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Design and Development of a Smart Plant Assistant

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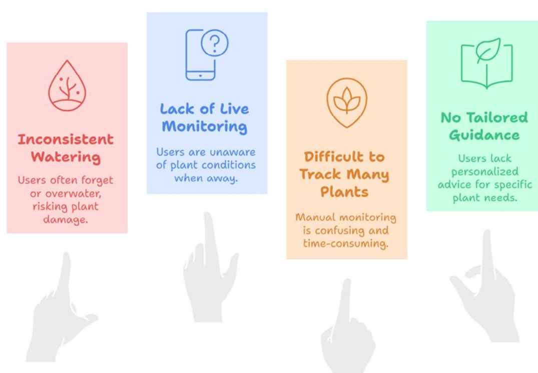
Abstract: This paper presents the design and development of a Smart Plant Assistant, an IoT-based device designed to support urban gardeners, plant shop owners, and hobbyists in monitoring plant health through real-time data and automation. The system integrates a solar-powered ESP32 microcontroller with a soil moisture sensor, DHT22 temperature-humidity sensor, BH1750 light sensor, OLED display, and a mobile application. A mini water pump controlled via relay enables automatic irrigation, while a Wi-Fi camera offers remote visual monitoring and helps detect plant infections. The mobile app includes a dashboard for managing multiple plants, real-time alerts, and care tips. Developed using a structured product design process—from user research to prototyping and testing—the system is modular, scalable, and adaptable to different garden sizes. Supporting 4–6 plants per device, it is cost-effective, compact, and encourages better plant care habits. Ultimately, it bridges the gap between manual gardening and smart agriculture by providing a comprehensive and sustainable solution for modern plant care.

Keywords: Smart Plant Assistant, Urban Gardening, IoT, ESP32, Soil Moisture Sensor, Automatic Irrigation, Mobile App, Plant Health Monitoring, Real-Time Alerts, Multi-Plant Care

I. INTRODUCTION

Gardening has long been valued for its contributions to well-being, environmental sustainability, and aesthetics. However, maintaining healthy plants can be challenging for urban dwellers, working professionals, and hobbyist gardeners due to inconsistent care routines, limited knowledge, and time constraints. With the rise of smart technologies and IoT, there is an opportunity to address these issues through automation and real-time monitoring.

The Smart Plant Assistant was conceptualized to bridge the gap between manual gardening practices and the advantages of smart agriculture. It leverages low-cost hardware and sensor-based intelligence to monitor vital plant parameters such as soil moisture, ambient temperature and humidity, and light levels. The system integrates with a mobile application to provide real-time data, alerts, and actionable care tips, thereby improving user engagement and plant health outcomes.



The project follows a human-centred design methodology that began with user research to understand gardening habits, pain points, and preferences. The insights gathered helped inform the functionality, form factor, and app features. The resulting prototype demonstrates a scalable and user-friendly system that supports up to 4–6 plants with a single device, providing an affordable and accessible solution for modern gardening challenges.

II. LITERATURE SURVEY

Several studies and technologies have been explored to understand existing smart gardening solutions and the challenges faced by plant caretakers. Research by Astuti et al. (2023) and Ranjitha & Lakshmi (2021) highlights the effectiveness of IoT-based systems for plant monitoring, emphasizing the importance of soil moisture, temperature, and humidity tracking. Commercial products such as the Xiaomi Smart Flower Monitor and Parrot Flower Power offer plant monitoring features but often focus on single-plant use and lack integration with automatic irrigation or modular scalability.

Additionally, literature from horticultural sources like the University of Florida IFAS Extension (2021) and Urban Homestead provides insights into practical plant care habits and common user pain points, such as inconsistent watering and sunlight exposure. The integration of sensors like BH1750 for light and capacitive sensors for soil monitoring is widely supported in both academic and practical gardening contexts.

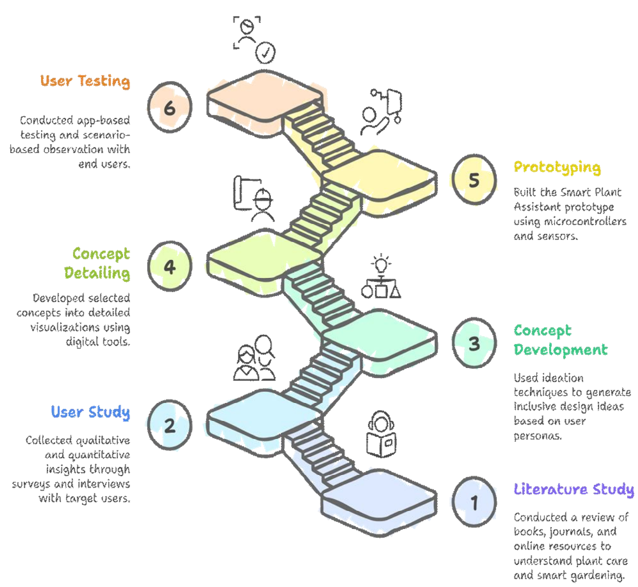
These references informed the development of a multi-functional, solar-powered plant assistant capable of monitoring multiple plants simultaneously while providing real-time alerts and actionable insights through a mobile application. The reviewed literature provided essential direction in designing a user-centred, scalable system that bridges the gap between manual plant care and smart automation.

III. METHODOLOGY

The development of the Smart Plant Assistant was guided by a structured and multi-phase methodology aimed at delivering a user-centred and technically sound product. The process began with a literature review to understand the context of plant care and smart gardening technologies. This was followed by user research involving surveys and interviews to uncover real-world challenges and expectations across diverse user groups.

Insights gathered during the research phase informed the ideation and concept development stages, which involved sketching, form exploration, and early visualization. These ideas were refined through CAD modelling and digital rendering before moving into manual and electronic prototyping using ESP32 and various environmental sensors. The final phase involved user testing, where the working prototype was evaluated through direct feedback and scenario-based observation to validate usability, effectiveness, and alignment with user needs.

This comprehensive methodology ensured that each design decision was backed by research, iteration, and real-world validation. The Smart Plant Assistant was developed using a structured, user-centric product design methodology. The process began with a literature review and user research to define the problem space. This was followed by concept development, prototyping, and testing to ensure alignment with real user needs.



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The design methodology followed six key stages:

1) Literature Study: Analysis of existing academic and market research on plant care, IoT systems, and gardening behaviour.
2) User Research: Surveys and interviews with diverse plant owners to understand pain points and feature expectations.
3) Concept Development: Ideation, sketching, and brainstorming based on personas and research insights.
4) Concept Detailing: CAD modelling, UI mock ups, and digital rendering to finalize form and function.
5) Prototyping: Development of a working prototype using ESP32, sensors, and a mobile interface.
6) User Testing: Scenario-based testing and user feedback to evaluate usability and system performance.

This iterative process ensured that the final solution was research-backed, functionally relevant, and user-friendly.

IV. DATA COLLECTION AND ANALYSIS

To understand user behaviour and validate the need for a Smart Plant Assistant, a mixed-method approach was adopted. Data was collected via an online Google Form survey (87 responses) and one-on-one interviews (8 participants) with plant owners across various settings—urban homes, balconies, terraces, shops, and small farms.

The survey collected both quantitative and qualitative data on:

1) Number and types of plants owned
2) Watering habits and schedules
3) Challenges in maintaining plant health
4) Awareness of smart gardening tools
5) Desired features and pricing expectations

Key insights included the need for:

a) Real-time mobile alerts for watering and light conditions
b) Automatic irrigation to reduce manual effort
c) Solar-powered operation for outdoor use
d) A single device capable of monitoring multiple plants

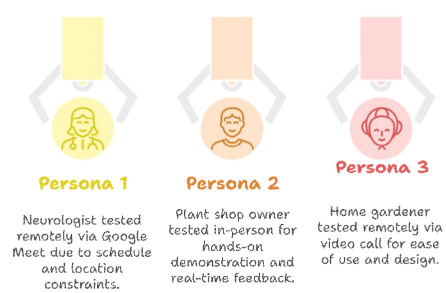
These findings informed the product's features and validated its relevance to a broad range of users. These insights directly influenced the design decisions, ensuring the product was practical, user-friendly, and scalable. Analysis revealed strong demand for a compact, scalable, solar-powered smart solution that provides real-time care tips, alerts, and automation.

V. USER PERSONA DEVELOPMENT

To guide the design and functionality of the Smart Plant Assistant, three detailed user personas were developed based on primary research data. These personas represented a diverse range of plant caretakers, helping to humanize user needs and prioritize design features.

The personas included

1) A full-time neurologist, uses balcony gardening as a therapeutic escape from her demanding medical schedule
2) A plant shop owner managing bulk stock with over 200 varieties of plants
3) A housewife who has a large kitchen garden with a variety of vegetables & herbs and a strong interest in plants



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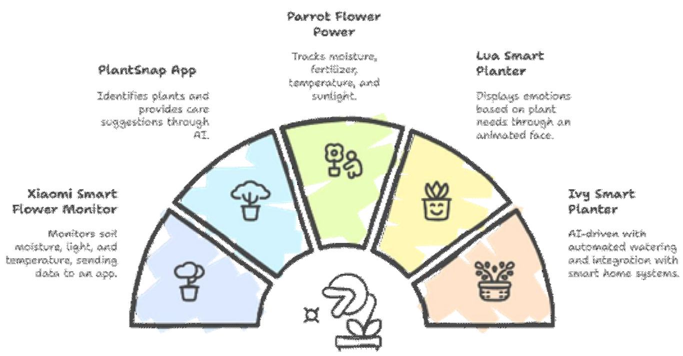
Each persona captured key information such as goals, challenges, gardening frequency, technical familiarity, and expectations from a smart assistant. This helped ensure that the final product addressed varying needs—whether for simplicity, affordability, automation, or scalability—making the solution accessible across different lifestyles and skill levels.

VI. BENCHMARK AND MARKET STUDY

The research began with a detailed evaluation of existing plant care and gardening assistant products, focusing on smart devices available in the market. This included both commercial solutions and DIY hobbyist systems aimed at automating tasks such as watering, light monitoring, and climate tracking.

A comprehensive market and product benchmarking study was conducted to evaluate existing smart plant care devices. This included both commercial products and hobbyist solutions such as the Xiaomi Smart Flower Monitor, Parrot Flower Power, Lua Smart Planter, Ivy Smart Planter, and PlantSnap. Each product was assessed based on functionality, usability, limitations, and cost-effectiveness



The benchmarking study examined these five existing smart gardening products to evaluate their features, limitations, and market positioning.

Key takeaways from this review were:

1) Most products are designed for single plant means lacking support for multi-plant monitoring
2) Primarily suited for indoor environments
3) Rely on battery-powered systems, making it less suitable for continuous outdoor adaptability
4) Users frequently reported issues with connectivity, battery limitations, and data inaccuracy.
5) There is little to no provision for real-time feedback on plant health or proactive care suggestions.

This comparative assessment revealed that while many products offer isolated functionalities—like soil moisture detection or ambient light measurement though lacks multi-plant monitoring experience. Furthermore, affordability, outdoor use capability, and adaptability across different plant types were commonly lacking.

These insights revealed critical gaps and inspired the concept of a solar-powered, compact Smart Plant Assistant that not only senses real-time conditions but also sends alerts and guidance through a connected mobile app—making it useful for plant lovers in both urban and rural contexts.

VII. SYSTEM ARCHITECTURE AND DESIGN PROCESS

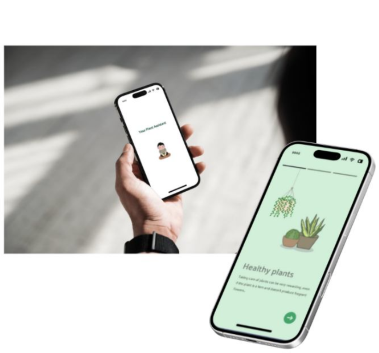
The Smart Plant Assistant was designed with a modular architecture that integrates hardware sensors, a microcontroller, a solar-powered system, and a user-friendly mobile application. The core of the device is based on the ESP32 development board, which supports Wi-Fi connectivity for real-time data transmission and remote monitoring.

Key hardware components include:

1) Capacitive Soil Moisture Sensor for detecting soil hydration levels
2) DHT22 sensor for temperature and humidity readings
3) BH1750 sensor for ambient light detection
4) OLED display for real-time on-device feedback
5) Relay-controlled mini water pump for automatic irrigation
6) Wi-Fi camera module for visual plant monitoring
7) Solar panel, 18650 battery and TP4056 charging module for power supply

All sensors are connected to the ESP32 through specific GPIO pins, with power distribution via a breadboard. The sensors continuously transmit data to the mobile app, where users can monitor real-time parameters, receive alerts, and activate watering manually or through automation logic.

The mobile application interface was developed with a focus on simplicity and clarity. It allows users to:
1) Add and manage multiple plants
2) View real-time plant health parameters
3) Receive alerts and care tips
4) Track watering history



This design ensures that the system is compact, scalable, and suitable for a wide range of users—from balcony gardeners to small-scale farm owners.

VIII. PLANTATION LAYOUT & SPACE CONSIDERATION

This section focuses on spatial considerations for practical plant setup using the Smart Plant Assistant. The system was tested across various planting arrangements including balcony pots, terrace rows, and clustered plant groups. Layout planning emphasized maximizing sunlight access, sensor range efficiency, and minimal disruption to plant spacing.

Layout and space guidelines include:
1) Each device can effectively monitor 4 to 6 plants when placed centrally among them
2) Optimal distance between plants: 25–40 cm depending on species
3) Solar panel requires unobstructed sun exposure for at least 5–6 hours daily
4) Plant grouping around the sensor allows consolidated watering via the mini-pump

Additional layout configurations explored during testing included:

a) Rectangular planter box (e.g., 60cm x 20cm): Ideal for herbs and balcony plants with the sensor positioned at one end or in the middle.
b) Soil bed layout: Used in terrace or outdoor gardens, where plants are aligned in a single row or linear cluster.
c) 2×3 grid layout: Suitable for outdoor or semi-urban gardens where six plants are arranged in two rows of three. The device is placed centrally for equal access to all plants.

This layout flexibility ensures the assistant is effective in both small balcony gardens and semi-structured terrace or farm setups.

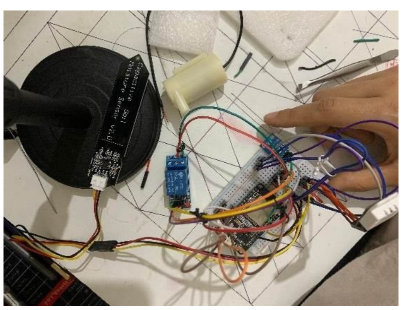
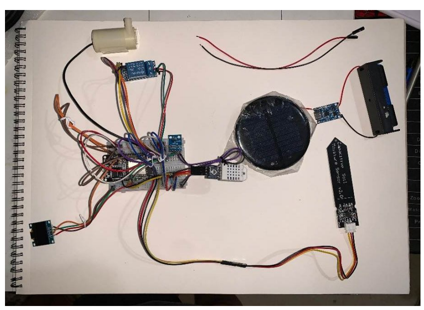
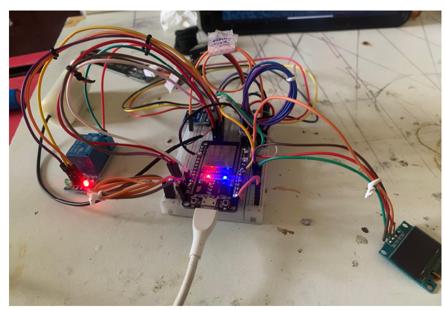
IX. HARDWARE AND SOFTWARE IMPLEMENTATION

The Smart Plant Assistant was built around the ESP32 microcontroller, chosen for its built-in Wi-Fi, GPIO flexibility, and low power consumption.

A. *Hardware Implementation*

1) Capacitive Soil Moisture Sensor connected to GPIO D34
2) DHT22 Temperature & Humidity Sensor connected to GPIO D4
3) BH1750 Light Sensor using I2C via GPIO D22 (SDA) and D21 (SCL)
4) OLED Display (128×64) connected via I2C to GPIO D22 (SDA) and D21 (SCL)
5) Relay Module (for water pump control) connected to GPIO D14
6) Mini Water Pump powered through relay switching
7) Wi-Fi Camera Module (used for remote visuals and infection monitoring)
8) Solar Panel, 18650 Battery, TP4056 Charging Module as power supply system

All components are assembled on a breadboard during the prototype phase. Power regulation is handled through the TP4056 module, and connections are organized with jumper wires and 10k resistors where needed for sensor like DHT22.

B. *Software Implementation*

The firmware was written using the Arduino IDE. Libraries such as Adafruit_SSD1306, DHT, Wire, BH1750, and Wi-Fi were used for controlling the OLED, sensors, and network communication. The ESP32 sends live data to the connected mobile application via Wi-Fi, and triggers irrigation when soil moisture is below threshold.

The mobile app was developed using UI mock ups that included dashboards for each plant, real-time readings, alert systems, and a watering history log. It was designed to be intuitive for both tech-savvy and non-technical users.

X. TESTING AND RESULT

The Smart Plant Assistant was tested in real-world scenarios across a variety of planting conditions—indoor, balcony, and terrace gardens. The testing phase was aimed at evaluating sensor accuracy, device reliability, irrigation logic, and user satisfaction.

Key outcomes from testing:

1) Sensor Accuracy: Moisture, temperature, humidity, and light readings were consistently accurate with minimal calibration drift.
2) Irrigation Response: The mini water pump was triggered automatically when moisture levels dropped below the threshold. Manual override via app worked effectively.
3) App Connectivity: The device maintained stable Wi-Fi communication with the app, delivering real-time data and notifications without lag.

4) Battery Life: The solar-charged 18650 battery lasted through daily operations with minimal sunlight dependency.
5) Multi-plant Coverage: A single device successfully monitored and assisted up to 6 plants in grid and linear arrangements.

User Feedback Summary: Participants reported increased confidence in plant care and appreciated the automation. Most found the app interface intuitive, though some requested advanced analytics and reminders.

Overall, testing confirmed the device's practical viability, and iterative improvements were implemented based on feedback.

XI. CONCLUSION AND FUTURE SCOPE

The Smart Plant Assistant demonstrates a promising solution for simplifying and automating plant care for urban gardeners, plant enthusiasts, and small-scale growers. The integration of environmental sensors, automatic irrigation, remote monitoring, and mobile app connectivity provides users with actionable insights and reduces manual dependency. Testing confirmed the system's reliability, energy efficiency, and usability across varied plant setups.

Looking ahead, the project offers scope for improvements such as waterproof casing for long-term outdoor use, integration with AI-based plant disease detection, and expansion of app features like calendar-based scheduling and plant-specific care databases. Further development can also explore compact PCB design, Bluetooth fallback, and compatibility with smart home systems to elevate the Smart Plant Assistant into a fully connected plant care ecosystem.

XII. ACKNOWLEDGMENT

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I would like to thank all participants who took part in the user interviews and surveys. Their insights into plant care habits and pain points were essential in shaping the features and usability of the Smart Plant Assistant.

Lastly, I am grateful to my peers, faculty, friends, and family for their constant support and encouragement, which helped me successfully complete this project.

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