Mars: Jurnal Teknik Mesin, Industri, Elektro dan Ilmu Komputer
Volume. 2 Nomor. 6 Tahun 2024
e-ISSN : 3031-8742, dan p-ISSN : 3031-8750, Hal. 211-224
DOI: https://doi.org/10.61132/mars.v2i6.556
Available online at: https://journal.arteii.or.id/index.php/Mars

IoT-Based Irrigation Control System with ESP32 for Sustainable Agriculture

Nazwa Amelia Purnama[1], Rafif Abyakto[2] , Muhammad Gilang Nur Rosyid[3], Danna Rayyana Irfawan[4], Muhammad Soli[5], Didik Aribowo[6]
[1-6]Sultan Ageng Tirtayasa University, Indonesia

Address : Jl. Raya Palka Km 3 Sindangsari, Pabuaran, Kab. Serang Provinsi Banten
Author's correspondence : 2283230005@untirta.ac.id

Abstract. The global food crisis has become one of the most pressing issues requiring serious attention, especially as the world's population continues to grow. This growth has led to an increasing demand for food, while agricultural resources such as fertile land, water, and labor become increasingly limited. These conditions present significant challenges for farmers, including droughts that damage crops, floods that devastate agricultural lands, and pest attacks that significantly reduce yields. Furthermore, global climate change exacerbates the situation, directly impacting the stability of food production. Unpredictable weather patterns threaten harvest success, increase the risk of crop failure, and decrease agricultural productivity. Therefore, innovative solutions, such as utilizing Internet of Things (IoT)-based technologies, are urgently needed to support the sustainability of the agricultural sector by enhancing efficiency, effectiveness, and global food security. This study aims to contribute to addressing these challenges through a modern technological approach.

Keywords Agricultural, technology, IoT, Soil, moisture, monitoring.

1. INTRODUCTION

Food availability is a top priority for everyone around the world.Therefore, when some countries face food crises, including in certain parts of the world today, Indonesia, as a country with a high level of food consumption, must address this issue seriously (Risandi, n.d.2021). With the continuously growing population, especially in developing countries, the demand for food has also increased significantly. However, not all agricultural resources, such as fertile land, water, and labor, can keep up with this growth. As a result, the imbalance between demand and supply leads to rising food prices and uncertainties in supply, culminating in food crises in certain regions.

In the agricultural sector, the presence of global climate change has become a factor that threatens the success of harvests. The relationship between agriculture and climate change is very close because the agricultural sector is substantially affected by changes in weather and climate. Therefore, farmers' knowledge and preparedness to face climate change are crucial. The impacts of climate change include decreased crop quality, increased pest attacks, crop failures, and reduced farmers' incomes, ultimately lowering their overall well-being (Nuraisah & Kusumo, 2019).

Received: Oktober 06, 2024; Revised: November 20, 2024;Accepted: Desember 04, 2024;
Published: Desember 07, 2024

In Tangerang Regency, there is significant potential to develop extensive agricultural land, particularly in Tegal Kunir Lor Village, which could contribute to achieving food self-sufficiency in the region. Tegal Kunir Lor Village is located in Mauk District and spans an area of 335 hectares. This village is known for its considerable potential in agricultural land management, particularly for rice farming. In addition to having adequate land area, Tegal Kunir Lor Village also has active and enthusiastic farmer groups in managing agriculture, demonstrating strong participatory potential in developing the agricultural sector in the area.

Interviews with local farmer associations (Gapoktan) revealed that, despite the high enthusiasm of farmers in Tegal Kunir Lor Village for agriculture, many lack an understanding of the necessary steps before starting rice planting. They tend to assume that selecting high-quality rice seeds and using good fertilizers are sufficient for achieving successful harvests. However, a commonly overlooked aspect is the importance of monitoring water levels in paddy fields and addressing the uncertainties of weather, which are often difficult to predict accurately. Additionally, proper irrigation management is vital, as deficiencies in these areas can lead to crop failures. Therefore, it is crucial for farmers to enhance their understanding of comprehensive preparatory steps before planting to achieve maximum yields and reduce the risk of losses due to crop failure.

Technological advancements in the current era present a golden opportunity to address various problems. One of the emerging solutions is the development of smart irrigation systems based on the Internet of Things (IoT) to tackle these issues. Various studies have been conducted to develop this technology, such as the one by Kontogiannis et al. They integrated an artificial intelligence system to control the servo used in regulating the irrigation gates (Kontogiannis, 2017). Another study also utilized an on/off control system for operating water pumps based on a web interface, communicating via the ESP8266 module and integrating ultrasonic sensors to measure distance and detect water levels (Shofiyun, 2021).

Several of the studies mentioned above used the ESP8266 microcontroller (Sen., 2020) (Ariyanto, 2021), which only has one analog pin. This creates problems when trying to integrate multiple sensors that require analog pins. Based on this, this study develops an IoT-based agricultural irrigation management system using the ESP32 microcontroller. The ESP32 has the advantage of providing more analog pins, making it easier to configure when multiple analog inputs are needed.

Components integrated into the microcontroller include a solenoid valve, which regulates the flow of water to the agricultural land, and a soil moisture sensor used to control the solenoid valve. The system is also equipped with a wireless network to ensure effective data communication and to cover large agricultural areas. The user interface is a key aspect of this research, where the system's interface is built using a mobile-based platform with a client-server model. This makes it easier for users to access and control the developed system.

For database management, the system operates in real-time using the Blynk IoT platform. The main contribution of this research is the development of a system that provides fast, easy, and accurate information related to monitoring and controlling soil fertility, so that this information can be used as a basis for decision-making by users. This technology also has the potential to serve as a reference or guideline for future agricultural technology development, supporting the realization of the industrial revolution in Indonesia through the "Making Indonesia 4.0" program, particularly in the agricultural sector.

1.1 Problem Formulation

Based on the background described previously, the following research problems can be formulated as questions:

a) To what extent do Indonesian farmers understand the preparatory steps needed before starting rice cultivation?
b) How do farmers perceive crucial factors such as water levels in rice fields, handling unpredictable weather, and proper irrigation management in the context of achieving a successful harvest?
c) What are the main challenges faced by farmers in preparing agricultural land, particularly in selecting rice seeds, using fertilizers, and other factors affecting harvest productivity?
d) How can modern IoT-based technology be utilized to enable farmers to control and monitor the conditions of their rice fields effectively?

1.2 Research Objectives

a) To develop solutions for addressing drought and flooding issues in agricultural land by improving rice field irrigation systems, thereby preventing losses during rice planting.
b) To implement smart water irrigation technology that can be automatically regulated, replacing traditional rain-fed systems, enabling more efficient water management in rice fields during planting.

c) To provide training and assistance for farmers in creating irrigation system modules that can be mass-produced, allowing the widespread adoption of this technology by other farmers for use in their agriculture.
d) To develop a water control system for rice fields that can be operated via smartphones or computers, leveraging the work-from-home (WFH) concept.

1.3 Research Benefits

a) Ensuring the availability of rice field irrigation throughout the season, eliminating the risks of drought or flooding that disrupt agricultural processes.
b) Enhancing farmers' technological literacy through the use of smart water irrigation systems and pest monitoring. Developing IoT-based technology for smart rice fields to regulate water supply from planting to harvest.
c) Improving the economic welfare of farmers by increasing agricultural productivity through the implementation of efficient irrigation systems.
d) Producing tools and modules that can be mass-produced and marketed to the broader community, with the hope of being adopted in other regions to enhance their agricultural efficiency and productivity.

2. LITERATURE REVIEW

To achieve food self-sufficiency through increased food production, particularly rice, the utilization of groundwater can be a solution for regions experiencing surface water shortages. This is especially relevant in areas with agricultural potential but insufficient water supply. The use of groundwater must align with the capacity of local aquifers and be regulated in accordance with established policy frameworks, such as the Water Resources Law No. 7 of 2004, Government Regulation No. 43 of 2008 on Groundwater, and other relevant regional regulations (Winskayati, 2011).

Irrigation plays a crucial role in agriculture, as water is an essential factor in determining the yield of agricultural production in a given area. If agricultural land receives an adequate water supply, the production results will increase. Conversely, if the water supply is insufficient, crops will wither or die, leading to reduced yields. The utilization of groundwater as an irrigation solution to enhance food production, particularly rice, represents a strategic step in addressing food security challenges. However, this approach faces various complex issues. In addition to inadequate surface water supply, agricultural areas often experience unpredictable weather fluctuations and the risk of pest infestations that can damage crops. Therefore, beyond evaluating groundwater availability, it is crucial to consider the impacts of weather fluctuations and pest attacks on agricultural productivity.

Risk analysis of these factors is key to designing effective irrigation solutions. Thus, the development of appropriate technical solutions and policies, coupled with regular monitoring, is expected to support the use of groundwater in agriculture as a step toward achieving sustainable food security. E-Tani functions as an intelligent irrigation controller. It begins with managing water flow to achieve the desired water level and can drain excess water to prevent over-irrigation in the rice fields. Conversely, if the fields dry out due to a lack of water in the irrigation channels, this tool will automatically supply water from a prepared underground source. Additionally, it supports fertilization and pest control. The smart irrigation system consists of essential modules, each playing an active and interconnected role to ensure efficient and automated operation.

3. METHODS

The sampling process in this study aims to obtain representative information about the population by collecting data from only a portion of it. This approach allows researchers to gather high-quality data without involving the entire population, making it more efficient in terms of time, cost, and effort. By selecting an appropriate sample, the results can provide an accurate and relevant overview of the conditions or characteristics of the population as a whole (Franco, 2019).

The data collection through literature review discusses previous research efforts aimed at addressing challenges in the agricultural sector to ensure its continued operation without being affected by seasonal changes. These studies focused on enhancing agricultural productivity by integrating information and communication technologies (ICT). This technology is applied through the measurement of variables such as groundwater availability, soil moisture, air humidity, planting environment temperature, and real-time monitoring of plant conditions (Khairudin, 2023).

The measurement of various key agricultural variables is accompanied by appropriate responses to the results. This approach is expected to enable continuous crop quality maintenance throughout the day until harvest time. The technology is designed to assist farmers in monitoring conditions such as soil moisture, water level, and water flow rate. Additionally, the system is developed to integrate with the Internet of Things (IoT), allowing data on soil moisture, water level, and flow rate to be processed and transmitted directly to users. This data is linked to a platform that can be easily accessed via smartphones, enabling a "Work from Home" system where farmers can oversee and manage their agricultural activities remotely without needing to be physically present in the fields.

Picture 1 Panel

The soil moisture sensor functions as a device that can detect the water content within the soil. This information is valuable in various applications, such as agriculture and horticulture, where managing soil moisture levels is essential to ensure optimal conditions for plant growth. By using this sensor, the system can automatically monitor and provide real-time data on soil moisture levels, allowing for quick decision-making, such as for irrigation. This sensor has three connector pins. The first pin is connected to the Vcc pin on the Arduino Mega2560 as a power source, while the second pin is connected to the GND pin as the ground line. The third pin acts as an analog input connected to one of the analog pins on the Arduino Mega2560. This analog input reads the voltage signal generated by the sensor, representing the soil's water content. A reference voltage of 5 VDC is used to calibrate the sensor and ensure accurate readings. As the moisture level increases, the voltage read by the sensor will change, and this change can be monitored through the microcontroller to determine the desired moisture level. Sirait, R. (2020).

The push button works by pressing it to connect or disconnect the electric current in a circuit. When pressed, the push button closes the circuit, allowing current to flow; when released, the circuit opens, stopping the current. This type of switch is widely used in various electronic devices due to its ease of operation and ability to provide quick and simple control over electrical flow. Push buttons are available in different types, including momentary, which is only active while pressed, or latching, which remains active until pressed again, making them suitable for various manual control applications. Iman, F. (2018).

Limit switches are commonly used in various industrial and automation applications because of their ability to detect the position or movement limit of an object. For example, a limit switch can be installed on a machine to detect if a part has reached a certain point, allowing the machine to stop or initiate another process. With a valve mechanism sensitive to pressure, the limit switch enables precise and safe control, especially for moving or rotating equipment. The normally open (NO) and normally closed (NC) settings provide flexibility, depending on the application needs—whether to turn the circuit on or off when the valve is pressed. Rahmawati, V. (2017).

A microcontroller is an electronic device designed to control various systems or applications by automatically processing data. This microcontroller typically consists of several components, such as a processor, memory, and input/output interfaces that allow interaction with other devices. The ESP32-CAM, as an example of a microcontroller, has the advantage of featuring a camera, enabling image or video capture. This makes the ESP32-CAM ideal for applications that require image processing, such as surveillance systems, object recognition, and various Internet of Things (IoT) applications. Additionally, the ESP32-CAM is equipped with Wi-Fi and Bluetooth connectivity, allowing integration with networks and other devices for remote data transmission or control. Atikah, N. (2022).

An LED (Light Emitting Diode) is an electronic component that emits light when an electric current passes through it. This process occurs due to the p-n junction, which is formed from two different layers of semiconductor material: the p-layer (positive) and the n-layer (negative). When current is applied in the correct direction (forward current), electrons move from the n-layer to the p-layer and release energy in the form of light. The color of the light emitted by the LED depends on the semiconductor material used, which affects the energy released when electrons move. LEDs have advantages over incandescent or neon lamps because they are more efficient, durable, and generate less heat. Additionally, LEDs are more resistant to shock and vibration and are smaller in size. However, due to their polarization properties, LEDs can only operate in one direction of electric current (forward current), which requires proper polarity when installing them. LEDs also typically have a lower breakdown voltage compared to other components, so it's important to consider this in circuit design to avoid damaging the LED chip. Saputro, J. (2013).

A water pump is an essential mechanical device commonly used in various industries and household applications. It works by moving liquids, usually water, from one location to another, often from lower to higher elevations, which is crucial for tasks like irrigation, water supply, drainage, and industrial processes. The pump operates by converting mechanical energy, typically from an electric motor or engine, into hydraulic energy, causing the fluid to flow. In the process, the pump generates pressure, which forces the water through pipes and hoses, overcoming friction and other resistances in the system. Depending on the type of pump, it can either increase the fluid's velocity, pressure, or both. Some pumps, like centrifugal pumps, rely on spinning impellers to push the fluid, while others, like positive displacement pumps, move fixed amounts of water with each cycle. The efficiency of a pump depends on factors such as the pump design, the fluid's viscosity, and the resistance of the system. Yana, K. (2017).

4. RESULTS AND DISCUSSION

This system is designed by dividing its operation into three main parts: the control process through a microcontroller, input from various sensors and indicators, and output that manages supporting hardware. The microcontroller used is the Arduino Uno, a device based on the ATmega328 that functions as the central controller. The Arduino Uno is equipped with several features, including 14 digital input/output pins, 6 analog input pins, a USB connection, and a power jack. The microcontroller processes data from sensors and water level indicators to determine the conditions of the water gates and reservoir gates based on signals received from motor positions and limit switches.

The system's inputs consist of a soil moisture sensor, water level indicators, and limit switches. The soil moisture sensor detects water content in the soil and sends signals to the microcontroller if the soil is too dry or adequately moist. Additionally, water level indicators monitor the condition of water in reservoirs, rivers, and fields. These indicators have three primary states: LOW, MEDIUM, and HIGH. For example, in a LOW state, the reservoir water level triggers the water pump to fill the reservoir, while in a HIGH state, the water pump is turned off, and the indicator light signals that the reservoir is full.

The river water level indicator monitors the river's condition and sends signals according to the situation, such as warnings for dry, normal, or near-flood conditions. Meanwhile, the field water level indicator manages irrigation based on the farmers' requirements. Limit switches, on the other hand, send signals about the status of the water gates, whether they are open or closed.The system's output includes various hardware components, such as water pumps, water gate actuators, and indicator lights. The water pumps are used to fill the reservoir or drain excess water from the fields when needed. The water gate actuators automatically control the opening and closing of irrigation gates, while the indicator lights provide visual information about the operational mode currently being executed by the system.

To support connectivity, the system is equipped with an ESP8266 IoT module that allows the microcontroller to connect to a Wi-Fi network. This module processes and wirelessly transmits data to the Smartfarm platform, which can be accessed via a smartphone. With this technology, farmers can monitor field conditions, such as soil moisture, water levels, and water discharge, in real time, enabling more effective land management and maintenance processes.

In evaluating the performance of this soil moisture sensor, measurements were conducted to assess the moisture levels in different soil conditions. The tests involved three distinct types of soil conditions: dry, fertile, and flooded. During the testing process, the sensor was used to measure the soil moisture, and the results were converted and displayed in real-time. The LCD monitor, which is connected to the A0 pin of the ESP 32 module, plays a crucial role in this process by visually presenting the converted data. This setup allows for easy monitoring and interpretation of the moisture levels across the various soil types, providing valuable insights into the sensor's performance under different environmental conditions. The use of the ESP 32 module ensures that the data is processed and displayed efficiently, offering accurate readings that can be observed directly on the LCD screen.

This soil moisture sensor works by detecting the water table height within the soil. This measurement process allows the sensor to accurately identify changes in moisture levels, as the value obtained reflects how much water is contained in the soil at a certain depth. The data generated by the sensor will be used as a reference to determine the soil moisture level at a given time. Using the formula provided below, the obtained information can be converted into a more understandable moisture value, which can be applied for agricultural purposes or research related to soil conditions. This process is highly useful for monitoring soil moisture dynamics in real-time and helps in the efficient management of water resources.

$$ADC = \frac{1023 - Sensor\ detection\ point}{673} * 100$$

The values 1023 and 673 in the ADC calculation formula are obtained from the technical settings of the sensor and the system used. The value 1023 represents the maximum limit that can be read by the Analog to Digital Converter (ADC) on microcontrollers, such as those found in NodeMCU or ESP32, which typically have a 10-bit resolution. In this case, the ADC can generate values from 0 to 1023, where 1023 represents the strongest or highest analog input signal that the sensor can measure.

Meanwhile, the value 673 is derived from the difference in soil moisture between wet and dry conditions. This value is obtained from the sensor calibration that measures the change in the signal when the soil is in these two extreme states. When the soil is wet, the sensor detects a higher value, and when the soil is dry, the detected value is lower. By using the number 673 as a reference between these two conditions, the formula is able to accurately calculate the percentage of soil moisture based on the readings provided by the sensor.

The **Error (%)** formula is used to measure the deviation of the sensor's readings from a more accurate reference value. This formula calculates the absolute difference between the humidity value displayed on the sensor's LCD (**Humidity Record on LCD**) and the humidity value measured using a reference tool (**Assessed Humidity**), then divides it by the reference value and converts it into a percentage. The error result indicates the accuracy of the sensor, where a smaller error value signifies better accuracy. Factors affecting the error include the quality of sensor calibration, environmental conditions, soil type, and the accuracy of the reference tool. This formula is crucial for evaluating sensor performance and ensuring that the readings align with actual conditions

$$\text{ERROR (\%)} = \frac{|Assessed\ Humisty - humidty\ Record\ on\ LCD|}{Assessed\ Humidity}$$

The **Error (%)** formula is a simple way to evaluate the accuracy of a sensor by comparing its readings to a reference value. The error result helps determine whether the sensor is operating according to specifications or requires recalibration. The purpose of performing error calculation and moisture conversion on the soil sensor is to evaluate the accuracy of the sensor in measuring soil moisture levels. By comparing the sensor's readings with a more accurate reference value, we can determine whether the sensor is functioning according to its specifications or requires recalibration. This calculation is also important to ensure that the device provides valid and reliable data for applications that require precise soil moisture measurements, such as in agriculture or environmental research.

Table 1: Experiment for Performance Monitoring

Indicator	Sensor Detection Poin	ADC Value (%)	Humidity Record on LCD (%RH)	Assessed Humidity (%RH)	Error (%)
Dry	49	144.73	5	6	1.67
Dry	52	144.28	6	6	0
Dry	61	61.37	60	60	0
Wet/Moist	81	31.65	80	79	1
Wet/Moist	85,6	24.81	85	84	1
Over	91	16.79	90	90	0

The data was obtained in the following calculation:

1. Sensor Detection Point = 49
   - ADC VALUE (%)

     ADC VALUE (%) = $\frac{1023-49}{637} X 100$

     $= \frac{974}{637} X 100$ = 152.90
   - Humidity Record on LCD (%RH) : 5
   - Assessed Humidity (%RH) : 6
   - Error (%)

     Error(%) = $\frac{|6-5|}{6}\ x\ 100$ = 16.67%

2. Sensor Detection Point = 52
   - ADC VALUE (%)

     ADC VALUE (%) = $\frac{1023-52}{637} X100$

     $= \frac{971}{637} X100 = 152.43$
   - Humidity Record on LCD (%RH) : 6
   - Assessed Humidity (%RH) : 6
   - Error (%)

     Error(%) = $\frac{|6-6|}{6}\ x\ 100 = 0\ \%$
3. Sensor Detevtion Point = 610
   - ADC VALUE (%)

     ADC VALUE (%) = $\frac{1023-610}{637} X100$

     $= \frac{413}{637} X100 = 64.83$
   - Humidity Record on LCD (%RH) : 60
   - Assessed Humidity (%RH) : 60
   - Error (%)

     Error(%) = $\frac{|60-60|}{60}\ x\ 100 = 0\ \%$
4. Sensor Detection Point = 810
   - ADC VALUE (%)

     ADC VALUE (%) = $\frac{1023-810}{637} X100$

     $= \frac{213}{637} X100 = 33.44$
   - Humidity Record on LCD (%RH) : 80
   - Assessed Humidity (%RH) : 79
   - Error (%)

     Error(%) = $\frac{|79-80|}{79}\ x\ 100 = 1\%$
5. Sensor Detection Point = 856
   - ADC VALUE (%)

     ADC VALUE (%) = $\frac{1023-856}{637} X100$

$$= \frac{167}{637} X100 = 26.22$$

- Humidity Record on LCD (%RH) : 85
- Assessed Humidity (%RH) : 84
- Error (%)

  Error(%) = $\frac{|84-85|}{84}\ x\ 100$ = 1%

6. Sensor Detection Point = 910

- ADC VALUE (%)

  ADC VALUE (%) = $\frac{1023-910}{637} X100$

$$= \frac{113}{637} X100 = 17.74$$

- Humidity Record on LCD (%RH) : 90
- Assessed Humidity (%RH) : 90
- Error (%)

  Error(%) = $\frac{|90-90|}{90}\ x\ 100$ = 0%

LIMITATION

It is inevitable that your research will have some limitations, and this is normal. However, it is critically important to strive to minimize the scope of these limitations throughout the research process. Additionally, you need to acknowledge your research limitations honestly in the conclusions chapter.

Identifying and acknowledging the shortcomings of your work is preferable to having them pointed out by your final work assessor. While discussing your research limitations, do not merely list and describe them. It is also crucial to explain how these limitations have impacted your research findings.

Your research may have multiple limitations, but you should discuss only those that directly relate to your research problems. For example, if conducting a meta-analysis of secondary data was not stated as your research objective, there is no need to mention it as a limitation of your research.

REFERENCES

Alkaff, S. M., Ahmad, R., & Sukandar, D. (2023). IoT-enabled smart drip irrigation system using ESP32. IoT, 4(3), 221–243.

Andreu, A., & Damián, L. A. (2020). IoT-based smart irrigation systems: An overview on the recent trends on sensors and IoT systems for irrigation in precision agriculture. Sensors, 20(4), 1042.

Del Aguila, A., & Oliveira, J. P. (2023). IoT-enabled smart drip irrigation system using ESP32. MDPI IoT Journal.

Ikhwani, G. R., Pratiwi, E., Paturrohman, A., & Makarim, A. K. (2013). Peningkatan produktivitas padi melalui penerapan jarak tanam jajar legowo. Iptek Tanaman Pangan, 8(2), 72–79.

Iman, F. F., & Alfi, I. (2018). Purwarupa smart door lock menggunakan multi sensor berbasis sistem Arduino (Doctoral dissertation, University of Technology Yogyakarta).

Khairudin, M., Fajar Dwi U, A., Hakim, M. L., Widowati, A., Prasetyo, E., Kurniawan, Y., & Azman, M. N. A. (2023). IoT-based smartfarm technology for rice farming. Jurnal Nasional Teknik Elektro. https://doi.org/10.25077/jnte.v12n2.1102.2023

Kumar, R., Gupta, P., & Singh, V. (2020). Smart irrigation management system using IoT technology: A case study with ESP32. IEEE Internet of Things Journal.

Lalla, H., M., Saleh, A., & Saadah. (2012). Adopsi petani padi sawah terhadap sistem tanam jajar legowo 2:1 di Kecamatan Polongbangkeng Utara, Kabupaten Takalar. Teknologi, 12(3), 255–264.

Lita, T. N. S., Soekartomo, B., & Guritno. (2013). Pengaruh perbedaan sistem tanam terhadap pertumbuhan dan hasil tanaman padi (Oryza sativa L.) di lahan sawah. Produksi Tanaman, 1(4), 361–369.

Mungara, E. D., Indradewa, R., & Rogomulyo. (2013). Analisis pertumbuhan dan hasil padi sawah (Oryza sativa L.) pada sistem pertanian konvensional, transisi organik, dan organik. Vegetalika, 2(3), 1–12.

Rahmawati, V., & Efendi, A. T. (2017). Sistem pengendali pintu berbasis web menggunakan NodeMCU 8266 (Doctoral dissertation, STMIK AKAKOM Yogyakarta).

Saputro, J. H., Sukmadi, T., & Karnoto, K. (2013). Analisa penggunaan lampu LED pada penerangan dalam rumah. Transmisi: Jurnal Ilmiah Teknik Elektro, 15(1), 19–27.

Sirait, R. (2020). Sistem kontrol kelembaban tanah pada tanaman tomat menggunakan PID. Techno.Com, 19(3), 262–273.

Watemin, S., & Budiningsih. (2012). Penerapan pengelolaan tanaman terpadu (PTT) padi sawah di Kecamatan Kebasen Kabupaten Banyumas. Sepa, 9(1), 34–42.

Yana, K. L., Dantes, K. R., & Wigraha, N. A. (2017). Rancang bangun mesin pompa air dengan sistem recharging. Jurnal Pendidikan Teknik Mesin Undiksha, 5(2).