MODERN TRANSFORMATION IN AGRICULTURE FOR ONION WATERING AUTOMATION WITH SOLAR CELL AND IOT TECHNOLOGY

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ABSTRACT

Shallots are a key agricultural commodity in Indonesia, requiring careful water management for optimal growth. Excessive water can cause rot in shallot seedlings, while insufficient water leads to wilting and yellowing leaves, affecting crop quality. This research designs an IoT-based automatic monitoring and watering system to address these challenges. The system includes a soil moisture sensor, a DHT22 sensor for air temperature and humidity, an ESP32 microcontroller, a water pump, and a solar panel as its energy source, controllable via an Android application. The system maintains ideal soil moisture for each growth stage: 80-90% during germination, 60-70% for the vegetative stage, and 50-60% during the generative stage, with optimal air temperatures of 25-30°C. Real-time data from sensors are processed by the ESP32, which activates the water pump via a DC relay when soil moisture falls below the threshold. Testing shows the system operates continuously, with solar panels charging a VRLA battery daily to sustain nighttime operation. Battery voltage fluctuates between 12.5 V and 15.0 V, maintaining a charge above 12.0 V after sunset. To ensure reliability in extreme weather, the system employs waterproof enclosures for all components and uses sensors calibrated to maintain accuracy in saturated soils. An MPPT charge controller optimizes solar energy usage during low sunlight, while selected components operate in a wide temperature range, ensuring extreme heat or cold performance. This system improves water efficiency, reduces manual labor, and offers an environmentally friendly solution for shallot cultivation, particularly in remote areas without conventional power access. Its resilience to environmental challenges enhances productivity and supports sustainable agricultural practices.

Keywords: *Shallot cultivation, IoT-based automatic watering, Soil moisture monitoring, Solar-powered irrigation, Agricultural efficiency*

1. INTRODUCTION

Shallots are one of the most important commodities in Indonesia's agricultural sector. Onion plant maintenance requires extra attention, as the water balance is critical for growth. If shallot plants receive too much water, the seedlings will rot; conversely, if they lack water, the plants will wilt, and the tops of the leaves will turn yellow and even die. This is especially challenging during the dry season when the price of shallots can rise higher, but the cost of maintenance also increases. Despite the abundant yield of this crop, shallot cultivation is still mostly done manually, requiring a lot of labor and experience from farmers [1].

One of the primary needs of farmers today is an efficient crop watering system. The watering process that is still manually using diesel or water buckets is very time-consuming and labor-intensive. Therefore, this research aims to design an automatic monitoring and watering system using Internet of Things (IoT) technology based on soil moisture and air humidity [2].The system consists of a soil moisture sensor, DHT22 sensor, ESP32 as a microcontroller, water pump, and solar cell as an energy source, and can be remotely controlled using an Android application [3].

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Table 1. State Of The Art For This Research

Aspect	Prior Work	Contributions of the Research
Primary Crop	Focused on general crops or other plants (e.g., rice, corn) for IoT-based irrigation systems [2][3].	Specifically addresses shallot cultivation, highlighting its critical water balance needs during different growth stages.
Challenges in Irrigation	Lack of discussion on crop-specific water requirements or challenges during extreme weather conditions [1].	Tailor's irrigation parameters for shallot growth (soil moisture: 50-90%, air temp: 25-30°C) and identifies challenges like sensor and pump failure.
Irrigation Method	Conventional/manual irrigation or semi-automated systems [2].	Fully automated system using IoT for precision control of irrigation, including soil moisture sensors, air temperature, and humidity sensors.
Energy Source	Dependence on grid electricity or diesel generators for powering irrigation systems [2].	Incorporates solar cells for an environmentally friendly and sustainable energy solution, suitable for remote agricultural areas.
Monitoring and Control	Limited or manual monitoring via on-site systems [2].	Enables remote monitoring and control through an Android application with customizable displays for better user experience.
System Reliability	Rarely includes mechanisms for detecting sensor or pump failures, risking system downtime [2][3].	Implements periodic sensor calibration and pump monitoring with real-time alerts for maintenance, reducing risks of system failures.
Impact on Productivity	General productivity improvements mentioned, but lacks focus on specific crop quality or yield improvements [1].	Focuses on increasing shallot yield and quality by optimizing water use and maintaining ideal growing conditions at each growth stage.
Environmental Impact	Limited adoption of eco-friendly energy sources and systems [2][3].	Promotes sustainable farming through solar energy and precise irrigation, reducing water wastage and energy dependency.

However, implementing this IoT-based irrigation system is not without challenges. One potential issue is sensor failure, where soil moisture or temperature sensors may produce inaccurate readings due to wear, dirt accumulation, or exposure to extreme environmental conditions. To address this, the system incorporates periodic calibration and self-diagnostic features to detect and alert users about sensor anomalies via the Android application. Another challenge is pump failure, which could occur due to prolonged operation, electrical issues, or clogging in the irrigation pipes. The system includes pump usage monitoring and an alert system to notify users when maintenance is required. Therefore, a study was made that refined the above problems. The State of The Art for this research shown on Table 1.

The soil moisture sensor used in this research measures soil moisture content, while the DHT22 sensor measures air temperature and humidity. The data from these sensors is read by the ESP32, which then controls the DC relay to operate the water pump automatically. The pumped water will flow through pipes and be dispersed using sprinklers, mimicking the effect of rain. The system is designed to be operated with an Android application, with a customizable display according to the user's needs [4]. At the onion growth stage, the ideal soil moisture is 80-90% during germination, 60-70% during vegetative, and 50-60% during generative. Air temperature and humidity should ideally range from 25-30°C. If the soil moisture sensor detects soil moisture less than the setpoint set according to the needs of the plants, the water pump will automatically water the plants [5]. Conversely, the water pump will automatically switch off if the soil moisture exceeds the setpoint. This system is expected to increase watering efficiency and shallot yield significantly.

This research was conducted to provide solutions that can overcome the major challenges in onion cultivation in Indonesia, especially in terms of proper irrigation management [6]. This IoT-based automatic irrigation system aims to reduce dependence on intensive labor and minimize errors that occur due to manual irrigation. In addition, the use of solar energy as the power source of this system makes it more environmentally friendly and can be applied in areas far from power sources. The use of an Android app allows easy remote monitoring for farmers, providing greater flexibility in managing their land [7]. The system also has the potential to lower maintenance costs, especially during the dry season which increases production costs due to the need for additional irrigation. With more accurate soil moisture control, the system is expected to maintain plant health at every stage of its growth, reducing the risk of crop failure.

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The adoption of this technology is believed to increase the productivity of shallot yields while ensuring better product quality.

2. RESEARCH METODHOLOGY

After observing previous research and factual problems about plant monitoring systems, then realized that in these related studies, there are still many systems that are small in nature or can be said to be prototype systems. The previous research also did not use the Android application system for plant monitoring. Therefore, researchers are interested in conducting a study entitled "Modern Transformation in Agriculture for Automation of Watering Shallots Based on Solar Cell and IoT." This research uses a microcontroller that is different from previous research and uses natural objects. There are two modes, namely manual mode and automatic mode, so if there are improvements to sensors or other systems, this tool can still be used using manual mode by pressing the on / off button on the system or on the Android application.

2.1 Design

The design of the monitoring and control system for watering shallot plants based on IoT is shown in Figure.1 below. Figure 1 shows the placement of the sprinkle and the placement of the soil moisture sensor [8]. In Figure 1 use the appropriate type of spray sprinkle, and the distance of each sprinkle is 2 meters. This distance has been adjusted to the water pump used and the spray distance from the sprinkler so that the results of shallot watering can be evenly distributed on the bed. The humidity sensor is placed in the middle position between the sprinkles to produce accurate soil moisture readings. The above design has been consulted directly with partners so as to minimize the tool.

The Figure 2 shows block diagram system has been used in this research. Inside, there is DHT22 as an environmental humidity detector, soil moisture as a soil moisture detector, Relay as a pump controller to turn on, Oled LCD 64 as a measuring data viewer, and ESP32 as the brain processing sensor values and giving commands to relays.

2.2 Tool Power Source

In the area precisely in the rice fields usually rarely have electricity or lights. Therefore, in the automation tool of watering shallot plants this time using solar cells or commonly called solar panels [9]. The working principle of this solar panel is to convert heat energy from sunlight into electrical energy which is used to supply components in the panel box of the watering device to function properly, such as the ESP-32 module and sensors connected to the ESP-32 module (DHT 22 and Soil Moisture sensors). Figure 3 shows a schematic view of the electrical power source used.

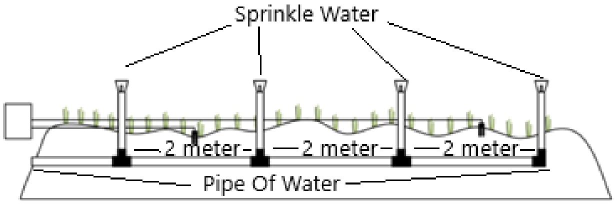

Figure 1. Sprinkle and Sensor Laying Design

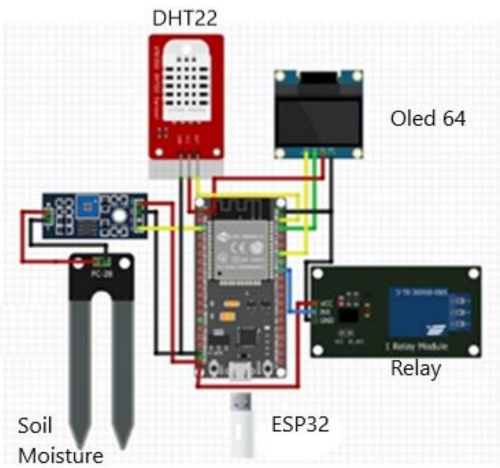

Figure 2. Block Diagram System

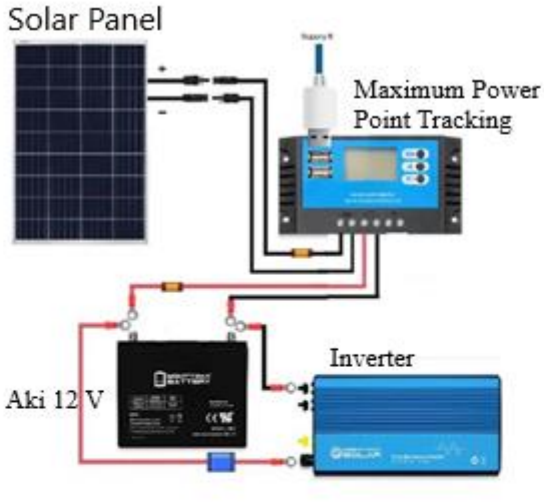

Figure 3 . Tool Power Supply Diagram

This solar panel is mounted on the top of the support pole of the tool panel box and then connected to the MPPT (Maximum Power Point Tracking) tool [10]. This MPPT functions as a controller or regulator of the electrical energy generated from the solar panel. The electrical energy generated from solar panels is usually around 15V with DC (Direct Current) current or what is commonly called direct current. So that the output electricity from the solar panel can power a water pump that has an input voltage of 220 VAC, the output of the solar panel is connected to an inverter. This inverter serves to change the current that originally came from the solar panel's DC into AC (Alternate Current) or alternating electric current with an output voltage of 220 VAC. After going through the inverter, the water pump can turn on or function properly. Especially for the ESP-32 module does not need to be connected using a DC adapter to the inverter. It is enough to prepare a micro-USB data cable to connect the ESP-32 module to the USB port on the MPPT tool. The voltage issued from the USB port of the MPPT is the same as the voltage required for the ESP-32 module, which is 5VDC.

In order to be able to do automatic watering at night, a battery or battery is added to this tool to store electrical power. The battery or battery used this time is a VRLA battery which has an output voltage of 12 VDC and has a capacity of 12 AH or 12,000 mAh [11]. This battery is connected to the MPPT tool to the connector that has the battery logo. After being connected to the MPPT tool, the battery will automatically store the electrical energy generated from the solar panel. In order to extend the service life of this battery, the battery is installed in the panel box. During the day or when there is still sunlight, this tool will use electricity directly from solar panels, and this VRLA battery will be charged or recharged to be used at night or with no sunlight. At night, this tool will use electricity from this VRLA battery as its power source, and then the output of this battery is connected to the input of the inverter.

2.3 Automation and Tool Monitoring System

The shallot plant watering tool made this time has a function as automation so that it can do the job automatically without the need for users to control the tool via a smartphone. For example, when the soil is less moist or the water content in the soil is less, then this tool will automatically turn on the water pump to water the shallot plants. To be able to make this automation system, a sensor is needed [12]. The sensor that plays a role in the automation of this tool is the soil moisture sensor. The soil moisture sensor in this tool is used to read the soil moisture level of shallot plants. Figure 4 is a picture of the flowchart for the watering tool automation system.

When the soil condition read using the soil moisture sensor has a humidity level of less than 60%, the device will automatically turn on the water pump to pour water onto the shallot plants. After the soil moisture level equals or exceeds 80%, the water pump will turn itself off. The module that can receive digital commands from the ESP-32 module, which acts as an automatic switch on this sprinkler, is a relay module. This relay module has the same working principle as a switch, namely as an electric current breaker in a circuit or electrical component. In these sprinklers, the relay module is used to cut off the electric current flowing in the water pump. So, the ESP-32 module will send a command, which is then forwarded to the relay module to control the water pump by disconnecting or connecting the electric current from the inverter to the water pump.

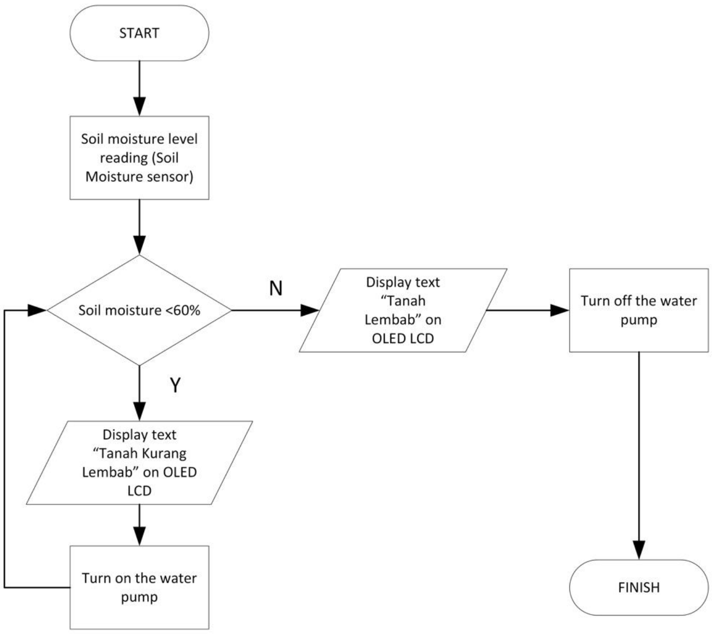

Figure 4. Flowchart of Tool Automation System

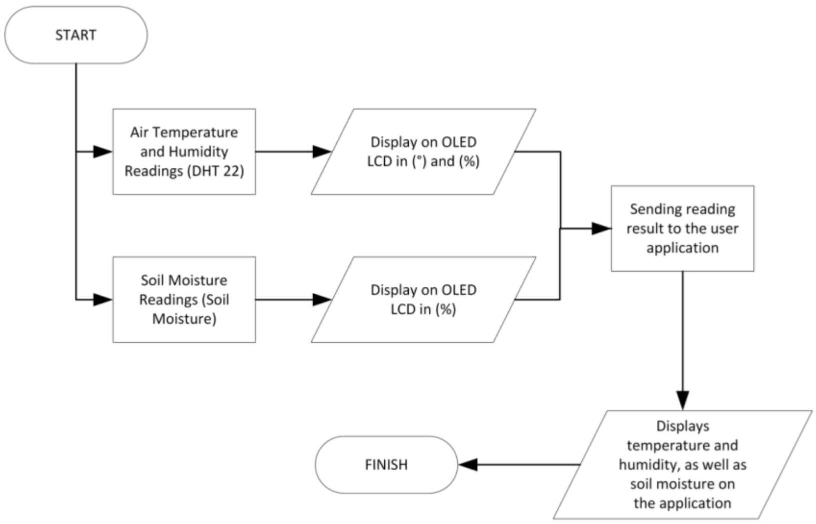

Figure 5. Flowchart of Tool Automation System

The tool made this time has functioned as a monitoring system. This monitoring system includes monitoring soil moisture levels and temperature along with air humidity around the shallot plant area. This monitoring data is sent via the internet network, and then the data will be displayed on the user's smartphone application. The application on the user's smartphone besides having a function as a monitoring tool. Figure 5 is a picture of the flowchart of the monitoring system of the watering device.

Data from the readings of the air temperature and humidity sensors using DHT 22, as well as data from the soil moisture sensor readings using soil moisture, can not only be seen using the application on the user's smartphone. But it can be seen on the front of the panel box. The front of the panel box is equipped with one OLED LCD that can display the soil moisture level, air temperature, and air humidity from the area around the shallot plant. The unit of data from the DHT 22 and soil moisture sensor readings, displayed on the OLED LCD screen and those on the user's smartphone application, is degrees Celsius (°C) for temperature, percent (%) for air and soil humidity.

Data transmission from the reading results of the temperature sensor and soil and air humidity can be sent via the internet because the ESP-32 module has a WiFi module that can be used to connect to wireless network devices such as access points, MiFi modems, routers, and other wireless devices that support wireless connections. This can also be utilized in this tool as a remote monitoring system. Users can monitor the condition of soil moisture or the temperature and humidity of the air around the shallot plant through an application on their smartphone. This can be done, but on condition that the ESP-32 module is connected to the internet network. A MiFi modem installed in the panel box is the device used to provide a wireless internet connection on this tool. This MiFi modem device has a SIM card like in a smartphone as an internet source. This device has a working principle, like the general hotspot feature available on smartphones.

2.4 Alternative Tool System

If the user experiences technical problems with the device, such as the device experiencing network problems that result in an inability to connect to the internet network, the device needs system repairs. The user's smartphone is also experiencing problems, such as being unable to connect to the internet, and even the application on the user's smartphone is experiencing problems [13]. So that the shallot plants' soil conditions maintain moisture, watering can be done manually without going online through a smartphone. The way to do this is to select the selector switch to the manual section, and to turn on or turn off the water pump, which can be done by pressing the ON or OFF button on the panel box with the scheme shown in Figure 6. The water pump will turn on without using commands from the ESP-32 module. This method is done when the device or the user's smartphone has a problem that results in being unable to water online.

3. RESULTS AND DISCUSSIONS

In the first part, the results of this research tool can be seen in Figure 7, which shows the complete structure and main components of the automatic watering system. The system is designed to improve the watering efficiency of shallot plants, especially in rice fields where conventional power sources are difficult to obtain. The solar panel mounted on top of the supporting pole allows the device to convert solar energy into electricity to support the device's function for 24 hours. The MPPT module is tasked with optimizing the power generated from the solar panel, as well as managing the energy storage in the VRLA battery for nighttime use. The ESP-32, as the automation control center, is connected to the DHT22 sensor and soil moisture sensor to monitor temperature, air humidity, and soil moisture in real time. The data obtained from the sensors is displayed on an OLED screen on the panel box as well as sent to a smartphone app for remote monitoring, providing users with the flexibility to effectively monitor plant conditions.

The Table 1 shows the test results of the electrical power source of the automatic watering system using solar panels and VRLA batteries. In the morning, starting at 07:00 until the afternoon at 17:00 [14], the solar panel produces a voltage that varies from 12.5 V to 15.0 V. During this period, the VRLA battery is in a state of charge, with the voltage output increasing from 12.0 V to 12.9 V. After sunset, from 19:00 until the early hours of 01:00, the solar panel no longer generates voltage, so the system switches to using power from the VRLA battery. At this time, the voltage output from the VRLA battery decreases gradually, indicating that stored energy is used to keep the system operational. This transition from charging to power usage ensures that the appliance continues functioning without depending on an external power supply.

Figure 6. System for Automatic Manual Change

(a). Overall external appearance of the tool (b). Overall inside view of the tool
Figure 7. Display of the Tool Made

Table 1. System Periodic Recharging.

No.	Time (Hour)	Solar Panel Output (V)	VRLA Battery Output (V)	Battery Charging Status
1	07:00	12.5	12.0	Fill out
2	09:00	13.2	12.4	Fill out
3	11:00	14.1	12.6	Fill out
4	13:00	15.0	12.7	Fill out
5	15:00	15.0	12.8	Fill out
6	17:00	13.5	12.9	Fill out
7	19:00	0	12.8	Battery Usage
8	21:00	0	12.5	Battery Usage
9	23:00	0	12.3	Battery Usage
10	01:00	0	12.0	Battery Usage

The Table 2 shows the relationship between time, soil moisture, water pump status, and environmental conditions in the automatic watering device. Based on the data, the water pump turns on when the soil moisture is below about 60%, and turns off when the moisture reaches 62% or more. In the morning to afternoon when the environmental conditions are hot or sunny, the pump tends to turn on as the soil moisture level decreases due to evaporation [15]. However, during the afternoon in cloudy and rainy conditions, soil moisture increases to as high as 83%, so the pump automatically shuts off to conserve water. During the night and early morning with cool or cold environmental conditions, the water pump continues to function automatically to maintain soil moisture when it reaches the lower limit of about 55%. This shows that the system works according to changing environmental conditions, keeping the soil moisture ideal for shallot plants.

Table 2. System Periodic Recharging.

No.	Time (Hour)	Soil Moisture (%)	Water Pump Stats	Environmental Conditions
1	08:00	55	ON	Hot
2	10:00	62	OFF	Sunny
3	12:00	58	ON	Hot
4	14:00	81	OFF	Sunny
5	16:00	57	ON	Cloudy
6	18:00	83	OFF	Rainy
7	20:00	59	ON	Sunny
8	22:00	75	OFF	Sunny
9	00:00	61	OFF	Cold
10	02:00	55	ON	Cold

Table 3. System Monitoring Parameter.

No.	Time (Hour)	Air Temperature (°C)	Air Humidity (%)	Soil Moisture (%)
1	08:00	25	70	58
2	10:00	27	65	60
3	12:00	30	60	56
4	14:00	32	55	82
5	16:00	28	68	58
6	18:00	26	72	80
7	20:00	24	75	60
8	22:00	22	78	77
9	00:00	21	82	63
10	02:00	20	85	55

The Table 3 shows the relationship between time, air temperature, air humidity, and soil moisture in the automatic watering device. From the data, it can be seen that the air temperature tends to be higher during the day, peaking around 14:00 with 32°C, while the air humidity decreases to 55% at the highest temperature. Soil moisture fluctuates with air temperature and air humidity; for example, at high temperatures with low air humidity, soil moisture decreases due to increased evaporation, as seen at 12:00 and 16:00. In contrast, air humidity increases in the afternoon and evening when temperatures decrease, such as at 18:00 until early morning, reaching 85% at 02:00. At these times, soil moisture remains higher, indicating that evaporation is decreasing and water is more easily absorbed by the soil. This analysis shows that the automatic watering device does a good job of adjusting soil moisture according to environmental conditions throughout the day, especially when soil moisture reaches a low point, the device will water to maintain soil moisture.

The Table 4 shows the use of water pump control methods based on time, method used, water pump status, and soil moisture. It can be seen that the water pump was activated using two methods, namely through a physical button (manual) and an app (remote). At any given time, the water pump is manually turned on when the soil moisture decreases to about 52-59%, indicating that manual control is performed when the soil moisture is below 60%. In contrast, the app was used to turn off the water pump when the soil moisture reached about 68-82%, indicating that control via the app was done to keep the moisture from being excessive. In addition, this pattern shows that users regularly monitor and control the water pump every 2 hours, both to ensure watering and to turn off the pump when the humidity is high enough. This control pattern indicates that the system works well in adjusting plant needs to soil moisture, and both control methods are effective in maintaining optimal soil conditions.

The proposed system demonstrates significant advancements over previous research by integrating real-time temperature, humidity, and soil moisture monitoring into an Android app, providing seamless control via both manual and remote methods. Unlike earlier systems, it incorporates calibrated sensors with self-diagnostic features to ensure accuracy, and uses a solar-powered energy source with VRLA battery backup, which enhances sustainability and reliability and can shown on Tabel 5. The inclusion of automated controls, customizable monitoring displays, and a focus on environmental impact (via solar energy and water conservation) establishes the system as superior. While prior studies often focused on single parameters (e.g., soil moisture) or lacked remote monitoring, this system's holistic approach to irrigation management ensures optimal conditions for shallot cultivation and addresses common challenges like sensor or pump failures.

Table 4. System Manual Testing.

No.	Control Method	Water Pump Stats	Soil Moisture (%)	Status
1	Physical Buttons	ON	55	Manual ON
2	Application	OFF	68	Virtual OFF
3	Physical Buttons	ON	52	Manual ON
4	Application	OFF	80	Virtual OFF
5	Physical Buttons	ON	54	Manual ON
6	Application	OFF	78	Virtual OFF
7	Physical Buttons	ON	59	Manual ON
8	Application	OFF	82	Virtual OFF
9	Physical Buttons	ON	57	Manual ON
10	Application	OFF	80	Virtual OFF

Table 5. Comparative Analysis of Monitoring Parameters in IoT-based Irrigation Systems.

Parameter	Proposed System	Research 1	Research 2	Research 3	Research 4	Research 5
Real-time Monitoring	Air temperature, humidity, and soil moisture monitored continuously via Android	Soil moisture only, no real-time app integration	Soil and air temperature monitoring, local only	Air temperature and soil moisture monitoring	Soil moisture monitoring with periodic logging	Soil moisture and air temperature monitoring
Control Mechanism	Automatic and manual control through app and physical buttons	Semi-automatic, manual intervention required	Fully automatic based on soil moisture	Semi-automatic with fixed time intervals	Manual control only	Fully automatic, app-based
Sensor Accuracy	Calibrated sensors with periodic diagnostics	Limited diagnostics, prone to errors	Moderate accuracy, occasional calibration required	Calibrated, but lacks error notification	Basic sensors, no diagnostics	Calibrated, moderate reliability
Energy Source	Solar-powered with VRLA battery backup	Grid electricity	Diesel generator	Grid electricity	Solar panels only, no battery backup	Hybrid (grid + solar backup)

4. CONCLUSION

The conclusion of this research shows that this solar-based automatic watering system works effectively in maintaining soil moisture in shallot plants, especially in rice fields that have difficulty getting conventional electrical power sources. The system can operate for 24 hours by utilizing energy from solar panels optimized by MPPT modules and stored in VRLA batteries for nighttime use. ESP-32-based automatic control connected with DHT22 sensor and soil moisture sensor enables real-time temperature, air humidity, and soil moisture monitoring. The data obtained is displayed on an OLED screen and sent to an app on a smartphone, making it easy for users to monitor plant conditions remotely.

Test results show that the voltage of the solar panel fluctuates between 12.5 V to 15.0 V from morning to evening. At the same time, the VRLA battery is charged until it reaches 12.9 V. After sunset, the system switches to using power from the gradually declining VRLA battery, ensuring the device continues to function without an external power source. The water pump setting is automatic based on soil moisture conditions, with the pump turning on when the humidity is below 60% and off when the humidity reaches 62% or above, according to changes in air temperature and humidity. In the manual test, the user can control the water pump through physical buttons or the app to maintain optimal moisture. This pattern shows that the automatic watering system is responsive to environmental changes and effectively retains soil moisture.

While the system demonstrates excellent performance in maintaining shallot growth conditions during testing, its long-term efficiency and durability require further analysis. Factors such as potential degradation of solar panels or VRLA batteries over extended periods, as well as wear and tear on hardware components like sensors and pumps, may affect the system's reliability. Regular maintenance, including cleaning solar panels, recalibrating sensors, and checking pump performance, is necessary to ensure consistent operation. Additionally, future enhancements could involve replacing VRLA batteries with more durable lithium-ion batteries or integrating advanced diagnostics for early detection of hardware failures. Addressing these long-term considerations will improve the system's sustainability, providing a robust and scalable solution for efficient, environmentally friendly irrigation in shallot farming.

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