Design of a Robot to Control Agricultural Soil Conditions using ESP-NOW Protocol

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***Abstract*—Internet of Things (IoT) is a concept that utilizes an internet network that always connected among some devices. Internet of Things requires a protocol to get the information quickly and real time to exchange the data needed, one of them is ESP-NOW. ESP-NOW protocol is a communication protocol that is able to send data over long distances, with relatively fast transfer speeds. In addition, technology that is developing rapidly at this time is the development of robots. Robot is a tool or technology used to facilitate human work. In this research, an IoT-based robot was developed to perform maintenance on various types of soil in accordance with optimal parameters. The robot can monitor the soil conditions and water the plant automatically. The robot monitors the temperature and humidity of the air, as well as the humidity of the agricultural soil. The desired crop condition is 70% for the minimum air humidity threshold and 60% for the minimum soil moisture threshold. The robot is also equipped with a GPS module to store the initial location of the robot. The test was conducted at 6 points, where all points were in the desired condition after 3 times of testing. The robot also uses ESP-NOW as the communication protocol to send necessary information in real-time such as agricultural soil data. The success rate of messages received by the ESP-NOW gateway at a distance of 0.5 up to 3 meters from the sender is 100%.**

Keywords—internet of things, ESP-NOW protocol, robot, air humidity, soil moisture

I. Introduction

Agriculture is one of the fundamental fields in human life. Since the beginning of its development, agriculture has been conducted using tools such as sickles, hoes, and similar devices. Humans are required to devote time and energy to carry out agricultural activities. Many jobs have used mobile technology especially in the agricultural sector. The agricultural sector is very helpful in the economy and food needs in Indonesia. In the period 2012-2016 agricultural land area in Indonesia experienced fluctuations [1].

The problem that may arise in the dry season is the limited availability of water resources, so it is not always available in both quantity and quality in location or time when it is needed [2]. Due to global warming, unpredictable weather also affects harvests and farmers face huge losses so the IoT Smart Agriculture application will allow farmers to take quick action to prevent that from happening [3]. Therefore, innovation is needed so that agriculture can be carried out more effectively, where maintenance can be carried out with a standardized process, with the best parameters previously set.

The purpose of the research is to develop a robot that can perform plant maintenance that can be directly used without having to require a complicated installation process. The Robot that is made can also maintain the crop plants in accordance with the conditions of existing agricultural soil without increasing the number of human resources.

II. Literature Review

A. Internet of Things

Internet of Things (IoT) is a concept in utilizing internet connectivity that is always connected at all times [4]. The benefit of the Internet of Things (IoT) is to connect one electronic device with other devices through internet media with the purpose of making the system easier for humans to perform some tasks or jobs.

B. ESP-NOW

In its implementation, Internet of Things (IoT) requires a protocol for data communication so that it can be accessed quickly and easily [5]. ESP-NOW is a wireless communication protocol developed by Espressif, which allows many devices to communicate with each other without using Wi-Fi [6]. On the ESP-NOW network, all devices can communicate through three methods, i.e., broadcast, unicast, and multicast with data rates of 1Mbps or more [7].

C. Robot with Internet of Things

The development of IoT is increasingly rapid, comparable to the increasingly widespread use of robots in everyday life [8]. This makes robotic technology combined with the IoT a new innovation at this time. Automatic robots are able to move, measure as well as run commands autonomously because of the sensors that are used as input parameters which will be processed in accordance with the program that has been previously defined into the robot system. In general, to process the program, the robot uses a microcontroller that matches the system requirements criteria.

D. Previous Research Studies

Several studies have been carried out by previous researchers related to the research conducted. Maulidiyah *et* *al.* proposed a robot namely ROBUN (abbreviated from *Robot Pengaman Kebun Pengusir Hama Bajing*) as a squirrel repellent garden robot. They succeeded in creating a robot system for securing orange plantations from squirrel pests. The robot will move when it catches the movement detected through an ultrasonic sensor and moves towards the source of the movement and makes a sound to repel squirrel pests [9]. While, Sahara *et al.* developed an indoor smart garden system based on Arduino Uno from Microcontroller ATMega 328 to produce a system of monitoring and control of the soil moisture level of the garden [10].

Budiman had developed an agricultural soil system on rice plants (*Oryza Sativa L.*) based on IoT. The result is that the system is able to monitor both rainfall and water levels in paddy fields with the concept of IoT using MQTT protocol through a website-based application. In his study, there was no QoS trial of MQTT and using WeMOS D1 R2 board as the primary node [5]. In other research, Rohadi *et al.* proposed an IoT-based monitoring system for catfish cultivation using Raspberry Pi. The result is that the system is able to monitor water quality with water temperature and pH indicators in catfish farming using an Android-based application. In this work, the system was built using the HTTP protocol for data circulation [11].

An Android-based monitoring system for water quality and temperature in fish ponds had been proposed by Ardiansyah. The system was built using the HTTP protocol and Ethernet shield as a communication medium. In addition, there is no control connected to the system [12].

III. Design and Implementation

A. System Design

The robot was built on the basis of the Arduino Nano microcontroller which was integrated with NodeMCU. The sensing system used for robot motion control are two HC-SR04 sensors, each of which is located on the left side and the front side of the robot's body. In addition, there is a NEO-6M GPS module that functions is to look for the coordinate of the robot's initial position, and is used to determine when the robot stops moving. Furthermore, sensing systems are used to determine the physical parameters of agricultural or plantation soil, including the BME280 sensor for temperature and humidity, and the capacitive soil moisture sensor for soil moisture. Robot actuator system is divided into two parts, i.e., the motion system and watering system. The robot motion system consists of 2 (two) DC motors for each wheel (left and right) which are controlled with the help of the L298N DC Motor Driver, as well as other wheels (without DC motors) that act as robot balancer. In the watering system, there is a water pump that is connected to a water container through a hose, which will flow out water to the growing media. The water pump is controlled with the help of a relay. NodeMCU's role is to transmit data to the gateway through the ESP-NOW communication protocol. In addition, there are other components such as servomotors that are used to drive capacitive soil moisture sensors into the soil and batteries with boost converters as system power supplies. Figure 1 depicts a block diagram of the robot's system.

As explained earlier, the robot's motion system is determined from the reading of 2 (two) HC-SR04 sensors located on the left and front of the robot's body. The sensor will read the distance between the sensor and the object or barrier wall, this distance will be processed to determine the robot's motion. The minimum distance or threshold between the sensor and the barrier in this case is 10 cm. Figure 2 indicates the workflow of the agricultural robot in the form of a flowchart.

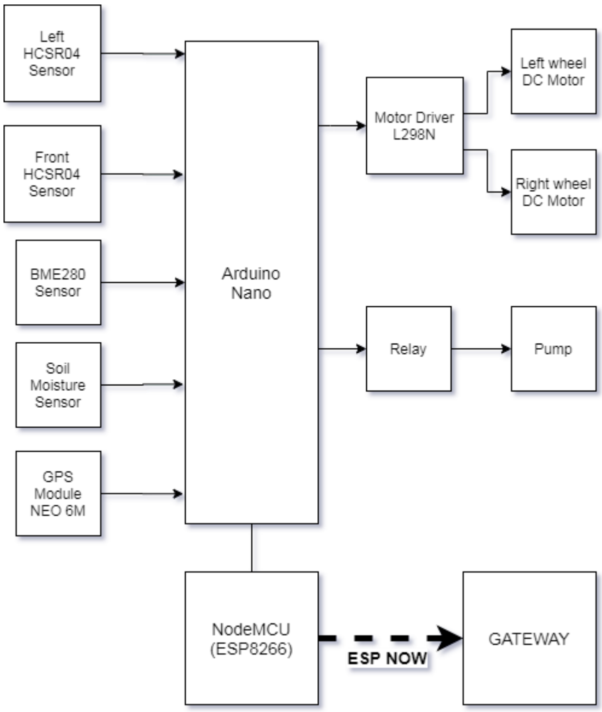

Fig. 1. Block diagram of the robot

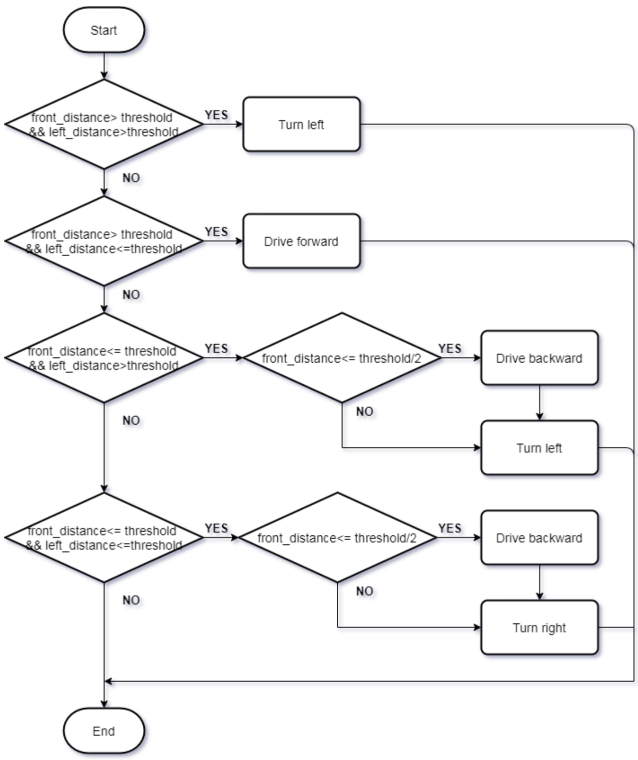

Fig. 2. Flowchart of the robot motion system

Robot workflow starts when the switch is on. The robot will initialize the activity by reading the coordinates of the initial position of the robot, and once obtained, the coordinates are stored in a variable. Next, the robot will start to move and check the condition of the soil. The robot will do watering if the humidity is in accordance with the criteria. In this case, the criteria are 70% for the minimum air humidity threshold, and 60% for the soil minimum moisture threshold. Figure 3 shows a complete flowchart of the steps of the robot system designed.

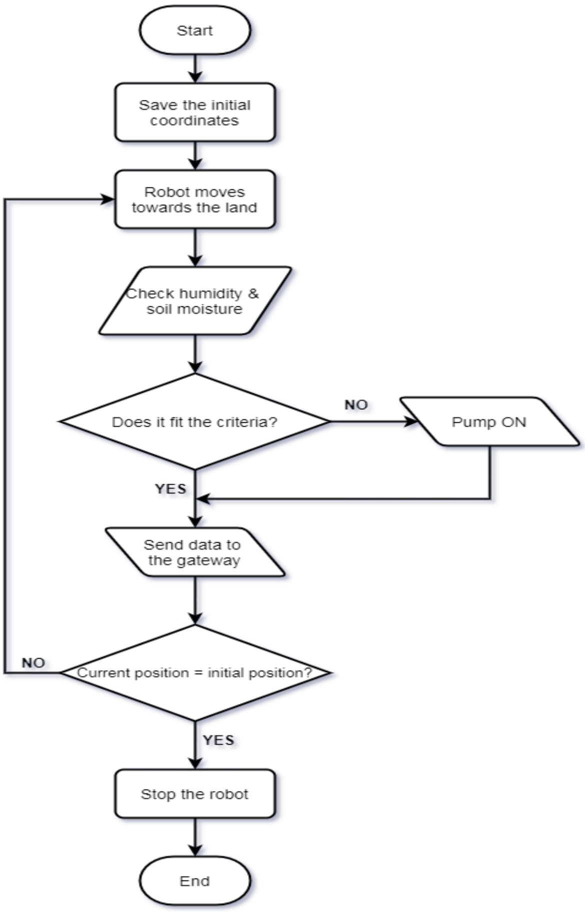

Fig. 3. Flowchart of steps of the robot system.

B. Hardware Design

Arduino Nano acts as the main microcontroller, where all components will be connected to pins on Arduino Nano. Figure 4 depicts the overall robot system circuit scheme with the power supply being 2 3.7V lithium-ion batteries arranged in series and then boosted using a boost converter module to 12 V. The robot will have a dimension of 30 cm long and 18 cm wide.

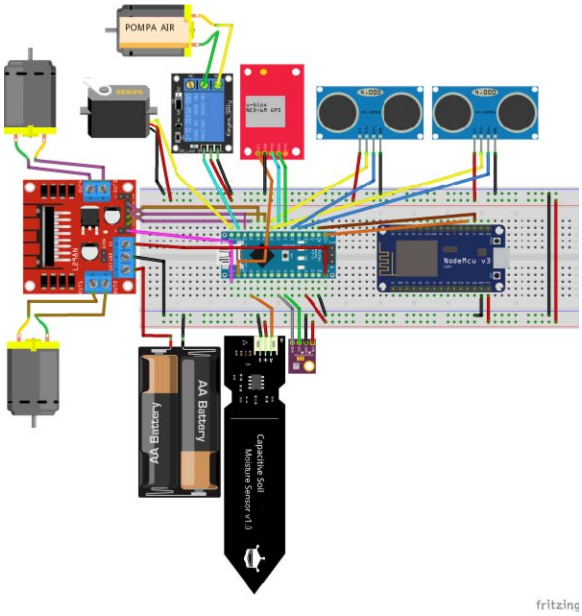

Fig. 4. Schematic of robot circuit

C. Communication Protocol Design

Communication between the robots and gateway, i.e. ESP8266 microcontroller is done using the ESP-NOW protocol. After the data is received by the gateway, data can be forwarded and sent using internet media. In this research the data is forwarded using the MQTT protocol at test.mosquitto.org with "FarmingBot" topic. Block diagram of robot communication protocol can be indicated in Fig. 5.

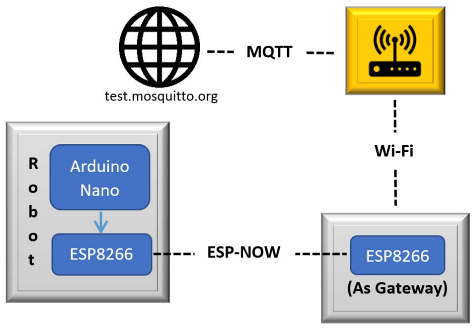

Fig. 5. Block diagram of robot communication protocol

To use the ESP-NOW protocol, we use the ESP8266 microcontroller as its communication media. The robot itself is controlled using Arduino Nano. After processing data from the sensor is complete, the data will be forwarded to ESP8266 using serial communication (i.e. the RX-TX pin on each controller). After that, ESP8266 will send the received data to the gateway using the ESP-NOW protocol. The gateway is also connected to the internet via Wi-Fi. After the data is received by the gateway, the gateway will send messages that have been received to the internet, i.e. via MQTT.

IV. Results and Discussion

A. GPS Module Testing Results

The GPS module will start working which is indicated by the LED on the GPS module blinking. The time it takes for the GPS to get to the location when it is first turned on is varied and tends to be long, i.e., 3-5 minutes. Table I shows the first GPS Module test results.

TABLE I. THE FIRST GPS MODULE TEST RESULTS

Trial	Waiting Time	Result
1	2 minute 50 seconds	Location found
2	2 minute 30 seconds	Location found
3	>5 minute	Location Not Found
4	4 minute 42 seconds	Location found

However, when the GPS module has previously found a location, the module is deactivated for only a few moments (<30 seconds), then with a short time (less than 20 seconds) the location can be immediately found when the GPS module is turned on again. Table II indicates the second GPS Module test results.

TABLE II. THE SECOND GPS MODULE TEST RESULTS

Trial	Waiting Time	Result
1	12 seconds	Location found
2	15 seconds	Location found
3	13 seconds	Location found
4	19 seconds	Location found
5	12 seconds	Location found
6	18 seconds	Location found
7	19 seconds	Location found

B. Robot Steering Test Results

The test is carried out by determining the robot's motion, determining left and right wheel DC motor duty cycles, and determining its duration, then recording the distance or magnitude of the turning angle generated by the robot's motion. The term duration here is the length of the DC motor or left and right wheels spinning. Table III shows the results of testing the steering wheel of the robot.

TABLE III. ROBOT STEERING TEST RESULT

Motion	*Left DC Motor Duty Cycle*	*Right DC Motor Duty Cycle*	Duration	Distance (cm)/ Degree (°)
Forward	76 %	100 %	600 ms	21 cm
Turn Left	0 %	100 %	400 ms	30° - 45°
Turn Right	76 %	0 %	400 ms	35° - 45°
Turn Left	0 %	100 %	400 ms	30° - 40°

From Table III, it can be shown that the forward motion is generated when the left DC motor duty cycle is 76% while the right DC motor duty cycle is 100%. Supposedly, forward motion is produced when both DC motors have the same speed (duty cycle). This irregularity may occur because the left DC motor and right DC motor are not identical motors, so there is a difference in the speed range produced by the motor. In addition, from observations, another cause is because the contact area between the right wheel to the surface of the track is not optimal/imperfect or the right wheel is slightly raised so that the contact that occurs is not perfect. The data in Table III is used as a guide to determine how far the robot travels or how much the robot's desired turning angle in one go. The data is necessary if recalibration will be performed because if the robot will be applied to the field, the length of the plot will be different, the number of check points on each plot is also different, then the distance of the robot in one trip will also be different, therefore calibration is needed.

C. System Response Test Results to Sensor Readings

This test is divided into 2 (two) sections, i.e., testing the robot's response to the ultrasonic sensor reading and testing the pump response to the readings of BME280 sensor and soil moisture sensor. Motion response testing is done by providing variations in the distance of objects to the ultrasonic sensor, then records the motion produced by the robot. Table IV shows the robot motion response test results which indicates that the motion response produced by the robot is correct and suitable.

TABLE IV. ROBOT MOTION RESPONSE TEST RESULTS

Distance between an object and the left sensor (cm)	Distance between an object and the front sensor (cm)	Robot Motion Response
29	10	Turn left
23	12	Turn left
17	5	Backward then turn left
10	7	Turn right
7	4	Backward then turn right
7	11	Forward
6	26	Forward
3	31	Forward

Next, pump response testing will be influenced by the reading of BME280 sensor and soil moisture sensor, or more precisely, it is influenced by air humidity and soil moisture. Meanwhile, air temperature does not affect the pump response. Table V shows the pump response test result.

TABLE V. PUMP RESPONSE TEST RESULTS

Humidity (%)	Soil Moisture (%)	Pump Condition
72.33	37	ON
72.39	56	ON
73.14	64	OFF
68.91	42	ON
69.76	63	ON
70.21	72	OFF

As explained in the system design section, the minimum threshold for air humidity is 70% and the minimum threshold for soil moisture is 60%. It can be seen from the Table IV, that when the soil moisture is less than 60%, regardless of the air humidity conditions, the pump will start. Meanwhile, when the air humidity is less than 70%, regardless of the soil moisture conditions, the pump will start.

D. ESP-NOW Protocol Testing Results

Testing is done by sending a ping message from NodeMCU on the robot to another NodeMCU (gateway). The sending interval for each message is 100ms with the number of messages sent is 200. The independent variable of this test is the distance between them. With these distance variations, the success rate of the message will be indicated at each distance variation. Table VI depicts the ESP-NOW Protocol test results.

TABLE VI. ESP-NOW PROTOCOL TEST RESULTS

Distance	n-th Trial (received/sent)			Success Rate (%)
	1st Trial	*2nd Trial*	*3rd Trial*	
0.5 meter	200/200	200/200	200/200	100%
1 meter	200/200	200/200	200/200	100%
2 meters	200/200	200/200	200/200	100%

3 meters	200/200	200/200	200/200	100%
10 meters	192/200	200/200	195/200	97.8%

From the above table, it can be indicated that using ESP-NOW protocol, the success rate at a distance of 0.5 meters, 1 meter, 2 meters, and 3 meters is 100%. Success rate will decrease as distance increases. Therefore, the lowest success rate is at a distance of 10 meters which is 97.8%.

E. Robot Testing Results on Agricultural Land

Figure 6 illustrates the soil used for robot testing. The test is conducted in open land not in a greenhouse.

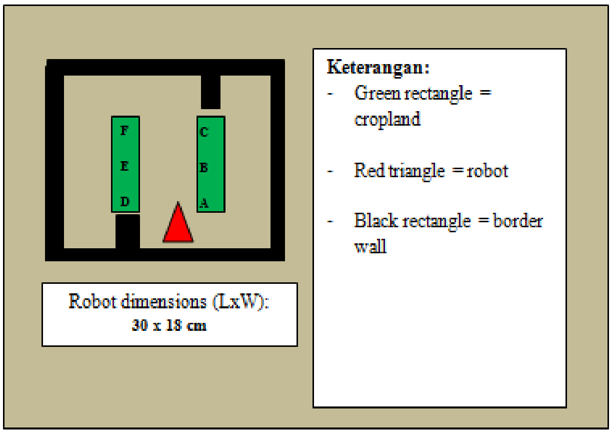

Fig. 6. Illustration of field test in an open land.

There are 6 (six) points that must be checked by the robot. Testing is done 3 (three) times in accordance with the workflow of the robot that has been described previously. Table VII - IX described the 3 (two) results of the first, second, and third robot tests on agricultural land, respectively.

TABLE VII. RESULTS OF THE FIRST ROBOT TESTING ON AGRICULTURAL LAND

Point	Air Temperature (°C)	Air humidity (%)	Soil Moisture (%)	Pump Condition
A	30.28	72.42	18	On
B	30.22	72.56	22	On
C	30.28	73.57	26	On
D	30.24	72.60	31	On
E	30.25	73.55	27	On
F	30.15	71.75	15	On

TABLE VIII. RESULTS OF THE SECOND ROBOT TESTING ON AGRICULTURAL LAND

Point	Air Temperature (°C)	Air humidity (%)	Soil Moisture (%)	Pump Condition
A	29.34	71.43	41	On
B	29.29	71.99	52	On
C	29.29	72.64	64	Off
D	29.35	72.43	62	Off
E	29.31	72.21	53	On
F	29.25	72.52	62	Off

TABLE IX. RESULTS OF THE THIRD ROBOT TESTING ON AGRICULTURAL LAND

Point	Air Temperature (°C)	Air humidity (%)	Soil Moisture (%)	Pump Condition
A	28.96	72.13	65	Off
B	28.96	72.42	70	Off
C	28.91	72.56	62	Off
D	28.85	72.20	60	Off
E	28.83	72.60	69	Off
F	28.82	72.11	60	Off

From the three tests above, it can be seen that all points have reached the desired condition after 3 (three) tests. For information, the water container used is ±160ml in volume, with the volume of water released per watering is ±25ml. Thus, in one test with 6 (six) test points, it takes 150ml or almost 1 (one) full container of water.

V. CONCLUSIONS AND SUGGESTIONS

A. Conclusions

From the results and discussion, the here below are some conclusions can be taken related to the research.

1) The time it takes for the GPS to get to the location when it is first turned on is varied and tends to be long, i.e., 3-5 minutes. However, when the GPS module has previously found a location, the module is deactivated for only a few moments (<30 seconds), then with a short time (less than 20 seconds) the location can be immediately found when the GPS module is turned on again.

2) Motion response testing is done by providing variations in the distance of objects to the ultrasonic sensor, then records the motion produced by the robot. The test results indicate that the motion response produced by the robot is correct and suitable.

3) When the soil moisture is less than 60%, regardless of the air humidity conditions, the pump will start. Meanwhile, when the air humidity is less than 70%, regardless of the soil moisture conditions, the pump will start.

4) With 6 (six) test points, ±160ml of water container volume, and the volume of water released for each watering is ±25ml, the robot succeeded in reaching all points in the desired conditions after 3 times of testing.

5) In ESP-NOW protocol testing, the success rate at a distance of 0.5 meters, 1 meter, 2 meters, and 3 meters is 100%. Success rate will decrease as distance increases. Therefore, the lowest success rate is at a distance of 10 meters which is 97.8%.

B. Suggestions

Based on several problems that arise during testing, the following are suggestions for further research.

1) Some study should be done to fix the problem of robot balance which is shown from the robot steering test, where the contact area between the right wheel to the surface of the track is not optimal/imperfect or the right wheel is slightly raised so that the contact that occurs is not perfect.

2) An advanced research should be done to find the best method to increase the success rate of ESP-NOW communication or using other protocol, especially in case of the distance of 10 meters or more.

3) For the more user-friendly purpose, one proper solution is configuration of Arduino IDE and MQTT broker. Serial monitor on Arduino IDE is used for information interface, while the MQTT broker is used for information viewer.

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