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An environment monitoring system for a rice production model adaptive to climate change in the Mekong Delta of Viet Nam

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ABSTRACT

This article presents an environment monitoring model for agricultural production applied to farmers in the Mekong Delta, Viet Nam. The proposed model's special feature is a system combining techniques such as IoT, agent-based, sensor networks, and data warehouses. Successfully deploying the model in monitoring the water level, and the environmental factors of the rice soil such as NPK, pH, EC, temperature, and soil moisture not only aids managers and farmers monitor environmental quality indicators in real time, but also experts to analyze data, give warnings and appropriate response solutions in agricultural production according to the pivot strategy towards Agriculture 4.0 proposed by the Minister of the Ministry of Agriculture and Rural Development of Viet Nam.

1. INTRODUCTION

1.1. Current status of agriculture in the Mekong Delta

The Mekong River Delta (MRD) of Viet Nam is one of the biggest and important regions in South-east Asia for rice production and it plays a vital role in global food security. MRD is located in the southern part of Viet Nam, has a tropical monsoon climate, with rainy seasons and dry season, high temperatures, and relatively heavy rainfall, respectively (Rainer, 2023). It is the country's largest delta and encompasses the majority of south-western Viet Nam. The Mekong River Delta produces about 17 million tons of rice annually (52% of national rice production) and average yields are 4.3 t/ha, accounting for more than 90 percent of the country's agricultural export (Tay et al., 2022). In its entirety, the MRD covers about 6 million ha, of which 3.9 million ha are in Viet Nam (12% of the territory, 27% of agricultural land). This region has a population of 18.6 million people (22% of the national population of Viet Nam). Agriculture and aquaculture is predominant in this area, amount of 76 percent of its population is engaged in agriculture (Konishi et al., 2007). Though the Delta is favourable for rice production, it is also suitable for different fruit trees, upland crops, aquaculture, etc., all of which have been practiced really well by local farmers with high yield and quality (Can, 2002). Due to climate change, the MRD is facing with more frequent severe drought and seawater intrusion. In this context, the area of agricultural cultivation is shrinking with the replacing of brackish-water aquaculture. This has all significantly impacted farmers' livelihoods (Mien, 2022).

Moreover, the Mekong Delta is constantly threatened by a multitude of environmental pressures, including climate change-induced sea-level rise, delta-wide land subsidence, and sedimentation reduction (Tay et al., 2022). Many areas were seasonally flooded in the past. Many of them have been building flood-against dykes for plant cultivation in flooding season, leading to soil pollution due to the accumulation of many unfavorable compounds including chemical compounds from pesticides and fertilizers which should be flushed out of fields together with flood water (Vo et al., 2018). The Mekong Delta of Viet Nam is affected by tides from both the East and West seas. In recent years, saline intrusion in the dried season has been complicated, erratic, early and long lasting as compared to the same period time of previous years. Moreover, strong winds cause higher tides, leading to saltwater intrusion from the East Sea into coastal rivers, canals, and deep inland. Drought and saline intrusion create a significant pressure on the availability and use of freshwater which are used by local farmers to produce agriculture, leading to overuse of groundwater and crop failures. Although MRD owns 3.9 million ha, annually around 1.8 million ha faces salinity intrusion in the dried season when the water flows from the upstream to MRD of Viet Nam are decreased strongly.

The sea tide strongly affects the main river systems and inland canals of this delta, leading to a deep invasion of salt intrusion to both the rivers and inland canals. In the dried season of 2016, salt intrusion in MRD was considered as the most severe in the past 100 years. Rice yield is alleviated up to 50% when salinity of irrigating water reaches at salinity of 4.8 mS/cm. About 650,000 ha of high yield rice are grown in the lower delta. Annually about 100,000 ha of rice is highly risky to dried-season salinity intrusion. Moreover, soil properties of some provinces in MRD are exhausted. Soil biodiversity is degrading vigorously, and the land areas affected by salinity intrusion are increasing over time. Drought becomes more serious when conflicts occur between water use for agricultural production versus water use for living in the Mekong Delta during the dry season. Overuse of freshwater for the rice crop in upstream areas in the dry season has led to a shortage of water supplies for household use, livestock, and fruit tree management in downstream provinces (Rainer, 2023; Trung, 2006).

1.2. Rice farming model to adapt to climate change in the Mekong Delta

The Vietnamese Ministry of Agriculture and Rural Development (MARD) has issued an Action Plan to adapt to climate change in agricultural cultivation for the period 2008-2020 (MARD, 2011). Accordingly, major measures include (1) the development of large-scale salinity management structures (i.e. dikes, sluice gates, and water reservoirs), (2) the development of small-scale irrigation infrastructures (i.e. canals, sluice gates, pumping stations), (3) the development of adaptive farming technologies (i.e. crop varieties, farming techniques, and farming systems), (4) enhancement of farmer and staff capacity, and (5) improvement of policy systems.

Hence, the development of adaptive farming technologies plays a key role in reducing the vulnerability of the agricultural system. Besides building dams to keep fresh water for irrigation, and preventing saltwater intrusion, the most common adaptation options include Irrigation-saving techniques, using saline tolerance varieties; using organic fertilizer as well as bio-products to enhance salt-tolerance ability, growth, and yield of rice.

The Alternative Wetting and Drying (AWD) technique for irrigation has been researched and developed by the International Rice Research Institute (IRRI) and is known as a method to help plants cope with water scarcity in farming rice cultivation (Bouman & Tuong, 2001). In Viet Nam, it is expected that water-saving irrigation techniques can be used to replace traditional flooded irrigation techniques in rice cultivation in the Mekong Delta in the dry season. Currently, the technique of rice cultivation according to water-saving irrigation is interesting in the Mekong Delta. Irrigation-saving techniques are also being studied to be able to replace continuous flooding in rice cultivation in the Mekong Delta (Lan Phuong et al., 2012; Nguyen et al., 2022; Nguyen et al., 2021). In addition, according to Lan Phuong et al. (2012), applying water-saving irrigation techniques helps rice plants to sprout better than the continuous flooding method

The use of organic fertilizers in rice production increases sustainable cultivation and adaptation to climate change as well as meets export-oriented consumer de-mand for organically produced foods (Van Toan et al., 2019). In addition to plant nutrients, organic fertilizers maintain soil nutrient balance and health, are energy sources for soil microbe development, can mitigate problems associated with synthetic fertilizers, and may reduce production costs by re-use and recycling of natural materials and on-farm resources (Shaji et al., 2021).

To evaluate the impact of irrigation water and fertilizer on the growth of rice, we have proposed an environmental monitoring system that continuously collects water level and NPK indices in the soil in the rice fields instead of measuring the water level with a ruler, collecting soil samples, and analyzing NPK content. The data collected from the environmental monitoring system on rice fields help to build a model to assess the impact of environmental factors, on activities of rice farming in Model (Developing of a rice production model adaptive to climate change in the Mekong Delta of Viet Nam).

2. MATERIALS AND METHOD

2.1. Agent-based Environment Monitoring System

The rice environment monitoring system is being built on the basis of the AEMS (Agent-based Environment Monitoring System – Figure 1) mentioned in Truong et al. (2020). AEMS is an environment monitoring system that includes (1) a Wireless Sensor Network (WSN) with nodes are the IoTAgent, (2) Data Warehousing for storing collected data from IoTAgent, and (3) an analysis model based on Agent-Based Simulation combined with the Data Warehouse studied in (Truong et al., 2016). The major component of the AEMS system is the Monitoring and warning Services which are built up of three services: (1) data storage and retrieval; (2) Analysis and Simulation; (3) Warnings Services sending warning messages and appropriate solutions via web or mobile applications. IoTAgents are in charge of automatically collecting environmental factors over time defined by the user. The IoTAgent is an IoT device that acts as an agent, that could interact with the environment and other IoTAgents in the AEMS. The IoTAgent will send its collected data from the environment to the data center and simultaneously interact with the user through web or mobile applications. The monitoring stations were called IoT Agents because they were built on IoT and Agent technologies. IoT Agents connect and transmit data via wireless networks to create a wireless sensor network.

The IoT Agent (Figure 2) is an IoT device that operates based on schedule and is controlled by the Task Scheduling & Handling module, e.g. the OpenSensor Library turns on the sensors for collecting environmental factors, and the Communication Library transfers collected data from IoTAgent to the data center server and receives instructions from the user following the scheduled time.

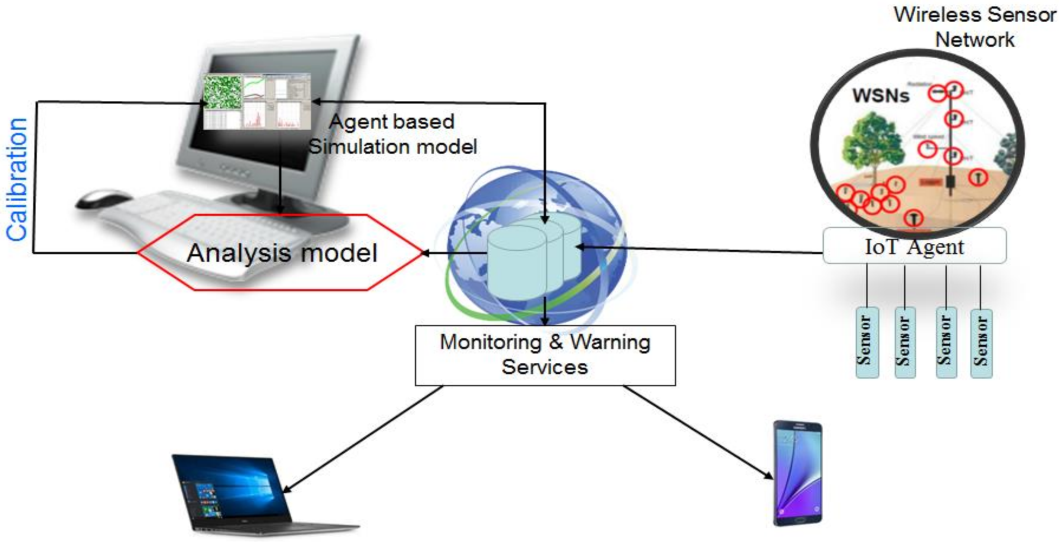
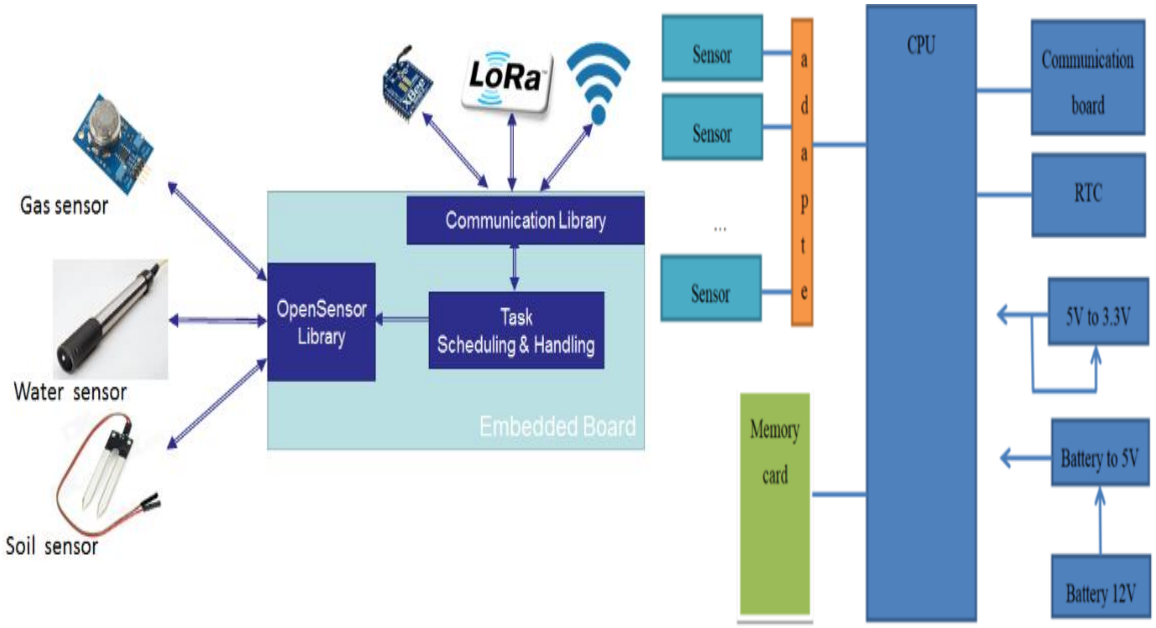


Figure 1. Agent based Environment Monitoring System



a. Components of the IoT Agent **b. Hardware diagram of IoT Agent**

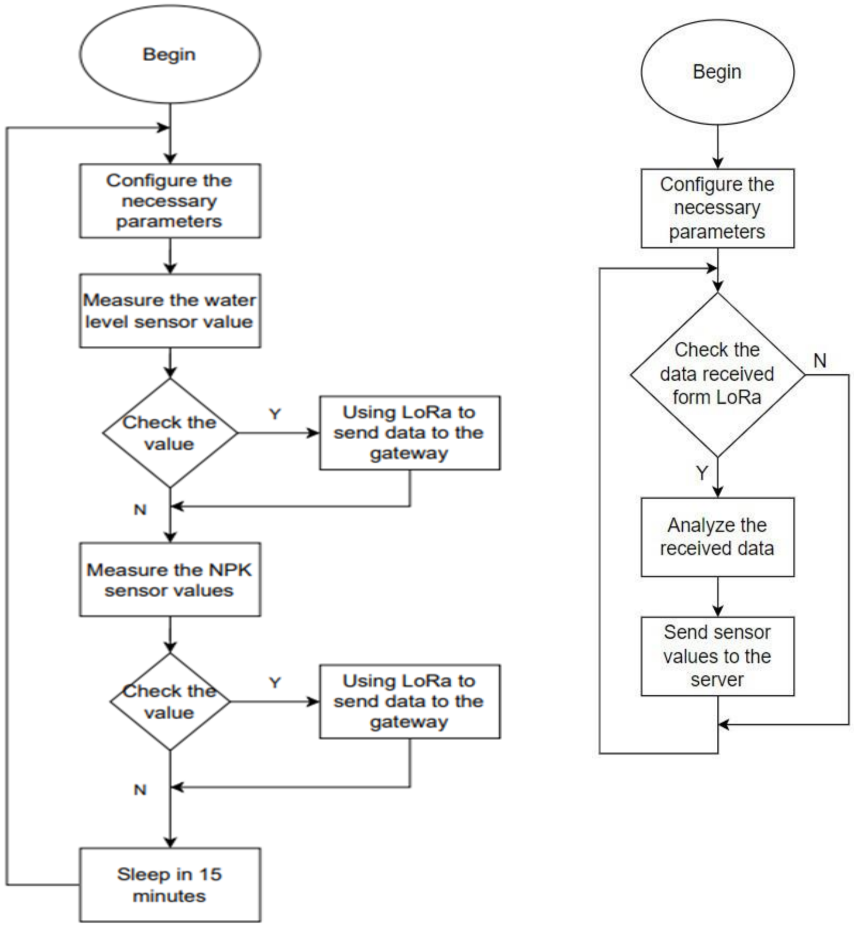
Figure 2. IoT Agent architecture

2.2. IoT Agent in a star network model

Based on the actual survey at 02 rice planting sites in Tran De district, Soc Trang province, and Hon Dat district, Kien Giang province, many sensor nodes needed to be placed to collect environmental factors on many different fields in a radius of R<=1000m, the LoRa RF 433M SX1278 transceiver circuit was used according to the star network model as shown in Figure 3. The sensor nodes transmitted the measured data to the sink node, and then the sink node transferred the data received from the sensor node to the data center by MQTT protocol through the 4G connection.

The sensor node and sink node were designed in a modular form, which was easy to disassemble and replace, and Waterproof (Figures 6a, 6b). To save energy, the sensor nodes were implemented as flow charts in Figures 4a and 4b corresponding to the state machine model (Truong et al., 2020). The sensor nodes measured parameters such as water level, soil moisture, soil temperature, soil conductivity, PH, and nitrogen - phosphorus - potassium content at different locations in the rice field in real time. To measure the water level, NPK, and other factors, the sensor node operated for around 1 minute to measure the environmental factors and send data to the sink node, then the sensor node went to sleep. The sleeping time could be set in configuration parameters, e.g., 15 minutes then continue measuring. The Senor node had a built-in battery and solar panel to power the sensor node. In 24 hours, the sensor node measured 90 times, the sensor node in the operating state for 90 minutes accounts for 6.25% of the operating time, and in the sleep state for 1,350 minutes, accounting for 93.75% of the operating time. With more than 90% sleep time, the sensor node consumed less power.

The sink node was designed on the same hardware architecture as the sensor node (Figure 2b). However, the communication with the sensor was omitted, and it was installed with 02 devices to transmit and receive data according to LoRa and wifi technology. When the sink node received environmental parameter data from the sensor node, it sent this data to the server using the MQTT protocol. The code for sending data to the server is presented in Figure 5.



a. Algorithm flowchart of sensor node **b. Algorithm flowchart of the sink node**

Figure 3. IoT Agent in a star network model

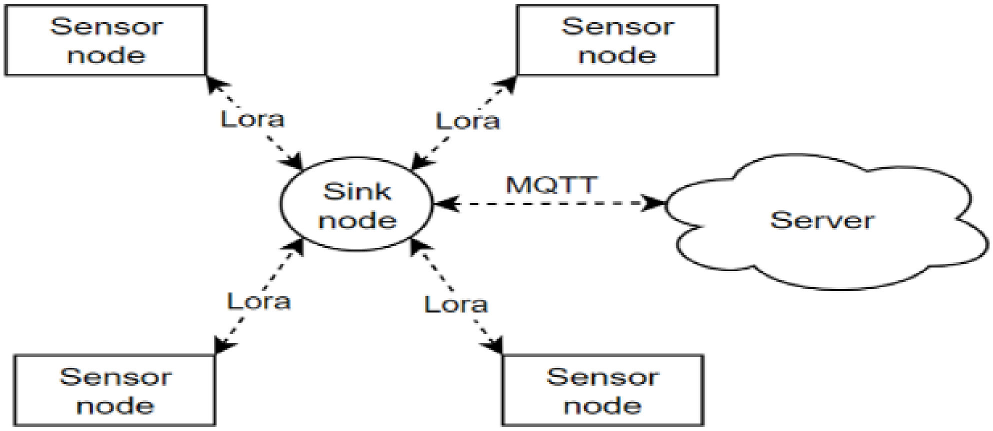


Figure 4. Algorithm flowchart of sensor and sink node

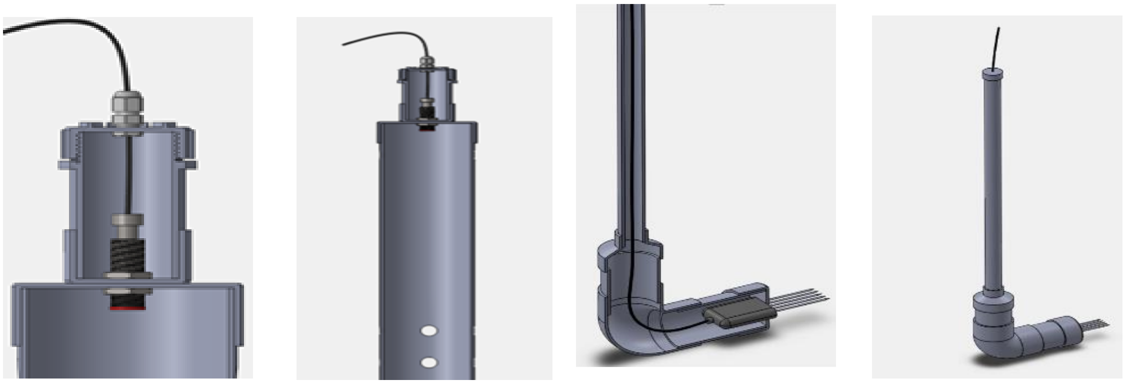
```
// Establish a connection to the MQTT server if the MQTT
client is not already connected
bool reconnect() {
  int attempts = 0;
  while (!client.connected()
           && attempts < max_connection_attempts)
  {
    if (client.connect(mqttClientId, mqttLoginName, mqttPW))
    {
      return true;
      // Return true if the connection is successful.
    } else {
      delay(5000);
      attempts++;
         }
  }
  return false;
}
```

```
// To publish data to the MQTT broker.
void publishData(String object) {
  if (!client.connected()) {
    if (!reconnect()) {
      return;
/*Return from the function if the
reconnection attempt fails.*/
    }
  }
  client.publish(topic, object);
}
```

Figure 5. Sink node connects and sends data to the data server via MQTT protocol

2.3. Water level and N-P-K sensors

To make the device to measure the water level, many types of sensors with different measuring techniques such as using ultrasonic waves, infrared, and lasers were conducted in the field. A laser measuring device with RS485 communication standard was chosen. It measured the distance from 4 to 400 cm with an accuracy of ±2cm. The distance sensor was enclosed in a water-resistant plastic tube and easily removable (Figure 6a). The sensor was designed to measure the water level from 20cm (-20cm) lower than the field surface to 20cm (+20cm) above the field surface according to the requirement of monitoring the water level in the AWD farming model.



a. Water level sensor **b. N, P, K, Soil moisture, EC, pH, and temperature sensor**

Figure 6. Implementation of sensor nodes

To measure NPK and some other environmental factors in the soil, a 7-in-1 soil parameter measurement sensor (N, P, K, Soil moisture, EC, pH, and temperature) with RS485 communication standard was applied. The sensor used electrodes to generate an electric current through the soil sample. The conductivity of a soil sample depends on the concentration of nutrients present in the soil. The electrode in the sensor registered the changes in the current and converted them into a measurement signal. The soil NPK sensor had to be placed in the wetlands, easy to install, and maintain, which was challenged when this meter was built. The solution was to repackage the sensor in a plastic tube (Figure 6b) to ensure water resistance and ease of installation and maintenance.

The water level and NPK sensors were connected to the sensor node (data logger) as shown in Figure 7a, and they were deployed practically as shown in Figure 7b. Data collected from sensor nodes could be viewed via the web application or smartphone application. In addition, The water level and NPK sensors are in the experimental manufacturing stage, and because we do not have the same type of measuring equipment yet, we are doing experiments, collecting samples, and comparing them with the NPK values analyzed in the laboratory. experiments, the results will be published in the next articles.

a. Sensor node

b. Deploy sensor nodes in Tran De district and Hon Dat district

Figure 7. Implementation of sensor node

3. CONCLUSION

The study and implementation of a monitoring model of environmental factors in rice fields for the Alternative Wetting and Drying (AWD) rice farming model based on the AEMS platform presented application in rice cultivation effectively. Sensor nodes were installed to support measuring water level, NPK, pH, etc. In the initialization, sensor stations collected environmental data on rice fields automatically and continuously. These data can help agricultural experts analyze the impact of irrigation as well as fertilizer applications on the growth and yield of rice plants. The studies to improve and develop environmental monitoring devices for agricultural production to adapt to climate change in the Mekong Delta as well as build data analysis and forecasting models based on the environmental data collected by monitoring system are going to be established.

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