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SPICE: Smart Precision IoT-Controlled Environment for Chili Seedling Irrigation

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Abstract: Manual watering of chili plants often leads to soil moisture imbalance, which can hinder the growth of seedlings. This research focuses on the implementation of the Internet of Things (IoT) in chili seedling systems to create a more efficient, automated monitoring and watering process. The proposed system employs an ESP32 microcontroller as the main controller, two Soil Moisture sensors to measure real-time soil humidity, a relay module, and a 12V DC pump for automatic irrigation. Sensor data are transmitted and displayed via the Blynk application, a cloud-based IoT platform that enables remote monitoring and control through mobile devices. The research process includes hardware and software design, sensor testing, and soil moisture data analysis conducted over three days at a farming area in Sungai Langka Village, Pesawaran Regency. The test results indicate that the system successfully maintains soil moisture within the optimal range of 60-80%, automatically activating the pump when the humidity drops below the threshold and deactivating it once the desired level is reached. The integration of IoT technology significantly enhances water-use efficiency, minimizes manual intervention, and supports stable and measurable chili seedling growth. Overall, this study demonstrates that IoT-based automation can serve as an innovative solution for the modernization and digitalization of agricultural systems, contributing to sustainable smart farming practices.

Keywords: Internet of Things (IoT); Soil Moisture Sensor; Chili Seedling; Agricultural Automation; Blynk.

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1. Introduction

Technology has increasingly shaped many sectors, including agriculture, where it now plays an important role in improving productivity and competitiveness. In chili cultivation, watering is still commonly done manually, and this often causes soil moisture to fall outside the ideal 60–80% range for healthy growth [1]. Such inconsistencies contribute to Indonesia's relatively low chili production, which averages only about 6.7 tons per hectare, with weather and poor water management being major contributing factors [2].

To address these issues, automatic irrigation systems have been proposed as a way to stabilize soil moisture and reduce reliance on manual watering [3]. The use of Internet of Things (IoT) technology during chili seed germination has also shown promise in improving efficiency and early-stage growth [4]. By integrating soil moisture sensors with

automated pumps, farmers can monitor and control watering remotely, ensuring that irrigation is applied only when needed [5].

Several related studies support this approach, including systems that use ESP-based controllers for real-time moisture-based irrigation [6], smartphone-based irrigation control for field monitoring [7], microcontroller-driven moisture regulation systems [8], and fuzzy-logic-based irrigation strategies for more adaptive watering decisions [9]. These developments strengthen the potential of IoT-assisted irrigation to create a more reliable environment for chili cultivation in Indonesia.

Theoretical Framework

This chapter discusses the concepts and models that form the foundation for developing a soil moisture sensor implementation system in chili seed germination equipment. The theoretical framework includes an understanding of the technologies employed, the methods of seed germination, as well as various related technical and non-technical aspects.

Chili Cultivation

Chili is one of the key commodities in Indonesia's horticultural sector and is considered a vegetable crop with high cultivation potential [10]. The increasing daily consumption demand for bird's eye chili among the public has led to a growing market demand. Both in its fresh and processed forms, bird's eye chili is widely used as an additive and flavor enhancer to improve the taste of food and is known for its high nutritional value. Furthermore, bird's eye chili serves as a raw material in the food industry for products such as sauces, chili powder, and seasonings, as well as in the pharmaceutical industry [11].

IoT in Agricultural System

In IoT-based agricultural systems, several hardware components work together to enable automated monitoring and irrigation. The ESP32 microcontroller serves as the central processing unit, providing wireless connectivity and managing data acquisition as well as control operations within the system [12]. Soil moisture sensors are used to detect the water content in the growing medium, allowing the device to determine when irrigation is required based on real-time measurements [13]. When the soil reaches a dry condition, the microcontroller activates a DC pump that functions as the primary actuator for delivering water to the plants [14]. This activation is executed through a relay module, which acts as an electrically controlled switch that safely isolates the low-voltage control circuit from the higher-voltage pump load [15]. Together, these components form an integrated IoT architecture capable of maintaining optimal soil moisture levels and supporting efficient smart-agriculture applications.

2. Materials and Method

Research Time and Location

This research was conducted in Sungai Langka Village, Gedong Tataan District, Pesawaran Regency, Lampung Province, specifically on the agricultural land of local villagers. The research was carried out over a period of one week. Data collection was performed after the device was completed. The research environment experiences high temperatures during the daytime. The author expects that this device can create a more stable artificial environment to support chili seed germination.

Device Flowchart

In designing an effective device, several stages are required, including creating the device flowchart, designing the system block diagram, circuit schematics, device design, and Blynk application design, as illustrated in Figure 6.

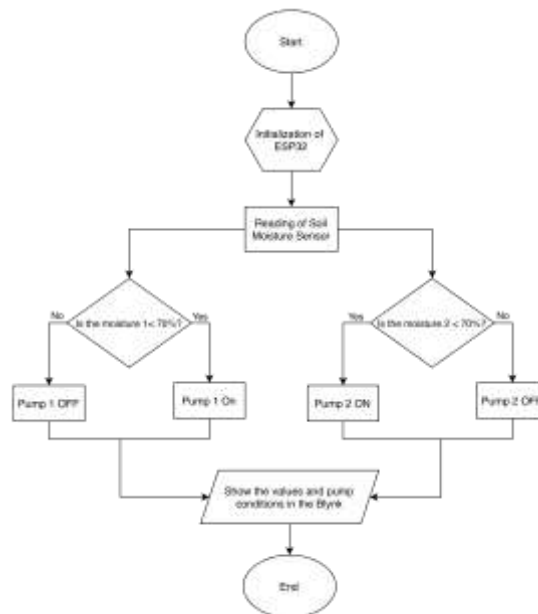


Figure 1. Flowchart

The figure shows the system flow diagram for monitoring soil temperature and moisture. The overall working principle of the device is based on the ESP32 microcontroller and the Blynk application.

Schematic Design

The schematic circuit used in this study is shown in Figure 7.

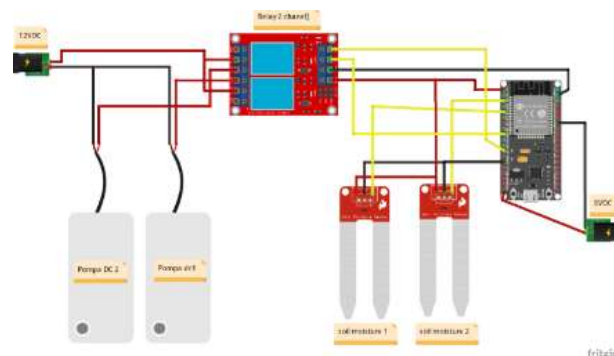


Figure 2. Schematic Design

The figure illustrates the schematic circuit employed in this research. The author used the ESP32 as the microcontroller for all connected components. Additionally, a soil moisture sensor was used to detect soil humidity in the chili seed germination box, and the DC pump operates when receiving input from the soil moisture sensor if the soil is detected to be dry.

The device design used in this study is shown in Figures 8 below.

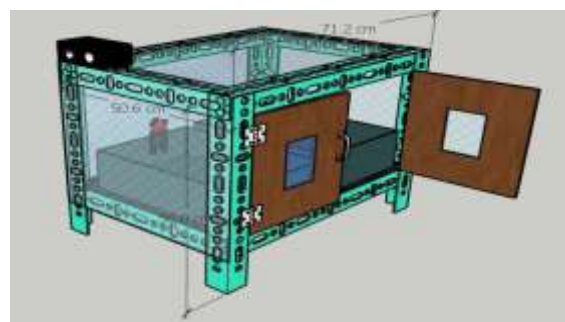


Figure 3. 3D Device Design

These figures present the design of the device employed in this research, illustrating the overall shape of the device and the placement of components. The design resembles a box with a height of 50 cm and a width and length of 40 cm, modeled in a 3D format.

3. Results and Discussion

Blynk Application Testing

Testing of the Blynk application was conducted to ensure that it could display data from the soil moisture sensor and the status of the pump used in this study. The testing process involved connecting Blynk to the ESP32 microcontroller, allowing the application to display soil moisture readings and pump status notifications. The Blynk interface is shown in Figure 12.

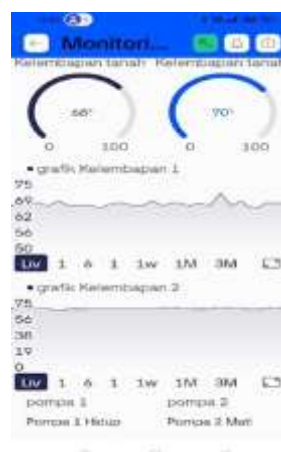


Figure 4. Blynk Testing

In Figure 12, Blynk displays readings from two soil moisture sensors and the operational status of the pump used in this study, demonstrating that the application functions effectively in monitoring soil moisture and pump conditions.

Test Data

The data for the IoT-based soil moisture monitoring and automatic irrigation device for chili seed germination were collected through a series of tests conducted every hour for three days. Measurements were taken at each interval to enable comprehensive data collection and to evaluate the effectiveness of the device in maintaining soil moisture. The measurements obtained on the first day are presented in Table 1.

Table 1 First Day Sensor Testing

Time	Soil Moisture 1	Soil Moisture 2	Pump 1	Pump 2
07.00	75%	74%	OFF	OFF
08.00	74%	73%	OFF	OFF
09.00	74%	73%	OFF	OFF
10.00	73%	72%	OFF	OFF
11.00	72%	70%	OFF	OFF
12.13	72%	69%	OFF	ON
12.14	72%	71%	OFF	OFF
13.00	71%	75%	OFF	OFF

Table 1 presents soil moisture readings from two soil moisture sensors and the operational status of two pumps at different times. At 07:00, sensor 1 recorded 75% moisture, and sensor 2 recorded 74%, with both pumps OFF, indicating sufficient soil moisture. Similar conditions were observed at 08:00 and 09:00, with soil moisture remaining above 70%, so the pumps remained inactive. However, at 11:00, soil moisture

from sensor 2 dropped to 69%, and at 12:00, pump 2 was activated (ON) to irrigate the soil, while pump 1 remained OFF. By 12:30, sensor 2 moisture increased back to 75%, returning both pumps to OFF. This table demonstrates how the automatic system manages irrigation based on measured soil moisture levels. The data collection process was repeated hourly over three days. On the second day, measurements are presented in Table 2.

Table 2 Second Day Sensor Testing

Time	Soil Moisture 1	Soil Moisture 2	Pump 1	Pump 2
07.00	75%	75%	OFF	OFF
08.00	75%	75%	OFF	OFF
09.00	75%	74%	OFF	OFF
10.00	74%	73%	OFF	OFF
11.00	73%	72%	OFF	OFF
12.00	72%	70%	OFF	OFF
13.10	68%	69%	ON	ON

Table 2 shows soil moisture readings from two sensors and the operational status of two pumps based on these measurements. At 07:00 and 08:00, both sensors indicated 75% soil moisture, so both pumps remained OFF, meaning no irrigation was required. At 09:00 and 10:00, soil moisture remained stable at 75%, confirming suitable soil conditions and keeping pumps OFF. At 11:00, moisture decreased to 72%, and by 12:00, it further dropped to 68%, prompting pump 2 to turn ON for irrigation, while pump 1 remained OFF. This table illustrates the automatic system's response to soil moisture fluctuations, managing irrigation to maintain optimal soil conditions. On the third day, measurements are presented in Table 3.

Table 3 Third Day Sensor Testing

Time	Soil Moisture 1	Soil Moisture 2	Pump 1	Pump 2
07.00	76%	75%	OFF	OFF
08.00	75%	74%	OFF	OFF
09.00	74%	74%	OFF	OFF
10.00	72%	71%	OFF	OFF
11.00	73%	72%	OFF	OFF
12.13	72%	72%	OFF	ON
12.14	72%	71%	OFF	OFF

Table 3 provides soil moisture data from two sensors and the operational status of the two pumps over specific time intervals. At 07:00, sensor 1 recorded 76% and sensor 2 75%, with both pumps OFF, indicating sufficient soil moisture. At 08:00, moisture slightly decreased to 75% (sensor 1) and 74% (sensor 2), but the pumps remained OFF as the levels were still adequate. Between 09:00 and 11:00, soil moisture continued to decline, reaching 72% for both sensors. Despite this decrease, the pumps remained OFF because the moisture was still above the predetermined threshold. This table illustrates how the automatic system regulates irrigation based on soil moisture measurements, ensuring that plants remain in optimal condition without unnecessary watering.

4. Conclusion

The conclusions drawn from the study entitled "Implementation of Soil Moisture Sensor in a Chili Seed Germination Device" are as follows:

1. The IoT-based soil moisture monitoring device designed in this study successfully monitored the environmental conditions for chili seedling growth in real-time.
2. By using a soil moisture sensor, the system can automatically activate the water pump when soil moisture reaches a predetermined threshold, thereby reducing the risk of overwatering and underwatering.
3. The IoT-based soil moisture monitoring device performed effectively, maintaining soil moisture within the optimal range of 60%–80%, which is crucial for the healthy growth of chili seedlings.

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