RESEARCH ARTICLE

Development and Evaluation of an IoT-Based Monitoring System for Patchouli Cultivation: An Integrated Approach to Enhance Agricultural Efficiency

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Abstract

This study investigates the application of Internet of Things (IoT) technology in agriculture, focusing on the cultivation of patchouli, a medicinal plant known for its therapeutic properties. The research highlights the specific growth requirements and medicinal benefits of patchouli, and proposes a monitoring system based on ZigBee technology. The system's hardware design incorporates cc2530 and esp8266 chips for wireless data transmission, while communication between the OneNET cloud server and the MySQL database is managed through MQTT, TCP/IP, and HTTP protocols. This integration showcases the potential of IoT to significantly enhance agricultural efficiency by providing real-time data collection and analysis, leading to informed decision-making and improved crop yields. The study underscores the transformative impact of IoT on agricultural practices, highlighting its role in fostering sustainable and efficient farming methods.

Keywords: Medicinal plants, Patchouli, IoT, ZigBee.

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1 Introduction

China is one of the countries with the most abundant medicinal plant resources, boasting a long history of discovering, using, and cultivating medicinal plants. Ancient Chinese historical records indicate that the discovery and use of medicinal plants resulted from the gradual accumulation of experience and knowledge by ancient humans through their long-term life and production practices. Patchouli, a medicinal plant with significant commercial and cultivation value, has traditionally required extensive human involvement in its cultivation and could not be monitored in real-time efficiently. With advancements in science and technology, agriculture is transitioning from traditional methods to modern, systematic, and automated management practices, thereby enhancing industrial efficiency without relying heavily on labor.

Modern agricultural practices integrate both hardware and software components. By deploying sensor equipment in farmlands and other plantation areas, environmental elements such as temperature, humidity, light, wind, rainfall, and soil moisture are detected and collected. This data is then transmitted through wireless sensor networks to cloud servers and databases. The availability of real-time, diverse agricultural data enables efficient development in the planting industry, facilitating informed decision-making and optimizing crop management.

Research on environmental monitoring has been ongoing for decades. The United States pioneered the use of computers for greenhouse control and management, significantly advancing planting technology and environmental control methods. The Netherlands is globally recognized for its advanced horticultural technology and greenhouse environmental control, which considers the plant growth cycle and six major factors affecting plant growth [1]. In Israel, the natural environment consists mainly of plains, hills, rift valleys, and deserts. Israeli scientists have developed special plastic films for climate control, antiviral protection, UV protection, and natural corrosion resistance, leading to the construction of modern desert and greenhouse facilities [2]. Early adopters of C/S mode in the Netherlands and Belgium utilized specific software to monitor and control equipment operations on-site, leveraging network and wireless communication technologies. Since the 1960s, Japan's modern greenhouse agriculture has rapidly developed, focusing on automation and transforming greenhouse structures from loose and small-scale to more robust designs [3]. The UK also prioritizes monitoring and controlling environmental parameters such as biological growth, temperature, and humidity, excelling in remote sensing technology that can manage greenhouse environments over distances exceeding 50 kilometers.

Despite the advanced capabilities of intelligent greenhouse control systems [13–17], their high cost and significant financial requirements limit their use primarily to large enterprises and companies. Our objective is to achieve efficient monitoring of the patchouli growth environment using a simple and cost-effective approach. By leveraging IoT technology, we aim to implement a monitoring system that provides real-time data and supports the sustainable cultivation of patchouli, demonstrating that modern agricultural practices can be both efficient and accessible.

2 Cultivation conditions of patchouli

Patchouli thrives in regions with an annual average temperature ranging from 19 to 26 ℃. It exhibits slow growth or ceases to grow altogether at temperatures exceeding 35 ℃ or falling below 16 ℃. This plant is best suited for wet, rainy environments and is susceptible to drought, necessitating an annual rainfall of more than 1,600 mm. During its seedling stage, patchouli favors rainy conditions and a consistently humid environment; however, excessively high soil moisture can be detrimental and cause plant death [4]. In areas with insufficient rainfall, irrigation is essential to support patchouli growth. While mature patchouli plants can thrive under full sunlight, seedlings require shaded conditions to protect them from direct sun exposure. The roots of patchouli are relatively cold-resistant, allowing the plant to overwinter in northern regions.

Patchouli does not have stringent soil requirements but prefers fertile and loose sandy loam. The seeds of patchouli have a viability of 2 to 4 years, and their germination requires light. The optimal temperature for seed germination lies between 18 ℃ and 22 ℃. Consequently, a monitoring system designed for patchouli cultivation should primarily focus on collecting data related to temperature, humidity, soil temperature, soil moisture, and light conditions in the surrounding environment.

By understanding these specific growth requirements, we can better design and implement an effective monitoring system. The system should include sensors to measure environmental parameters such as air temperature, humidity, soil moisture, and light intensity. These sensors will provide real-time data, enabling farmers to make informed decisions about irrigation, shading, and other cultivation practices. This approach ensures that the environmental conditions are maintained within the optimal range for patchouli growth, thereby enhancing the overall efficiency and yield of the cultivation process.

By leveraging modern IoT technology [18], the proposed monitoring system will offer a comprehensive solution for managing the delicate balance of environmental factors essential for the healthy growth of patchouli. This integration of technology into traditional agricultural practices exemplifies the shift towards more sustainable and efficient farming methods, ultimately contributing to the advancement of agricultural productivity and sustainability.

3 System design

In the hardware design, the equipment layout is primarily determined based on the actual environmental conditions, with sensor data being transmitted via ZigBee components, such as Wi-Fi modules. In the software design, reception interfaces are tailored to various environmental parameters. These interfaces retrieve historical data from the cloud platform and store it in a database. The technical workflow is illustrated in Figure 1.

To elaborate, the hardware design involves strategically placing sensors and equipment in accordance with the specific environmental factors of the cultivation area. This careful placement ensures accurate and reliable data collection on crucial parameters such as temperature, humidity, soil moisture, and light intensity. The collected data is then transmitted using ZigBee technology, which offers a robust and efficient wireless communication protocol suitable for agricultural applications.

On the software side, the design focuses on developing interfaces that can effectively receive and process the transmitted sensor data. These interfaces are built to handle a variety of environmental parameters, ensuring comprehensive monitoring and analysis. By connecting to the cloud platform, the system can access historical data, enabling trend analysis and better decision-making based on past conditions. This historical data is then systematically stored in a database for easy retrieval and further analysis.

The integration of both hardware and software components forms a cohesive system that enhances the monitoring and management of the patchouli cultivation environment. The technical route, as depicted in Figure 1, outlines the seamless flow of data from sensor detection to cloud storage and analysis, demonstrating the potential of IoT technology in revolutionizing agricultural practices.

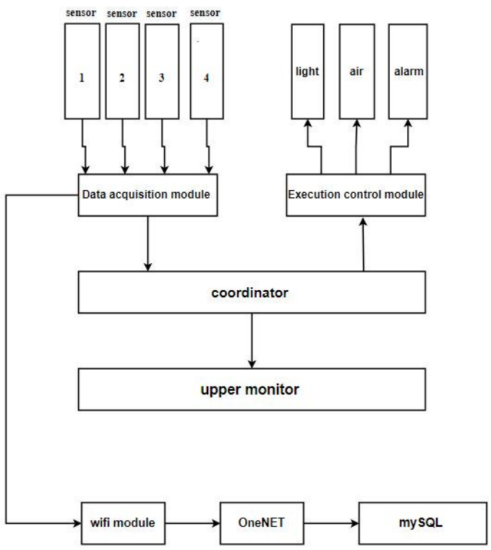

Figure 1. Technical workflow of the monitoring system.

3.1 Hardware design

In this system, ZigBee components and corresponding terminals are primarily utilized to monitor the patchouli growth environment. The ZigBee motherboard integrates CC2530 microcontrollers (MCs) and ESP8266 Wi-Fi modules.

3.1.1 CC2530

The CC2530 microcontroller combines the superior performance of leading RF transceivers [6]. It supports various operating modes, making it particularly suitable for systems requiring ultra-low power consumption. The short conversion time between its operating modes further ensures minimal energy usage. The general structure of the CC2530 is illustrated in Figures 2 and 3.

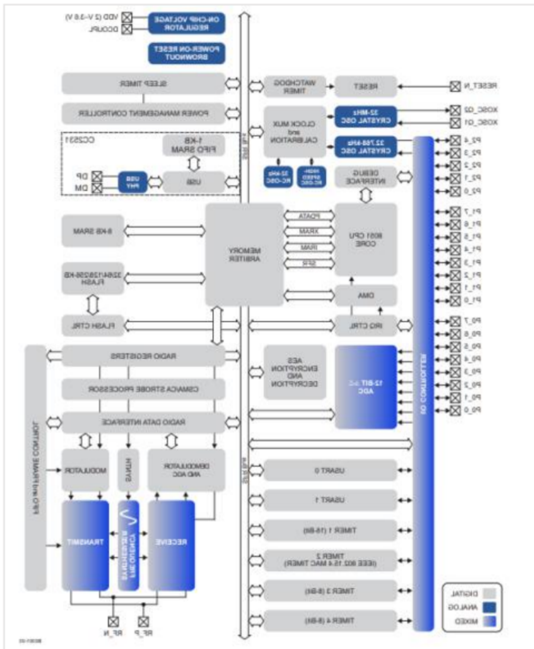

Figure 2. Diagrammatic sketch of the CC2530.

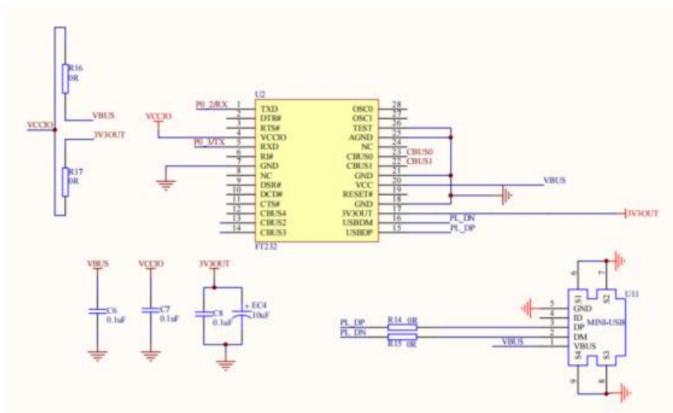

Figure 3. Circuit design of the CC2530 (partial view).

The CC2530's robust features and efficient design make it an ideal choice for integrating into IoT systems aimed at agricultural applications. Its ability to operate in various modes ensures that it can meet the specific needs of the environment while maintaining low power consumption, which is crucial for sustained monitoring in agricultural settings.

The ESP8266 Wi-Fi module complements the CC2530 by providing reliable wireless communication capabilities, essential for transmitting collected data to cloud servers for real-time analysis and storage. Together, these components form the backbone of the monitoring system, enabling precise and efficient tracking of the patchouli growth conditions.

By leveraging the advanced functionalities of the CC2530 and ESP8266, the system can deliver high performance while maintaining energy efficiency, ensuring long-term, reliable operation in monitoring the environmental parameters crucial for patchouli cultivation.

3.1.2 ESP8266

The ESP8266 module integrates several key components including antenna switches, an RF balun, a power amplifier, a low noise amplifier, filters, and power management modules [8]. This compact design minimizes the need for external circuits and reduces the overall PCB size. The internal structure of the ESP8266 is depicted in Figure 4.

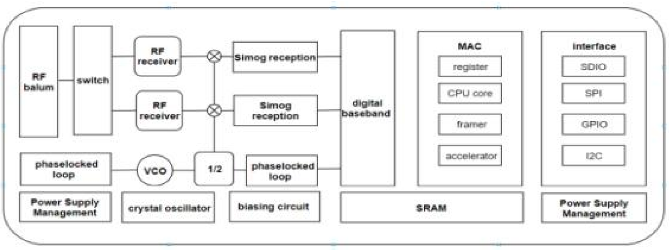

Figure 4. Internal structure of the ESP8266.

The ESP8266's design ensures efficient performance in wireless communication applications. By integrating critical components such as the antenna switches and RF balun, the module simplifies the overall circuit design and enhances signal quality. The built-in power amplifier and low noise amplifier contribute to robust signal transmission and reception, even in environments with significant interference.

Furthermore, the inclusion of power management modules within the ESP8266 helps to optimize energy usage, making it suitable for long-term deployment in IoT applications where power efficiency is paramount. This integration of multiple functionalities into a single module not only reduces the physical footprint but also simplifies the design and deployment process, allowing for more streamlined and cost-effective implementations.

The ESP8266's versatile and efficient design makes it an ideal component for the patchouli growth monitoring system. Its ability to handle complex wireless communication tasks with minimal external circuitry ensures that the system remains compact and efficient, delivering reliable data transmission from the sensors to the cloud server. This facilitates real-time monitoring and management of environmental conditions, ultimately contributing to the optimized cultivation of patchouli.

3.1.3 Related Sensors

The design requires several types of sensors, including MQ2 gas sensors, DHT11 temperature and humidity sensors, and infrared sensors. These sensors are illustrated in Figure 5.

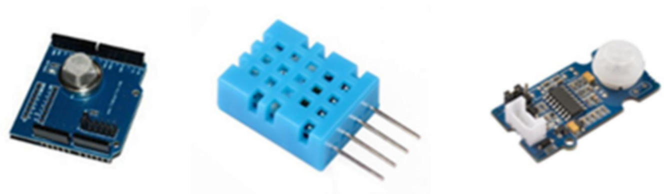

Figure 5. MQ2 gas sensors, DHT11 temperature and humidity sensors.

3.2 Software Design

The software design primarily focuses on developing the upper computer software. The sensors are connected to the ZigBee core control module and deployed in an actual patchouli planting scenario, with each sensor's pins corresponding one-to-one with the main board. The data collected by the sensors is transmitted through a coordinator. The Wi-Fi module facilitates wireless communication between the coordinator and the terminal, while the connection between the coordinator and the upper computer is established via Wi-Fi or a serial port.

The software on the upper computer is responsible for several critical functions. It collects sensor data and displays it in real time, allowing for continuous monitoring of the patchouli growth environment. Based on the collected information, the software evaluates whether the environmental conditions are within the optimal range for patchouli growth. If any parameter deviates from the norm, the system can adjust the terminal equipment accordingly to regulate conditions and ensure the health of the plants.

In summary, the integration of these sensors with the ZigBee core control module and the development of comprehensive software for the upper computer create a robust monitoring system. This system not only provides real-time data on essential environmental parameters but also enables automated adjustments to maintain optimal growing conditions for patchouli. This approach highlights the synergy between advanced hardware components and sophisticated software design in modern agricultural practices, leading to enhanced efficiency and productivity.

3.3 OneNET cloud platform

The OneNET cloud platform is an open PaaS IoT platform that offers an efficient, stable, and secure application environment for IoT interactions between real devices [9]. From a device-oriented perspective, it is capable of adapting to various network environments and common transmission protocols, providing rapid access schemes and device management services for various hardware terminals. From an application-oriented perspective, it offers a rich set of APIs and data resources to meet the development needs of application systems across all industries. In essence, the platform facilitates developers in easily realizing device access and connectivity, swiftly completing product development and deployment, and delivering comprehensive IoT solutions for intelligent hardware and smart home products.

The web server retrieves environmental parameters such as temperature and humidity, collected by sensors in the patchouli planting environment, from the OneNET cloud platform. These parameters are saved as data types compatible with Java. Data transmission between the web server and the cloud platform adheres to the HTTP protocol, ensuring secure and efficient communication. The web server can access data from the cloud platform within seconds and store it in a MySQL database. By collecting historical data, the system can analyze and study the growth conditions of patchouli.

This integration allows for real-time monitoring and historical analysis, providing valuable insights into the environmental factors influencing patchouli growth. The seamless connection between the OneNET cloud platform and the web server ensures that data is consistently updated and readily available for analysis. This comprehensive approach not only enhances the understanding of patchouli cultivation but also optimizes growth conditions through informed decision-making based on reliable data.

Overall, the OneNET cloud platform's capabilities, combined with the efficient data handling by the web server, underscore the potential of IoT in advancing agricultural practices and achieving greater efficiency and productivity in the cultivation of medicinal plants like patchouli.

4 System communication protocol

4.1 TCP/IP Protocol

Many IoT devices are designed to be compatible with TCP/IP protocols, which enables direct connectivity to the Internet of Things, such as Wi-Fi modules. TCP, being a connection-oriented communication protocol, ensures that normal communication can only occur once the client has successfully connected to the server side [10]. TCP's protocol response mechanism and false packet retransmission mechanism provide high transmission accuracy. The client-server connection is established using an IP address and a port number. Although TCP provides reliable transmission, it can lead to reduced speed and efficiency due to its connection-oriented nature and overhead.

4.2 HTTP Protocol

The HyperText Transfer Protocol (HTTP) is a protocol designed to provide and receive HTML interfaces, facilitating the transmission of web interface information over the Internet [11]. In the context of IoT devices, some devices may not directly connect to the Internet of Things and instead require intermediary protocols. For instance, in embedded web development, HTTP is used to enable communication between web servers and hardware devices. This protocol is crucial for providing user-friendly interfaces and ensuring seamless interaction between web applications and IoT hardware.

4.3 MQTT Protocol

Message Queuing Telemetry Transport (MQTT) is an instant messaging protocol developed by IBM specifically for the communication of remote sensors and control devices that have limited computational resources and operate on low-bandwidth, unreliable networks [12]. MQTT uses a publish/subscribe messaging model, which facilitates efficient data exchange in IoT environments. This protocol establishes network connections using TCP/IP, ensuring a reliable foundation for MQTT's lightweight and efficient messaging system. MQTT is particularly well-suited for IoT applications where bandwidth and power efficiency are critical.

By leveraging these protocols, the system can effectively manage and transmit data across various network conditions and device capabilities. TCP/IP ensures robust and accurate data transmission, HTTP provides a versatile interface for web interactions, and MQTT enables efficient communication for resource-constrained IoT devices. Together, these protocols form a comprehensive communication framework that enhances the overall functionality and reliability of IoT systems.

5 Conclusion

The growing contradiction between the production mode of medicinal plants and the protection and development of wild seed sources is becoming increasingly pronounced. In particular, the expanding demand driven by commercial interests has exerted significant pressure on the preservation of wild medicinal plant resources. Therefore, promoting systematic and automated management of medicinal plant fields is of great significance. This approach can expand the scale of medicinal plant cultivation, improve the growth quality of medicinal plants, and address the conflicts between artificial cultivation and the conservation of wild medicinal plant resources.

It is essential to enhance the artificial cultivation of patchouli by developing more productive cultivation techniques that address the deficiencies observed in current practices. Currently, pure artificial planting of patchouli incurs high costs. However, the implementation of automatic or semi-automatic planting management can effectively mitigate labor costs and facilitate the expansion of cultivation scale.

By integrating advanced technologies and adopting systematic management practices, we can achieve more efficient and sustainable cultivation of patchouli. This not only improves productivity but also ensures the conservation of valuable wild medicinal plant resources. Consequently, adopting these innovative agricultural methods can provide a balanced solution to meet commercial demands while protecting natural biodiversity.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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