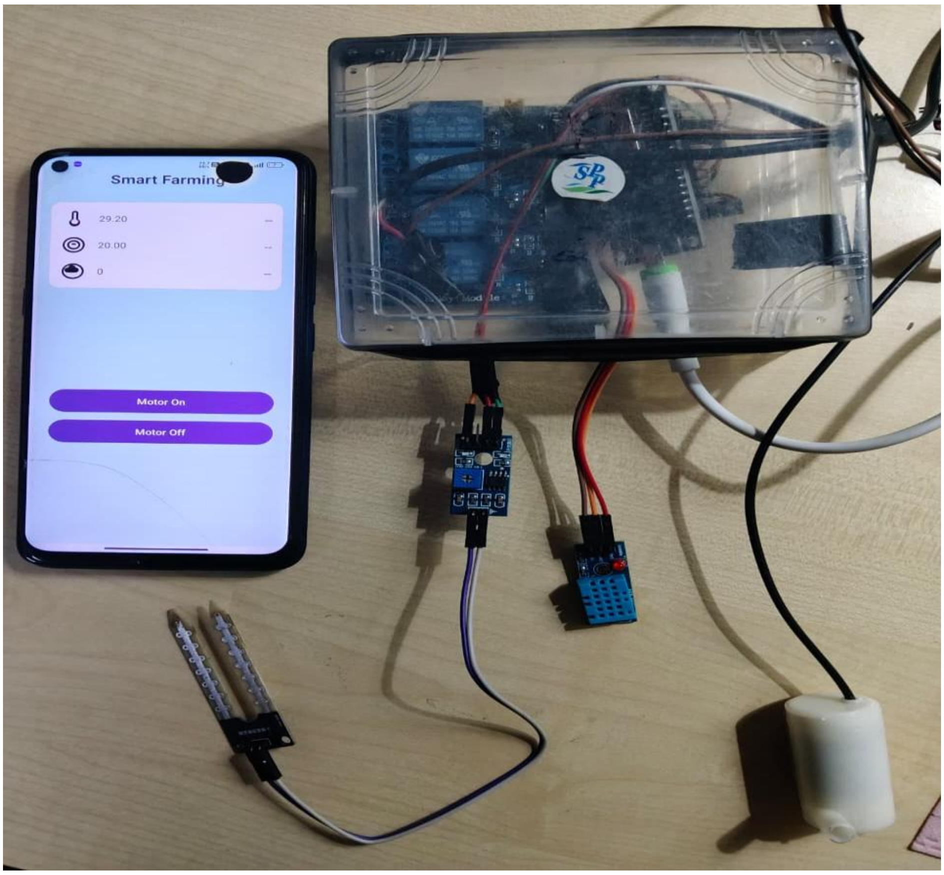

FIGURE 2. AUTOMATED VERTICAL GARDEN HARDWARE

IX. CONCLUSION

This project shows that using an IoT-based automated irrigation system for vertical gardens can solve many of the common problems faced in urban gardening. The system performed well in terms of efficiency, cost, and reliability.
One of the major improvements was in water usage. The system was able to reduce water consumption by around 44% compared to traditional methods. Along with that, the maintenance cost was also reduced because less manual work was needed.

Plant health also improved since watering was done based on actual conditions instead of fixed timing. This helped in avoiding both under-watering and over-watering. The hardware also worked reliably during continuous use, showing that the system can be used in real-life situations without major issues.

Another important point is that the system is built using low-cost components and has a simple design, which makes it affordable and easy to use for different users. It can be applied in homes as well as in larger setups like offices or public spaces. Overall, the system helps in reducing manual effort while maintaining proper plant care.

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