Smart Agriculture Monitoring and Management System using IoT-enabled Devices based on LoRaWAN

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***Abstract*— A fully automated, smart agriculture system using IoT-enabled devices connected to LoRaWAN network (Long Range Wide Area Network) is proposed in this study. The system is capable of measuring crop growing parameters using low-power and low-cost sensor devices. Environmental conditions are automatically regulated through actuator end devices that receive activation command from a network server, allowing precise control of the water and mist pumps. Real-time data and system status are sent to the cloud and can be accessed via customizable dashboard. The transmission range between LoRa end devices and gateway is found to vary from 300 m to 1700 m, depending on the quality of the LoRa antenna. Compared to a Wi-Fi implemented system, LoRa provides for a longer range of communication and 2.4 times the power reduction when operating in Working state. In an Idle state, the end device conserves power by entering a deep-sleep mode which offers up to 86% reduction in power when compared to an active mode.**

Keywords—Smart farming, Precision agriculture, Internet of Things, IoTs, LoRa, LoRaWAN, Node-RED

I. INTRODUCTION

The use of Internet of Things (IoT) and the need for a fully automated system in agricultural process is becoming increasingly important, especially in agricultural producing countries, where farming is typically done over a large area and the crops need to be constantly monitored. Without such a system, the manual labor requires to maintain a farm can be expensive and often does not yield the most optimal result. The widely deployed short-range radio technologies such as Wi-Fi or Bluetooth are also not suitable for this scenario which requires network coverage that spans across the entire farm [1]. Cellular technology solutions such as 4G/5G provide the necessary range, but they also consume too much power [2]. Low Power Wide Area (LPWA) technologies, including, NB-IoT, Sigfox, and LoRaWAN, have emerged as the most suitable solution for smart farming due to its long range transmission, low power consumption, and low cost implementation [3]. Among these three LPWA technologies, LoRaWAN is the only communication protocol that is free of subscription fee, and it is chosen as the main communication protocol for the proposed smart monitoring and management system.

II. LoRaWAN NETWORKING PROTOCAL

LoRaWAN is chosen as the main communication technology between end devices and gateway because it provides wide coverage, long range, low power consumption, low cost, and acceptable transmission rate for telemetry data. LoRaWAN relies on Chirp Spread Spectrum modulation to encode the information, and its physical layer, LoRa, uses unlicensed spectrum in the sub-gigahertz ISM band for data transmission. In Thailand, the frequency range is between 923 - 925 MHz [4].

III. OVERVIEW OF SMART AGRICULTURE SYSTEM

The smart agriculture monitoring and management system proposed in this work consists of four major parts.

1) Sensor End Device is a device that is deployed in the field to record and measure parameters such as temperature, humidity, and light intensity, which are relevant to the growth condition of a crop.

2) Actuator End Device is a device that switches on and off the actuators, such as a water or a mist pump, which can directly influence the environmental conditions.

3) Gateway Device acts as the central communication hub between sensor/actuator end devices and the network servers.

4) Network Servers can receive or send data to the gateway device through The Things Stack (TTS) network server, which is linked with Node-RED to receive commands for controlling end devices, and is integrated with Datacake for data visualization.

IV. HARDWARE AND SOFTWARE SYSTEM DESIGN

The overview of the hardware and software system design for the proposed smart agriculture system is summarized in Fig. 1. The diagram shows different hardware components and software applications running on network servers, as well as how the information is transferred between them.

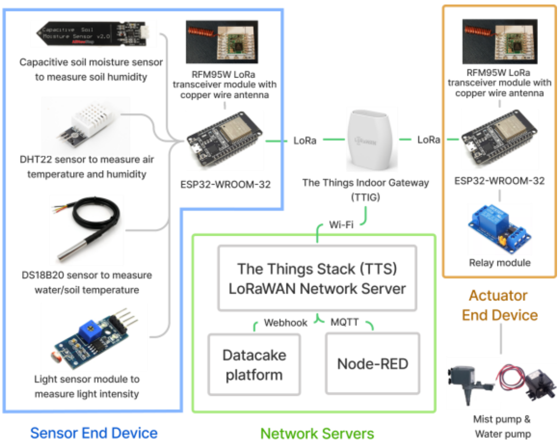

Fig. 1. System design of the smart agriculture monitoring and management system

A. Hardware System

The hardware components of the smart agriculture system consist of:

1) LoRa End Devices with Sensors and Actuators

All sensor and actuator end devices use the same microcontroller (ESP32-WROOM-32) and LoRa module (RFM95W LoRa transceiver module) with copper wire antenna, but with different sensors or actuators attached to them. Sensor end devices are connected to environmental sensors, such as DHT22 (for air temperature and humidity), DS18B20 (for soil temperature), capacitive soil moisture sensor (for soil humidity), and light sensor module (for light intensity measurement). For actuator end device, the microcontroller is connected to a relay module that is used to control the mist and water pumps. The end devices are powered by a LiFePO4 battery. Note that the pumps can also be powered by a battery unit, or they can be connected to the power outlet, depending on the specific irrigation design of the farm.

2) LoRaWAN Gateway

LoRaWAN Gateway is used for receiving and sending LoRa packets to the end devices and also to communicate with the network servers. The proposed system uses a multiple channel gateway, called The Things Indoor Gateway (TTIG), which is an 8-channel LoRa gateway that uses Semtech SX1308 LoRa concentrator chip with built-in Wi-Fi to provide data backhaul to the LoRaWAN network server. [4]

B. Software System

The software infrastructure of the proposed system is comprised of 3 network server platforms.

1) Things Stack Network Server (TTS)

TTS server is a public and open source LoRaWAN network server designed for the deployment and management of LoRaWAN devices [4]. Data collected by the gateway can be sent to the TTS server for data logging or for further processing. TTS can send data to the end devices by first sending it to the gateway device, which will act as the middleman. Moreover, TTS allows for integration with other platforms to enable automated control and data visualization.

2) Node-RED

Node-RED is a graphical programming platform in which the building blocks, referred to as 'nodes', are connected together to form a program flow that describes the logic and function of the program [5]. Node-RED is used for implementing the decision rules that will govern the growing parameter conditions of the crops. Activation command is sent from Node-RED via MQTT protocol to the TTS server, which will subsequently deliver the command to the actuator end devices to activate or deactivate the connected pumps, depending on the defined rules. Other system properties such as event scheduling and the frequency of data uplink from sensor end devices are also configured using Node-RED.

3) Datacake Platform

Datacake is a multi-purpose Internet of Things platform that stores and displays telemetry data of the smart farm. In the proposed system, Datacake is integrated with TTS server through webhook, which receives information when a triggered event has occurred. Data are visualized in an easy-to-use and fully customizable dashboard format.

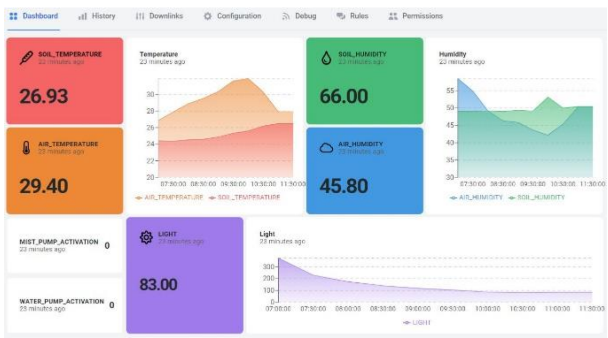

Fig. 2. Dashboard showing real-time data and status

4) System Flowchart

The operational flow chart of the proposed smart agriculture system is shown in Fig. 3. Sensor end devices measure environmental parameters and periodically send the data to the servers according to the as scheduled by Node-RED. The default schedule is set for data transmission every 30 minutes. When it is not transmitting data, sensor end devices will enter an Idle state by going into deep-sleep mode [6]. The instance the network servers receive data from the sensor end devices, the data are preprocessed using rule-based decision logic implemented in Node-RED to determine whether a change to the state of the system is required. If all the conditions are within the specified threshold limits, the system repeats the cycle.

If it is found that some conditions were not met, the algorithm will decide which actuator end devices need to be activated by sending out the activation command. Moreover, Node-RED will temporarily modify the transmission frequency of the end devices to be at a higher rate (i.e. every 2 minutes) in order to keep a close watch on the changing environmental conditions. Once the conditions fall back within the thresholds, command is sent to deactivate the pump and reset data transmission frequency to the original value.

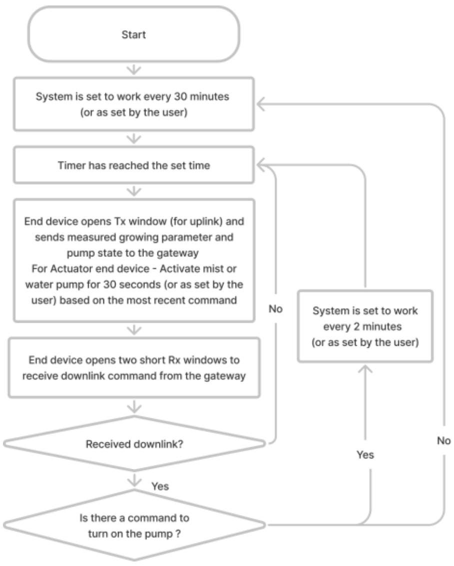

Fig. 3. System operation workflow

V. RESULTS AND DISCUSSION

Several experiments were carried out to characterize the different aspects of our proposed system, relating to performance, reliability, and power consumption.

A. Growth Parameters Control

The purpose of this experiment is to assess the effectiveness of the system response in controlling environmental conditions. Maximum threshold for air and soil temperature is set at 32 °C, and minimum threshold for soil humidity is set at 50%. If the observed conditions exceed or fall below these thresholds, actuator end device will turn on the pump to lower the temperature or increase the humidity. The experiment is performed with LoRa spreading factor SF 7, and the distance between the gateway and end devices is set to 50 m in an open outdoor setting. The result of the experiment is shown in Fig. 4. and Fig. 5.

The air temperature surpassed the set temperature threshold for a total of 5 times during this time period, with a peak temperature reaching 34.59 °C. In each time, the system was able to lower the temperature by activating the mist pump, with the longest duration exceeding the temperature threshold of 13 minutes. Similarly, it is observed that the soil humidity fell below the set threshold twice, with the lowest value being 49% and the longest duration being 8 minutes before the water pump was able to increase the humidity back into the desired range.

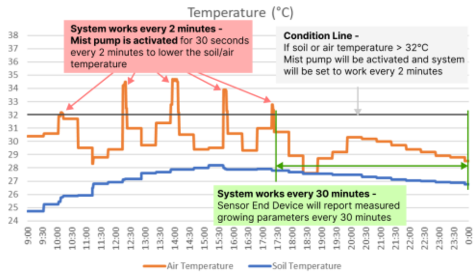

Fig. 4. Air and soil temperature monitoring

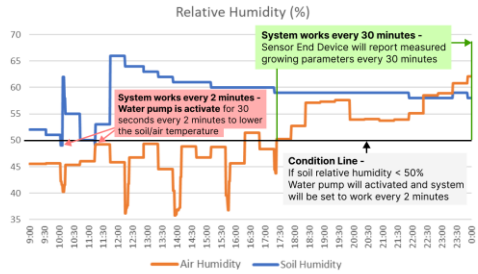

Fig. 5. Air and soil humidity monitoring

Note that as the mist pump was turned on, the air humidity was also influenced by it, as can be seen in the corresponding humidity data. The responsiveness and the time it takes to bring the system back into desired range will vary according to the system. If one requires a system to be very responsive, timer can be set for a shorter duration, at the expense of an increase in power consumption. Other design parameters such as pump capacity can also impact how fast the system is able to reach the desired set point.

B. Transmission Range of LoRa End Devices

To test the transmission range of a LoRa enabled device, 3 types of LoRa end devices were selected for the experiment: 1) Custom LoRa end device without antenna, 2) Custom LoRa end device with copper wire antenna (the default device in this work), and 3) Heltec LoRa 32 with antenna. Each end devices were placed at some distance away from the gateway and were required to send out 10-byte data packet every one minute for 10 consecutive times. Two configurations of spreading factor, SF7 and SF10, were used and the frequency bandwidth was set at 125 kHz. The success rate, defined as the number of times (%) that the packet is transmitted successfully, is summarized in Fig 6.

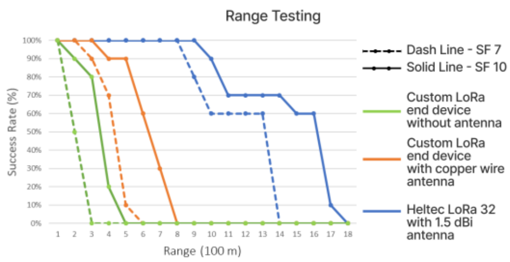

Fig. 6. Success rate of LoRa transmission

The maximum range in which LoRa can transmit with over 90% success rate with SF 7 and 10 using custom LoRa device without antenna is 100 m and 200 m, respectively, and 300 m and 500 m with a copper wire antenna. Heltec LoRa 32 with a high-quality antenna, and also costs twice as much, is able to the achieve the longest range of 800 m and 1000 m, which is approximately twice the range of the copper wire antenna. The comparison is summarized in Table 1.

Table 1. Range and price comparisons of end devices

Compare Custom and Commercial LoRa end device	Custom LoRa end device with copper wire antenna		Heltec LoRa 32	
	SF 7	SF 10	SF 7	SF 10
Effective Range [m] (success rate > 90%)	300	500	800	1,000
Max Range [m]	500	700	1,300	1,700
Price	290 Baht		500 Baht	

C. *Power Consumption of End Devices*

1) Idle State Power Consumption

While the end device is in Idle State, ESP32 is programmed to enter deep-sleep mode instead of active mode to save power. The power comparison in deep-sleep vs. active mode of end devices is shown in Fig. 7. Deep-sleep mode offers as much as 83% and 86% reduction in power consumption for sensor and actuator end devices, respectively.

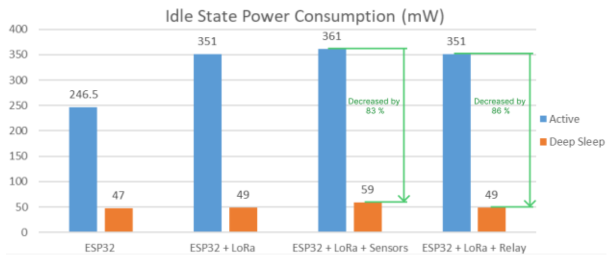

Fig. 7. Idle state power consumption

2) Working State Power Consumption

End device enters a Working state when it needs to send data packets back to the gateway. The class A LoRaWAN end device will open a transmission (Tx) window to transmit the data. Once completed, the device will open two short reception (Rx) windows to receive downlink command from gateway before going to sleep, as shown in Fig. 8. This is in stark contrast to the operation of a Wi-Fi enabled devices, which need to re-establish Wi-Fi connection every time that ESP32 wakes up from deep-sleep mode.

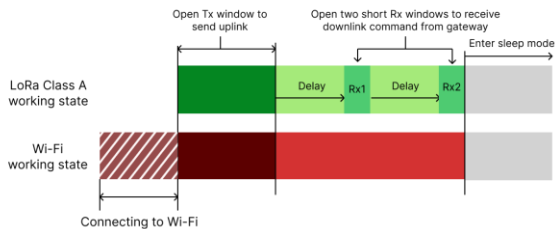

Fig. 8. LoRa Class A and Wi-Fi device working state

The comparison of power consumption for sending 100 packets of 10 bytes at a distance of 50 m using LoRa vs. sending them via Wi-Fi is shown in Fig. 9. The result suggests that Wi-Fi can consume as much as 2.5 times the power as compared to LoRa, with the primary increase in power coming from the Wi-Fi reconnection step.

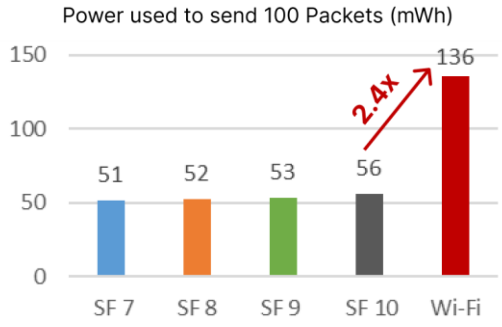

Fig. 9. Working State power consumption

VI. CONCLUSION

A smart agriculture system based on Lora protocol is shown to be effective in controlling the growth parameters of a crop, and is a promising candidate for smart agriculture implementation. The system is designed to be low-cost in hardware, free of service subscription fees, and easy to maintain. Decision logic can be updated instantaneously via network server, and more sensors and actuators can be added to provide for additional parameter monitoring.

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