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Conceptual Design of an Internet of Things (IoT)-Based Automatic Plant Irrigation System Using ESP8266 NodeMCU and the Blynk Platform

[1]Sri Lestari Sitohang, [2]Saliana Br Selian, [3]Breafly Chokes Lumbantoruan, [4]Dicky Wahyudi
[1, 2, 3, 4] Program Studi Teknik Informatika, Universitas Budi Darma, Medan, Indonesia

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Email :
srilestarisitohang561@gmail.com

ABSTRACT

The increasing demand for efficient plant maintenance has accelerated the adoption of Internet of Things (IoT) technologies in smart agriculture. This paper presents a conceptual design of an IoT-based automatic plant irrigation system utilizing the ESP8266 NodeMCU microcontroller and the Blynk platform for remote monitoring and control. The proposed system design includes the selection of hardware components, namely the YL-69 soil moisture sensor, a 5 V relay module, and a DC 5 V submersible water pump, as well as the development of software architecture incorporating automatic irrigation control logic and Blynk widget configuration. The proposed architecture adopts a three-layer IoT model consisting of the device layer, the Wi-Fi communication layer, and the application layer implemented through the Blynk platform. The designed system is intended to automatically activate the water pump when the measured soil moisture falls below a predefined threshold and deactivate it once sufficient soil moisture has been achieved. In addition, users can monitor soil moisture conditions in real time and manually operate the irrigation system through the Blynk mobile application. A comparative analysis of existing IoT-based irrigation studies indicates that the proposed conceptual framework provides a comprehensive integration of hardware architecture, communication mechanisms, software workflow, and user interface design. Furthermore, the selection of ESP8266 NodeMCU and the Blynk platform offers advantages in terms of ease of implementation, low deployment cost, scalability, and user-friendly operation. Although this study is limited to the conceptual design stage without prototype implementation or experimental validation, the proposed framework can serve as a practical reference for future development and implementation of IoT-based automatic irrigation systems.

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INTRODUCTION

The rapid advancement of the Internet of Things (IoT) has significantly transformed various sectors by enabling intelligent monitoring and automated control through interconnected devices. In agriculture, IoT has become one of the key enabling technologies for implementing smart farming practices, allowing environmental parameters to be monitored and managed remotely in real time. These technological developments contribute to improving resource utilization, operational efficiency, and decision-making processes in agricultural activities (Al-Fuqaha et al., 2015; García et al., 2020).

One of the most critical activities in crop cultivation is irrigation management. Conventional irrigation is generally performed manually and depends heavily on human intervention. Such an approach often results in inefficient water consumption because irrigation decisions are not based on the actual moisture condition of the soil. Furthermore, delayed or excessive watering may adversely affect plant growth, reduce water-use efficiency, and increase maintenance costs (Effendi et al., 2022). Consequently, there is an increasing demand for automated irrigation systems capable of monitoring soil conditions continuously and controlling watering processes autonomously.

Recent studies have demonstrated the potential of IoT-based irrigation systems using the ESP8266 NodeMCU microcontroller due to its integrated Wi-Fi capability, low cost, and ease of implementation. Mustofa and Sunardi (2023) developed an automatic irrigation system using NodeMCU and the Blynk platform, primarily focusing on pump automation. Similarly, Ramadhan et al. (2022) proposed an IoT-based soil moisture monitoring system capable of providing real-time information regarding soil conditions. In addition, Shahar et al. (2023) reported that the integration of NodeMCU with the Blynk platform enables efficient remote monitoring and control through smartphone applications.

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Despite these developments, several limitations remain. Previous studies have generally focused either on hardware implementation or on monitoring functionality without providing a comprehensive conceptual design that integrates system architecture, hardware selection, software design, communication mechanisms, and user interface development into a unified framework. Moreover, the technical justification for selecting system components and designing the overall IoT architecture has received relatively limited attention, reducing the potential for these studies to serve as comprehensive references for future system development.

Based on these research gaps, this study proposes a conceptual design of an IoT-based automatic plant irrigation system utilizing the ESP8266 NodeMCU microcontroller and the Blynk platform for remote monitoring and control. The proposed design encompasses system architecture, hardware component selection, software workflow, communication mechanisms, and mobile application interface design. Rather than emphasizing prototype implementation, this study aims to provide a systematic and comprehensive design framework that can serve as a reference for researchers and practitioners in developing low-cost, scalable, and user-friendly IoT-based irrigation systems.

The findings of this study are expected to provide practical guidance for the development of smart irrigation technologies while serving as a foundation for future research involving prototype implementation, performance evaluation, and the integration of intelligent decision-making techniques such as fuzzy logic and machine learning to enhance irrigation accuracy and efficiency.

METHODS

Research Design

This study employed a Research and Development (R&D) approach with a system design methodology to develop a conceptual framework for an Internet of Things (IoT)-based automatic plant irrigation system. The research focused on designing an integrated irrigation system rather than implementing and experimentally evaluating a physical prototype. The proposed framework was intended to provide a systematic reference for the future development of low-cost and intelligent irrigation systems.

The research process consisted of five sequential stages: problem identification, literature review, system design, conceptual evaluation, and documentation of the proposed system. Each stage was conducted systematically to ensure that the resulting design addressed the identified problems while maintaining compatibility among hardware components, communication protocols, and software architecture.

Research Procedure

The research procedure is illustrated in Figure 1 and consists of the following stages:

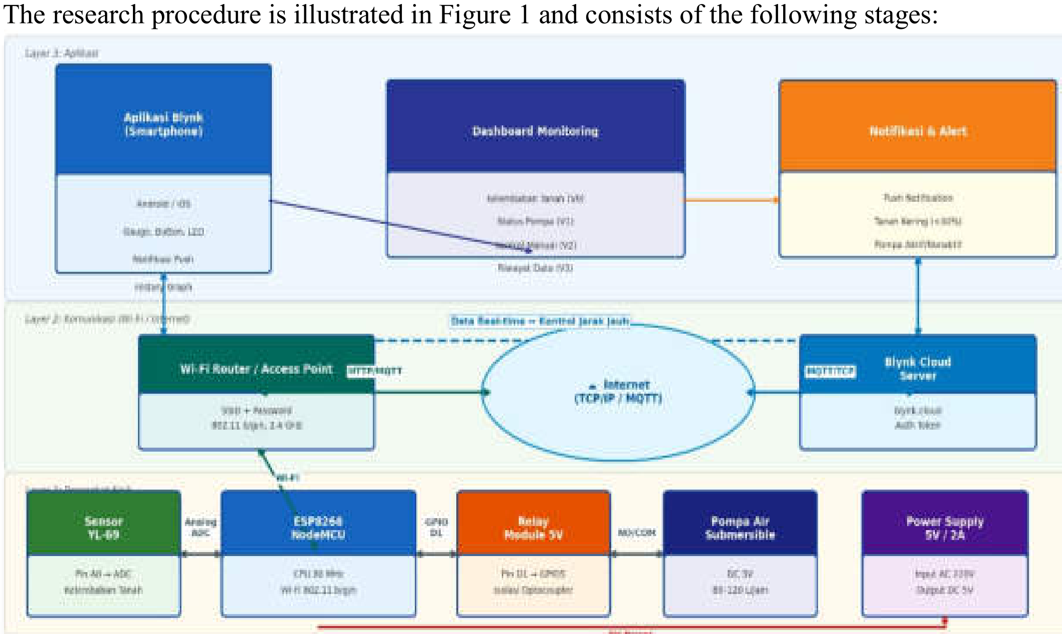

Figure 1. Overall Architecture of the Proposed IoT-Based Automatic Plant Irrigation System

Problem Identification

The initial stage involved identifying the limitations of conventional irrigation practices through an extensive literature review. Manual irrigation systems were found to be highly dependent on human intervention, resulting in inefficient water usage, inconsistent irrigation schedules, and the inability to monitor soil moisture conditions in real time. These limitations motivated the development of an automated IoT-based irrigation system.

Literature Review

A comprehensive literature review was conducted to investigate recent developments in IoT-based smart irrigation systems, soil moisture sensing technologies, wireless communication, cloud-based monitoring platforms, and microcontroller applications. Previous studies employing ESP8266 NodeMCU, Blynk, and soil moisture sensors were critically analyzed to identify existing research gaps and establish the design requirements for the proposed system.

System Design

Based on the identified requirements, a conceptual system architecture was developed. The proposed system integrates hardware and software components to perform automatic irrigation based on soil moisture conditions. The hardware architecture consists of:

a. ESP8266 NodeMCU as the main controller,
b. YL-69 soil moisture sensor for data acquisition,
c. Relay module for actuator control,
d. DC submersible water pump as the irrigation actuator,
e. Wi-Fi network for Internet connectivity.

The software architecture includes:

a. sensor data acquisition,
b. automatic irrigation control algorithm,
c. communication with the Blynk cloud server,
d. remote monitoring and manual control through the Blynk mobile application.

The overall system was designed using a three-layer IoT architecture comprising the device layer, network layer, and application layer.

Conceptual Evaluation

The proposed design was evaluated qualitatively through comparative analysis with previous studies reported in the literature. The evaluation considered several aspects, including system architecture, hardware integration, communication mechanism, monitoring capability, automatic control functionality, implementation complexity, and scalability. The objective of this evaluation was to assess the feasibility of the proposed design as a reference model for future implementation.

Documentation

The final stage involved documenting the complete system design, including the hardware architecture, electronic circuit configuration, system workflow, mobile application interface, and software design. The documentation provides technical guidance for researchers and practitioners who intend to implement or further develop the proposed irrigation system.

System Components

The proposed system consists of several hardware and software components. The ESP8266 NodeMCU serves as the central processing unit responsible for acquiring sensor data, processing irrigation decisions, and communicating with the cloud server through a Wi-Fi connection. Soil moisture is measured using the YL-69 sensor, while a relay module controls the operation of a DC submersible water pump. Remote monitoring and manual control are performed using the Blynk IoT platform installed on a smartphone.

Data Analysis

Since this study focused on conceptual system design, the collected information was analyzed descriptively. The analysis emphasized system functionality, component compatibility, communication architecture, ease of implementation, and comparison with previous IoT-based irrigation systems. The results of this analysis were used to evaluate the feasibility and potential applicability of the proposed design for future prototype implementation.

RESULTS AND DISCUSSION

Proposed System Architecture

The primary outcome of this study is the conceptual design of an Internet of Things (IoT)-based automatic plant irrigation system that integrates sensing, communication, control, and remote monitoring technologies into a unified framework. The proposed architecture consists of three interconnected layers: the device layer, network layer, and application layer, as illustrated in Figure 2.

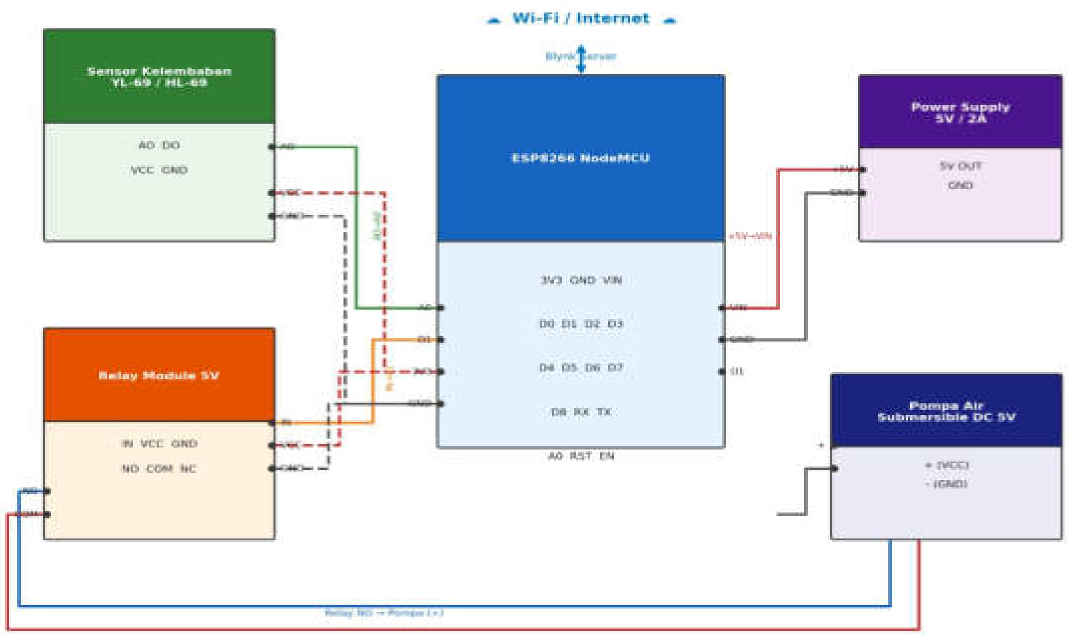

Figure 2. Electronic Circuit Design of the Proposed Irrigation System

The device layer comprises the ESP8266 NodeMCU microcontroller, YL-69 soil moisture sensor, relay module, and DC submersible water pump. The soil moisture sensor continuously measures the moisture content of the planting medium and transmits the collected data to the ESP8266 NodeMCU. Based on the predefined control logic, the microcontroller determines whether irrigation should be activated or deactivated.

The network layer provides communication between the microcontroller and the cloud server through a Wi-Fi connection using the TCP/IP protocol. This communication enables real-time transmission of sensor data and remote command execution.

The application layer consists of the Blynk cloud platform and the Blynk mobile application, allowing users to monitor soil moisture conditions, observe pump status, receive notifications, and manually control the irrigation system from any location with Internet access.

The proposed architecture emphasizes modularity and scalability, allowing additional environmental sensors or intelligent control algorithms to be integrated without significant modifications to the overall system architecture.

Hardware Design

The proposed hardware configuration was selected based on compatibility, implementation cost, power consumption, availability, and ease of integration.

Table 1. Proposed Hardware Components

No.	Component	Specifications	Function
1	ESP8266 NodeMCU v3	CPU 80/160 MHz, 64 KB RAM, 4 MB Flash Memory, IEEE 802.11 b/g/n Wi-Fi	Main microcontroller and wireless communication module
2	YL-69 Soil Moisture Sensor	Analog output (ADC 0–1023), operating voltage 3.3–5 V	Measures soil moisture content
3	5 V Relay Module	Single-channel relay, active LOW trigger, optocoupler isolation	Controls the water pump electrically
4	DC Submersible Water Pump	Operating voltage 5 V DC, flow rate 80–120 L/h, maximum head 40–110 cm	Supplies water for irrigation
5	Power Supply	Input: 220 V AC; Output: 5 V DC / 2 A	Provides power to all system components
6	Jumper Wires and Breadboard	Male-to-female jumper wires, 830-point breadboard	Provides electrical connections among hardware components

ESP8266 NodeMCU was selected as the primary controller because it integrates Wi-Fi communication within a single microcontroller, thereby reducing hardware complexity and overall system cost. The YL-69 soil moisture sensor was chosen because of its simple analog interface and compatibility with the analog input of the ESP8266. A single-channel relay module was employed to electrically isolate the low-voltage control circuit from the water pump, ensuring operational safety and reliability.

The DC submersible water pump serves as the irrigation actuator and is activated only when the relay receives an appropriate control signal from the microcontroller. All components operate using a common 5-V power supply, simplifying the electrical design and improving implementation efficiency.

Software Design

The software architecture was designed using the Arduino IDE development environment. The program consists of two primary functions: setup() and loop(). During initialization, the setup() function establishes the Wi-Fi connection, authenticates the ESP8266 NodeMCU with the Blynk cloud server, configures the input and output pins, and initializes the monitoring variables. The loop() function continuously performs four sequential tasks:

1. acquiring soil moisture data from the sensor;
2. processing the irrigation control algorithm;
3. transmitting monitoring data to the Blynk platform;
4. receiving remote commands from the mobile application.

This cyclic operation enables continuous monitoring and remote interaction while maintaining a relatively simple software structure suitable for low-resource embedded systems.

Irrigation Control Mechanism

The proposed irrigation system supports two operational modes: automatic mode and manual mode. In automatic mode, irrigation decisions are made based on the measured soil moisture level. When the soil moisture falls below a predefined threshold, the controller activates the relay, thereby turning on the water pump. Irrigation continues until the measured soil moisture reaches the upper threshold, after which the pump is automatically switched off.

Manual mode enables users to override the automatic operation through the Blynk mobile application. This feature provides operational flexibility when irrigation is required regardless of the measured soil moisture condition.

The dual-mode control mechanism increases system adaptability by combining autonomous operation with user intervention whenever necessary.

Mobile Application Interface

The proposed mobile interface was designed using the Blynk platform to provide intuitive real-time monitoring and remote control.

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Table 2. Comparison of IoT Platforms for Automatic Plant Irrigation Systems

No.	Evaluation Criteria	Blynk	ThingSpeak	Node-RED
1	Ease of Configuration	Very Easy	Easy	Moderate
2	Mobile Interface	Native Mobile Application	Web-Based	Web-Based
3	Real-Time Control	Supported	Limited	Supported
4	Push Notification	Supported	Not Available	Plugin Required
5	ESP8266 Compatibility	Native Library Support	REST API Support	MQTT Integration
6	Cost	Free / Paid	Free	Free
7	Server Requirement	Blynk Cloud	MathWorks Cloud	Self-Hosted Server

The proposed mobile application interface was developed using the Blynk platform to provide intuitive real-time monitoring and remote control of the irrigation system. The interface incorporates several interactive widgets, including a gauge to display real-time soil moisture readings, an LED indicator to show the operational status of the water pump (ON/OFF), a button that enables users to manually control the pump through the mobile application, a push notification feature that alerts users whenever the soil moisture level falls below the predefined threshold, and a history graph that visualizes historical soil moisture data over time. These integrated widgets provide users with comprehensive information regarding the current condition of the irrigation system while facilitating remote operation through a user-friendly graphical interface.

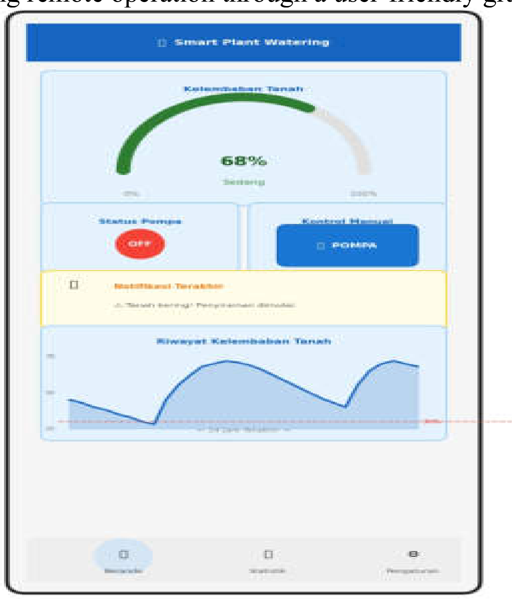

Figure 3. Graphical User Interface (GUI) of the Blynk Mobile Application

Table 3. Proposed Blynk Widget Configuration

No.	Widget	Virtual Pin	Mode	Function
1	Gauge	V0	Read	Displays real-time soil moisture readings
2	LED Indicator	V1	Read	Indicates the operational status of the water pump (ON/OFF)
3	Button	V2	Read/Write	Enables manual control of the water pump via the mobile application
4	Push Notification	–	–	Sends notifications when the soil moisture falls below the predefined threshold
5	History Graph	V3	Read	Visualizes historical soil moisture data over time

These widgets enable users to observe current environmental conditions, review historical moisture trends, and operate the irrigation system remotely without requiring direct interaction with the physical device. The graphical interface was intentionally designed to minimize user interaction complexity while maintaining essential monitoring and control functionalities.

Comparative Analysis

The proposed system was compared with previous IoT-based irrigation studies reported in the literature.

Table 4. Comparison with Previous Studies

No.	Authors / Year	Microcontroller	Platform / Interface	Research Focus	Main Contribution
1	Mustofa & Sunardi (2023)	ESP8266 NodeMCU	Blynk	IoT-based automatic irrigation for chili plants	Developed an automatic irrigation system using the Blynk platform.
2	Ramadhan et al. (2022)	ESP8266 NodeMCU	IoT Monitoring	Real-time soil moisture monitoring for ornamental plants	Proposed an IoT-based soil moisture monitoring system.
3	Subagja et al. (2023)	IoT-Based Controller	IoT Platform	Performance evaluation of an automatic irrigation system	Evaluated the operational performance of an IoT-based irrigation system.
4	Shahar et al. (2023)	ESP8266 NodeMCU	Blynk	IoT-based irrigation monitoring system	Developed a remote irrigation monitoring system using NodeMCU and Blynk.
5	**This Study**	ESP8266 NodeMCU	Blynk	Comprehensive conceptual design of an IoT-based automatic irrigation system	Proposes an integrated conceptual framework consisting of system architecture, hardware configuration, software workflow, communication mechanism, and mobile application interface for future prototype development.

Previous studies primarily emphasized either automatic irrigation implementation or soil moisture monitoring. In contrast, this study provides a comprehensive conceptual framework integrating hardware architecture, communication infrastructure, software workflow, mobile application design, and system documentation within a single design model.

Furthermore, the proposed architecture adopts a modular approach that facilitates future integration of additional sensors, cloud services, and intelligent decision-making algorithms without requiring substantial architectural modifications.

Although the study does not include prototype implementation or experimental validation, the comprehensive system design provides a practical reference for researchers intending to develop IoT-based irrigation systems using low-cost hardware platforms.

Research Limitations and Future Work

This study is limited to the conceptual design stage; therefore, system performance has not yet been validated through experimental implementation. Consequently, important performance indicators such as sensor accuracy, irrigation response time, communication latency, power consumption, system reliability, and water-use efficiency could not be quantitatively evaluated.

Future research should focus on prototype development and experimental validation under various environmental conditions. Performance evaluation should include hardware reliability testing, communication stability analysis, irrigation efficiency measurement, and usability assessment. In addition, the incorporation of intelligent decision-making techniques such as fuzzy logic, machine learning, or predictive analytics may further improve irrigation accuracy and adaptability in precision agriculture applications.

CONCLUSION

This study presented a conceptual design of an Internet of Things (IoT)-based automatic plant irrigation system utilizing the ESP8266 NodeMCU microcontroller and the Blynk platform for remote monitoring and control. The proposed design integrates hardware architecture, communication infrastructure, software workflow, and a mobile application interface into a unified framework that supports both automatic and manual irrigation operations. The proposed system architecture demonstrates that the integration of ESP8266 NodeMCU, a soil moisture sensor, a relay module, and the Blynk platform provides a simple, low-cost, and scalable solution for smart irrigation applications. The modular design facilitates future system expansion by enabling the integration of additional environmental sensors, cloud services, and intelligent control algorithms without requiring significant architectural modifications. However, this study is limited to the conceptual design stage and does not include prototype implementation or experimental performance evaluation. Consequently, important performance indicators such as sensor accuracy, response time, communication reliability, energy consumption, and irrigation efficiency have not yet been validated. Future research should focus on implementing the proposed system as a functional prototype and conducting comprehensive experimental evaluations under different environmental conditions. Furthermore, the integration of intelligent decision-making approaches, such as fuzzy logic, machine learning, or predictive analytics, is recommended to improve irrigation accuracy, adaptability, and resource utilization in precision agriculture.

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