CTU Journal of Innovation and Sustainable Development
ISSN 2588-1418 | e-ISSN 2815-6412

DOI:10.22144/ctujoisd.2024.285

Applications of IoT technology for climate change adaptation in the Mekong Delta

Luong Vinh Quoc Danh*

Faculty of Electronics and Telecommunications, College of Engineering, Can Tho University, Viet Nam

**Corresponding author (lvqdanh@ctu.edu.vn)*

Article info.

Received 13 Nov 2023
Revised 25 Dec 2023
Accepted 26 Dec 2023

Keywords

AWD watering, IoT, landslide early warning, Mekong Delta, water quality monitoring

ABSTRACT

The Mekong Delta, with an area of over 40,000 square kilometers, is the largest agricultural and fishery production center in Viet Nam. However, along with the Ganges River Delta and the Nile River Delta, the Mekong Delta is one of the three delta regions most severely impacted by climate change. In recent years, this region has faced drought, saltwater intrusion, environmental degradation, and land subsidence mainly caused by climate change. The Internet of Things (IoT) technology has been envisioned as a powerful tool for combating climate change. This paper presents some research projects that leverage the potential of IoT technology and applications to improve the effectiveness of rice cultivation and aquaculture; and support the development of riverbank landslide early warning systems for the region. Through these applications, IoT technology has provided practical answers to address climate change and save the environment.

1. INTRODUCTION

The Mekong Delta, with an area of over 40,000 square kilometers, is the largest agricultural and fishery production center in Viet Nam. The Delta contributes more than 50% of the nation's rice production, 65% of its aquaculture output, 70% of its fruit output, and 95% of its rice exports (Thu, 2023). However, along with the Ganges River Delta (India - Bangladesh) and the Nile River Delta (Egypt), the Mekong Delta is one of the three delta regions most severely impacted by climate change (Bui, 2023). In recent years, this region has faced drought, saltwater intrusion, environmental degradation, and land subsidence mainly caused by climate change.

The Internet of Things (IoT) technology has been envisioned as a powerful tool for combating climate change (Salam, 2020). An IoT system is a network of physical objects with many sensors, software, networking, and processing capabilities that can gather and share data with central units and each other over the internet to enable smart solutions. Through its sensing and monitoring capabilities, IoT technology offers important information about changes in environmental parameters. Its communication and sensing technologies, along with analytical tools and models, offer helpful insights into the specifics of environmental changes. Additionally, by predicting how the environment will change, IoT-enabled decision-making tools can assist communities in responding to environmental changes in a timely and appropriate manner (Figure 1). In recent years, IoT technology has been applied to monitor environmental parameters for agricultural production (Ullo & Sinha, 2020; Xu et al., 2022). According to a research carried out by the Precedence Research, IoT technology will have a substantially larger market as more companies come to recognize the technology's critical role in improving both human well-being and the environment. The market size for IoT platforms from 2022 to 2032 is statistically analyzed in Figure 2 (Precedence Research, 2023).

To further illustrate the effectiveness of IoT in adapting to climate change, the next parts will present some IoT applications that have been deployed in the Mekong Delta for agricultural and fishery production, and early detection of landslides. Through these applications, IoT technology has provided practical answers to address climate change and save the environment.

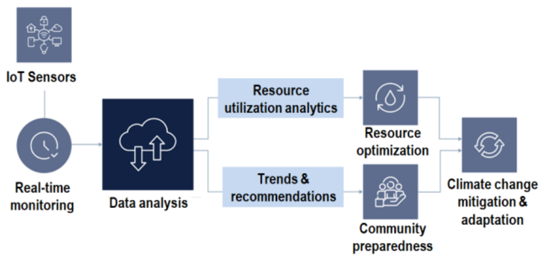

Figure 1. IoT technology aid in climate change mitigation and adaptation

(Source: sumatosoft.com)

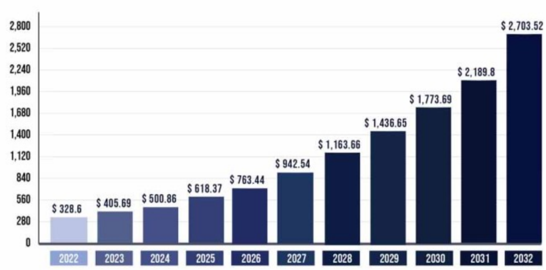

Figure 2. **The global internet of things (IoT) market size from 2022 to 2032 (*in USD billion*)**

(Source: Precedence Research, 2023)

2. IOT-BASED MONITORING SYSTEM FOR RICE CULTIVATION USING THE ALTERNATING WET- AND-DRY IRRIGATION METHOD

2.1. Introduction

Traditional rice farming requires a much higher amount of water than other crops because the field needs to be constantly maintained in flooded conditions. However, the impacts of climate change such as floods, droughts, and deep intrusion of salt water into the mainland have significantly affected the water source for agricultural irrigation in general and rice cultivation in particular. The scarcity of irrigation water poses an existential danger to current and future rice production in the Mekong Delta. Therefore, it is necessary to save water and effectively irrigate rice fields to ensure water sources for agricultural activities, especially in coastal water shortage areas due to saline intrusion.

The alternating wet-and-dry watering (AWD) is one of the water-saving rice farming techniques that has been applied in Viet Nam and some countries in Asia (Tin et al., 2014; Allen & Sander, 2019). The main feature of this technique is to monitor and adjust the field water level regularly and appropriately throughout the cultivation process from sowing to harvest. This irrigation technique has been applied to the practice of rice cultivation and is considered to be more effective than traditional irrigation methods in some parts of the Mekong Delta.

In the framework of the E-5 research program under the Can Tho University Improvement Project VN14-P6 supported by a Japanese ODA loan, a system for monitoring and controlling rice cultivation using the AWD approach was designed and implemented. Compared with some existing irrigation control systems, the system is built on top of the IoT structure that enables rice farmers to remotely operate the water pump devices, gather and store environmental data such as temperature, air humidity, light intensity, and soil moisture in addition to real-time monitoring of the field water level (Nguyen et al., 2020).

2.2. The alternating-wet - and- dry (AWD) technique

The AWD technique is the practice of irrigation management in rice fields that preserves rice harvests while conserving water and lowering greenhouse gas emissions. Figure 3 depicts the change of rice field water level in the crop with 2 methods of AWD and continuous flooding (CF). According to the AWD, the water in the rice field is allowed to dry up around two weeks after sowing so that enough water is still maintained for the growth of rice plants. Farmers have the ability to keep an eye on the moisture content of the soil and apply water to the rice field when its water level reaches a threshold level, often 15 cm below the surface of the ground. Water is then pumped into the rice field to obtain the water level of about 3-5 cm above the ground before continuing to dry the field. The above cycle can be continued except for the period of one week before and after the time of flowering (Siopongco et al., 2013).

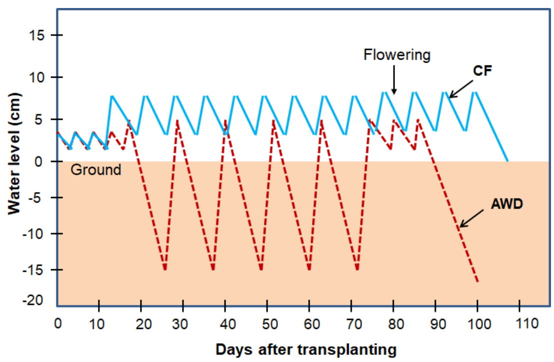

Figure 3. Comparison between the AWD and the CF methods

2.3. Design of Monitoring and Control System

The principal diagram of the monitoring and control system is shown in Figure 4. The system is designed based on IoT architecture and consists of 5 main components: central controller, sensor nodes, cloud server, application software on smartphones and water pump controller.

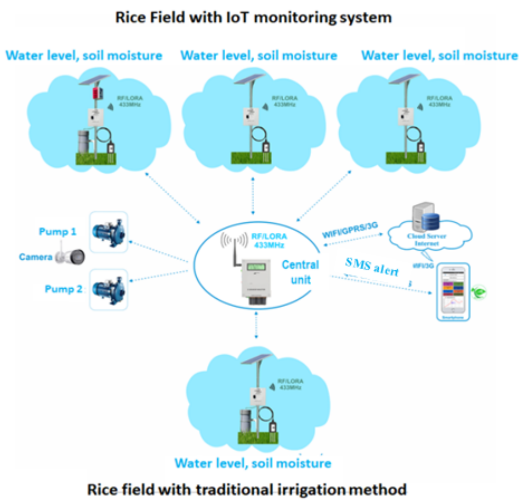

Figure 4. The structure of the monitoring and control system using IoT technology

Data is sent from the Central controller to the Cloud server over the internet. The Central controller manages 04 sensor nodes installed at different locations in the field. The data collected from the sensor nodes will be transmitted by the Central controller to the Cloud server every minute.

Sensors installed at a sensor node include temperature, air humidity, light intensity, soil moisture and water level sensors. These environmental parameters will be transmitted by the Sensor nodes to the Central controller via a 433-MHz wireless connection.

An application for mobile phones was developed to allow users to view the data stored on the Cloud server. This allows farmers to monitor field parameters anytime and anywhere with an internet connection (Figure 5). Besides controlling the irrigation water pump on site, users can also control the water pump remotely through this application software. Farmers can also monitor the process of pumping water in rice fields thanks to a camera installed at the location of the water pump.

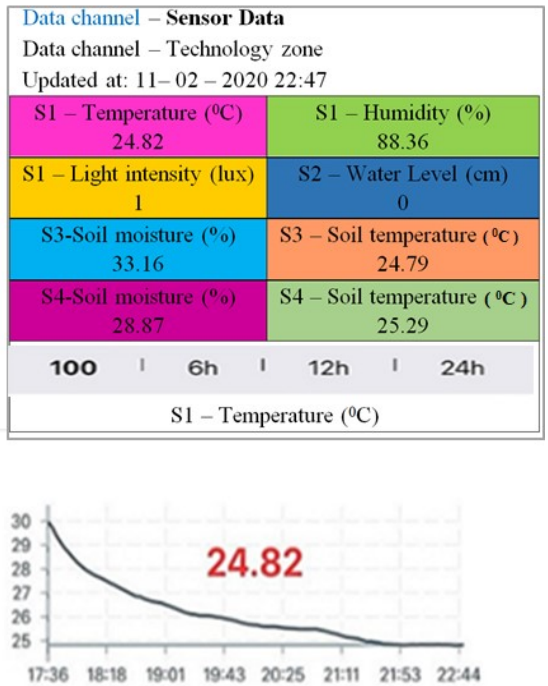

Figure 5. Environmental parameters displayed on the phone's screen

(This image is translated from the original interface in Vietnamese language)

2.4. Experimental Results and Discussions

The monitoring and control systems were deployed at 02 rice fields in Long Ho District (Vinh Long), and Nga Nam Town (Soc Trang), for the Winter-Spring rice crop in 2019, and 01 rice field in Long Phu Town, Soc Trang Province, for Summer - Autumn rice crop in 2020 (Figure 6). Figure 7 shows the installation of sensor nodes on the experimental rice fields in Soc Trang Province.

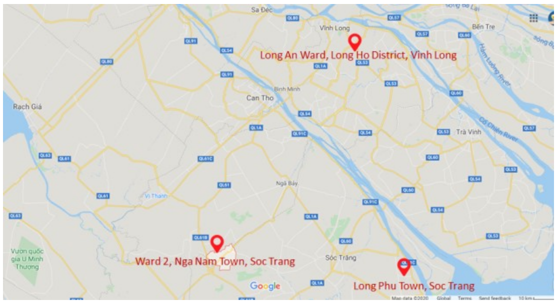

Figure 6. Locations for conducting the experiments in the Mekong Delta

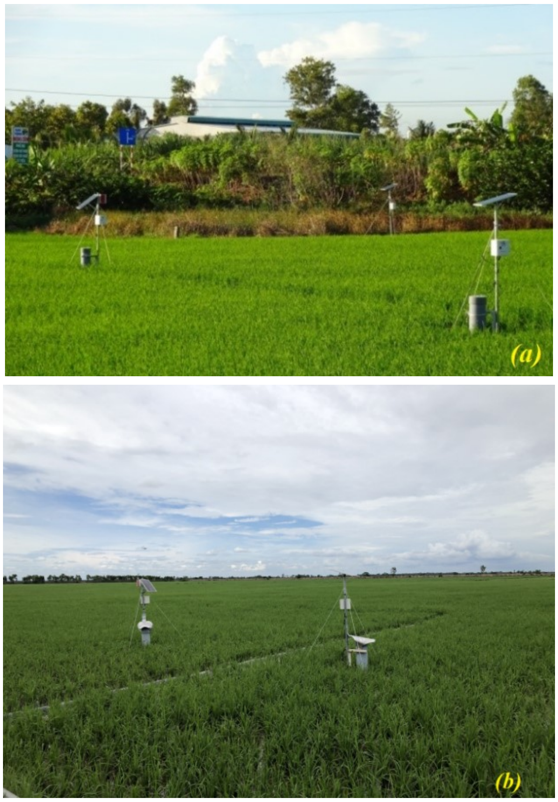

Figure 7. Sensor nodes installed at rice fields in Nga Nam Town (a) Long Phu Town (b), Soc Trang Province

Typical environmental parameters such as water level, soil moisture in the above-mentioned rice fields is depicted in Figures 8 and 9. Farmers are able to keep an eye on the environmental parameters of their fields by using their mobile phones to access to the Cloud server. Environmental parameter data is stored by the system for up to one year, creating favourable conditions for analysis and evaluation of farming techniques results through each crop.

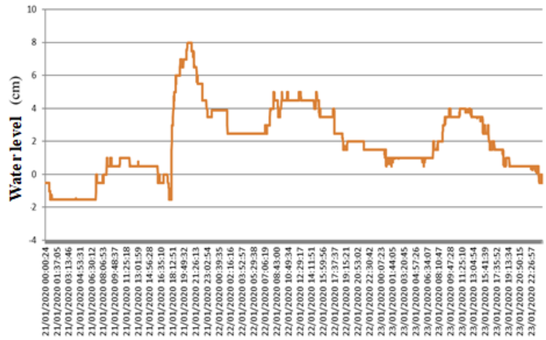

Figure 8. Measured data on water level at rice field in Nga Nam Town from 21 to 23/01/2020

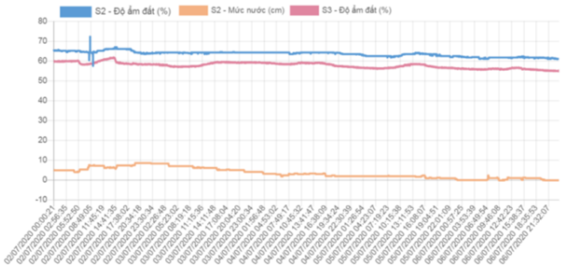

Figure 9. Measured data on water level and soil moisture at rice field in Long Phu Town during 02 to 06/07/2020

In general, the effectiveness of the AWD farming models depends on many technical parameters, the most important of which are soil moisture, field water level, humidity and air temperature. These parameters are related to rice farming techniques, such as nutrient supply and pest management. Previous studies have shown that AWD technique has advantages over traditional farming, such as saving water for irrigation, reducing greenhouse gas emissions and nitrogen fertilizer for rice; rice plants are less prone to fall and thus result in higher yield. The biggest limitation of the AWD technique is that farmers have to spend time and effort to observe the field's water level, soil moisture and air humidity manually. Moreover, manual measurement only gives the data value at a certain time, does not have a continuous update and requires careful recording, and this is difficult for farmers.

For the irrigation system model established in this study, measured data does not need to be manually recorded and is updated automatically and continuously. Data obtained is in series form, allowing to predicting the changing trend of the parameters. This helps rice growers (farmers, farms) to make rational decisions in the farming process to improve the efficiency of rice production. For example, when rice is affected by the Pyricularia oryzae disease, it is forbidden to let the rice field lack moisture (low water level), because when the rice field is dry, it will cause mineralization to release nitrogen. Rice plants absorb nitrogen nutrients, making rice leaves soft, susceptible to fungus, and the diseases become more serious. At this time, if not using IoT technology, rice growers have to measure soil moisture, observe water levels and come to a decision to adjust the water level (soil moisture) in rice fields appropriately to limit the development of the Pyricularia oryzae disease. If this process takes place for a certain time, it will create an opportunity for disease diffusion in the rice fields. On the contrary, by applying the IoT technology, the parameters on soil moisture and water levels are provided timely and continuously, helping farmers have enough information to make appropriate and timely decisions.

Further, by taking advantage of the IoT technology, researchers can build a decision support system application for rice field management. Accordingly, the optimal threshold of soil moisture, water level, nutrition, and pesticide spraying threshold for pest control at each growth stage of rice will be recommended for rice growers. From these conditions, combined with the actual conditions of rice cultivation, farmers are able to choose the best options to optimize production efficiency.

3. IOT-BASED SYSTEM FOR MONITORING WATER QUALITY IN AQUATIC ENVIRONMENTS

3.1. Scenarios

Viet Nam is among the top 5 nations in the world in terms of aquaculture production (Giang, 2016). The aquaculture business has been expanding recently in terms of both farming area and farm pond count. More than 66% of the nation's yearly aquaculture production comes from the Mekong Delta (Mai, 2017). However, extensive and intensive farming has resulted in a decline in the quality of aquaculture water and an increase in the prevalence of diseases in aquatic animals. Controlling water quality is thus essential for effective aquaculture operations. It establishes how effectively fish and shrimp in ponds use their food, as well as their survival and development rates. Monitoring pond water's physio-chemical and biological characteristics on a regular basis helps prevent catastrophic losses, enhance production yield, and shield aquatic life from adverse environmental effects. Temperature, dissolved oxygen, pH, and salinity are the most crucial parameters that must be watched over and managed. At the moment, aquaculture pond monitoring is an inefficient procedure since it relies heavily on the experience of the farmer and is labor-intensive and time-consuming. Typically, farmers don't measure pond parameters until they notice irregularities in the water.

Real-time water quality monitoring in aquaculture is now possible thanks to the recent rapid development of IoT technology. Much research has been done on water quality monitoring devices based on IoT technology and wireless communication. Sensor probes are constantly installed underwater for these applications in order to quickly record changes in pond water characteristics. However, if regular maintenance is not carried out, dirt, organic growth, and microalgae may eventually accumulate on the sensor probes. As a result, this has an adverse effect on the sensor's lifetime and the accuracy of the recorded data.

In the framework of the E-5 research program under the Can Tho University Improvement Project VN14-P6 supported by a Japanese ODA loan, IoT-based systems for monitoring water quality were designed and deployed at fish and shrimp farms in Vinh Long and Bac Lieu Provinces. The main objective of the system is to give farmers real-time access to the most crucial physiochemical parameters of pond water. In particular, this work presents a straightforward and effective method to automatically clean sensor probes, which improves the reliability of sensor readings and reduces maintenance costs (Luong et al., 2020).

3.2. System design

Figure 10 displays the block schematic of the proposed IoT-based aquaculture water quality monitoring system. There are five main parts in the system: Cloud server, Smartphone App, Actuator controller, Sensor node and Master control unit.

The Master control unit has the ability to manage up to four Sensor nodes that are situated at various ponds. The Master control unit is connected to the Cloud server via Wi-Fi/2G/3G networks with the use of a wireless communication module. The Master controller unit has the ability to upload sensor data to a cloud server once every minute. When pond water parameters rise above acceptable values, the Master control unit can also alert users via SMS.

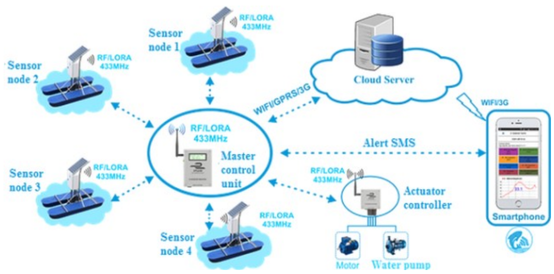

Figure 10. Architecture of the monitoring system

A smartphone app was developed to fetch the data from the Cloud server and display it on the screen of mobile devices (Figure 11). This gives consumers the flexibility to access sensor databases at any time and from any location using mobile devices. Moreover, this application also enables authorities to define threshold values for pond water metrics and alert users in the event that something strange happens.

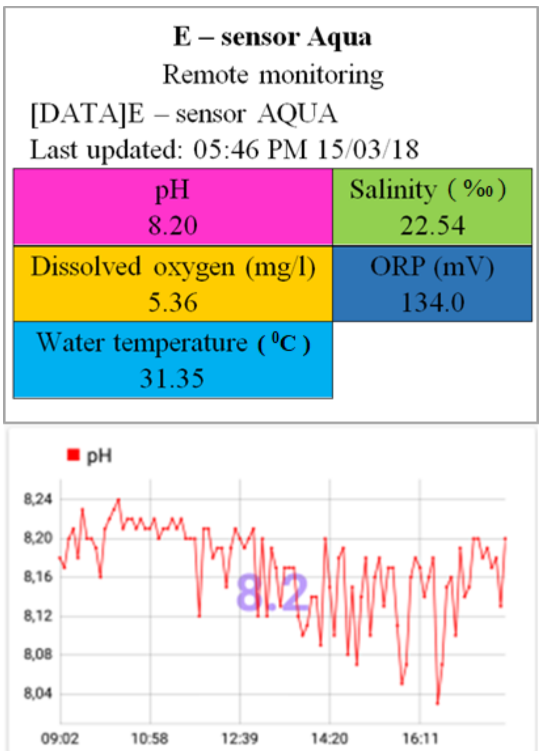

Figure 11. Pond water parameters displayed on smartphone screen

(This image is translated from the original interface in Vietnamese language)

After a few days of operation, sensor probes placed in ponds rapidly accumulate with fine dust, dirt, and algae due to the Mekong Delta's tropical temperature and high sediment water sources. Consequently, this may result in inaccurate sensor readings. In order to maintain correct data, the sensors must be cleaned and calibrated on a regular basis. In this study, air bubbles are created in the water to clean the dirt particles on the sensor surface by using an air compressor connected to air caps through plastic tubes. Air caps were specifically made to fit each sensor probe, as shown in Figure 12. The air pump's operation is planned to carry out periodic cleaning tasks. From the experimental data, one can observe that the suggested method can greatly lower the frequency of manual maintenance. Technology companies may more easily deploy sensor systems on fish and shrimp farms where farmers lack the technical know-how to properly maintain and calibrate the sensors thanks to this straightforward and effective approach.

Figure 12. The sensor probe has an air cap and air pump attached

3.3. System implementation

The proposed IoT system was implemented to monitor the water quality of fish and shrimp ponds in Vinh Long and Bac Lieu Provinces (Figure 13). Farmers can instantly check the water quality of their shrimp and fish ponds by using mobile devices to access the Cloud server. Additionally, when these metrics deviate from the permitted ranges, the system can notify farmers by SMS. As a result, after getting warning messages, farmers can perform appropriate measure for their ponds.

Figure 14 compares two cases: The sensor probe does not use automated cleaning mode, and when automated cleaning approach is applied. From Figure 14a, after four weeks of use, it is evident that the sensor probes are covered in dirt and algae. On the other hand, after two weeks of operation, the dissolved oxygen sensor surface stayed clean thanks to the automatic cleaning mechanism (Figure 14b).

This experimental data demonstrates the efficacy of the suggested automated cleaning technique. The proposed solution helps small-scale farmers in developing countries have more reasonable costs in applying high-tech farming methods.

Some important water quality metrics (pH, temperature, salinity, and dissolved oxygen) that are monitored in real time in shrimp ponds are shown in Figure 15.

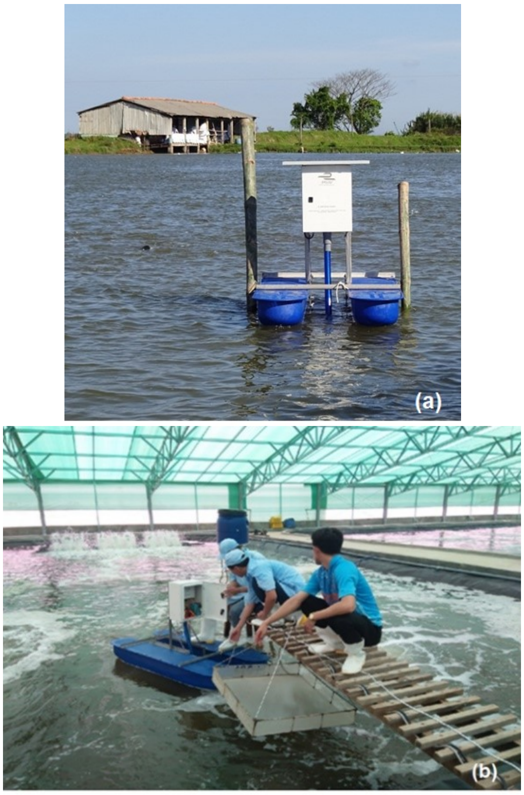

Figure 13. Sensor nodes installed at (a) Tra fish pond (Vinh Long province) and (b) shrimp pond (Bac Lieu province)

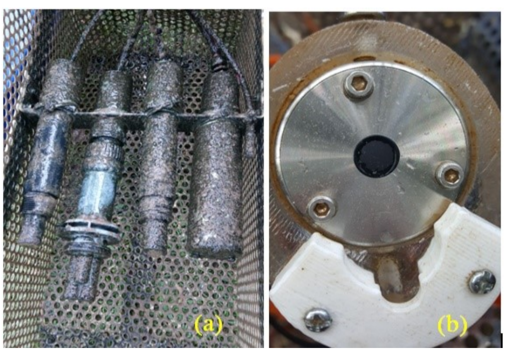

Figure 14. The effect of cleaning the sensor probe: (a) Four weeks without cleaning (b) DO sensor with automated maintenance

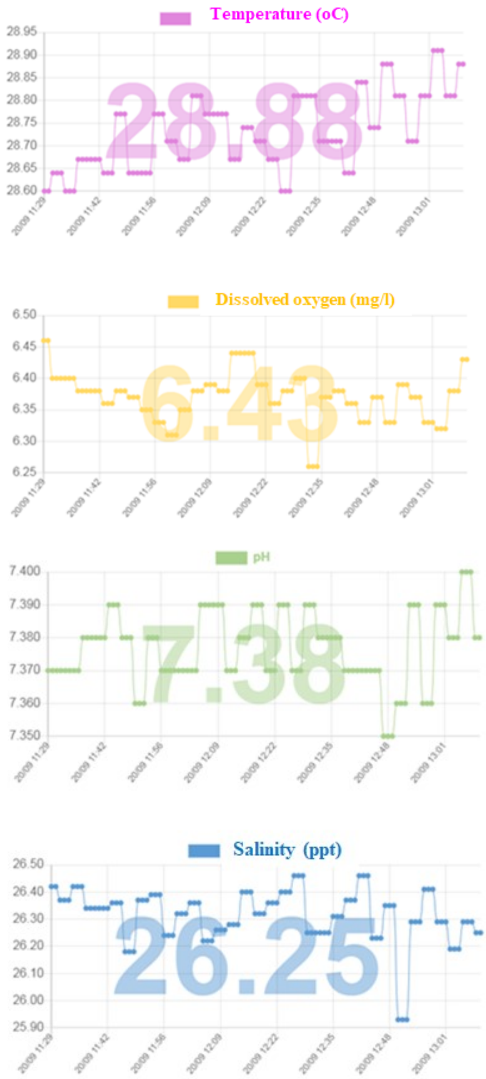

Figure 15. Pond water parameters (temperature, dissolved oxygen, pH, and salinity) are monitored in real-time

4. IOT-BASED SYSTEM FOR PREFAILURE DEFORMATION MONITORING OF RIVERBANK LANDSLIDES

4.1. Introduction

The Mekong Delta, one of the three world's largest delta plains, was formed by accretion over the last 6,000 years, and has weak geological structure, highly susceptible to landslides and subsidence (Nu & Thinh, 2020; Vietnam News Agency, 2020). Riverbank landslides in the Mekong Delta have been occurring for decades, but it is worth noting that the frequency of landslides has been increasing in recent years, causing serious damages to people and properties. Studies have shown that riverbank slope deformations are mainly caused by heavy rainfall, fluctuations in groundwater levels, shifting of river channels, shortage of sediment, and excessive sand mining. In addition, the rapid urbanization in the region increases the density of houses and roads along the riverbanks. This has an impact on the changes of ultimate stresses and horizontal displacements of the limited ground causing riverbank landslides. The impact of the load combined with the factors causing erosion at the base of the slope causes riverbank failure, as shown in Figure 16.

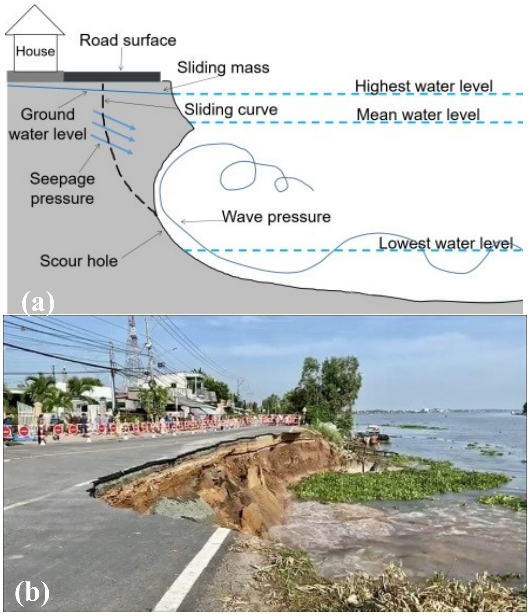

Figure 16. Riverbank landslides: (a) Main factors contribute to slope deformations; (b) Landslide sinks a roadway into Hau River in Chau Phu District, An Giang Province, Viet Nam

(Source: Natural Resources & Environment Newspaper).

Identifying the factors that contribute to landslides will help prevent and mitigate the damage they cause. Various approaches to the study of landslide processes have been implemented, such as using remote sensing information to monitor changes in riverbank shapes and developing landslide susceptibility maps and risk assessments. Recently, the IoT technology has been used to establish landslide monitoring systems for mountainous areas. However, there has been no specific study on evaluating the horizontal ground pressure in the sliding mass under the effect of the load and the horizontal displacements of soil mass causing riverbank landslides for the Mekong Delta.

This work introduces the design and deployment of an IoT-based system to monitor the displacement of riverbank soil mass under the influence of load. To study the tilting and sliding behaviour of riverbank slopes, inclinometers, soil moisture sensors, and soil pressure transducers were employed to monitor the soil mechanical parameters in real time at the experimental site. Measurement data of the designed system are compared with those obtained by the specialized measuring equipment. Preliminary results show that the measured data of the horizontal ground pressure in the sliding mass agree well with those measured by the Kyowa measuring instrument. The results obtained in this study will contribute to the development of landslide prediction models for early warning of riverbank failure in the Mekong Delta (Dang et al., 2023).

4.2. System design

The designed monitoring system consists of a Cloud server and Sensor nodes installed on riverbanks. Figure 17 displays the principle diagram of the whole system. In this study, the objects to be monitored are soil moisture, soil pressure, and soil displacement. Therefore, the Sensor node includes soil moisture sensor, soil pressure transducers, and inclination sensors. These sensors are fitted inside circular/square metal piles. Through 3G/4G mobile networks, measurement data from the Sensor nodes is sent to the Cloud server. Sensor node operations are powered by solar energy.

The Sensor node is comprised of one Master unit and Sensor units. The sensors for measuring soil pressure and displacement are connected to the Sensor units. Soil moisture sensors are connected to the Master unit. The system is powered by solar energy. Its block diagram is shown in Figure 18.

The soil moisture sensor and Sensor units will send measurement data to the Master unit via the RS-485 connection. Measurement data from the sensors are then FTPed to the Cloud server via the 4G module. The clock time of mobile base transceiver stations is used to synchronize the system operations. A 16-GB SD memory card is used to back up data in case the internet connection is lost. The Wi-Fi module is employed to perform system calibration and setting the sampling frequency of sensors. In this study, the frequency of reading data from the sensors was set to 5 Hz. Measurement data will be sent by the Master unit to the Cloud server every 60 seconds.

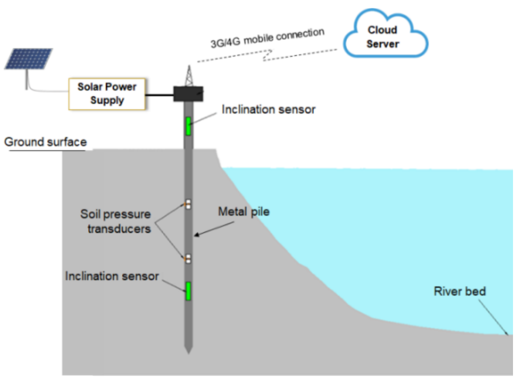

Figure 17. Structure of the designed IoT-based monitoring system

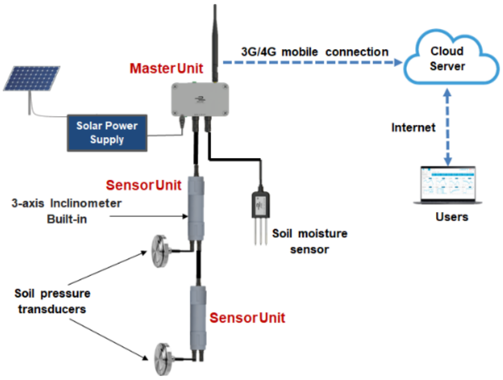

Figure 18. Structure of the Sensor nodes

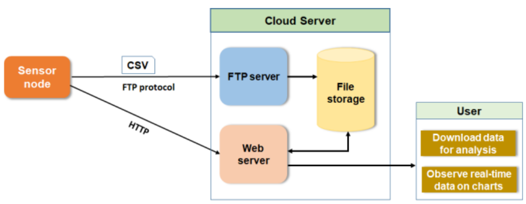

Figure 19. Structure of the Cloud server

The structure of the designed Cloud server is depicted in Figure 19. It composes of 2 main components: FTP server and Web server. The FTP server is in charge of receiving log files sent by sensor nodes. The Web server allows users to download measurement data for analysis and observe real-time measurement data on graphs.

4.3. Experimental results

The prototype monitoring system was built and tested. The electronic circuits of the Sensor unit and the Master one are shown in Figure 20. The Sensor unit (housed in a waterproof plastic box) containing the SCL3300 inclinometer was installed on top of a rectangular steel tube (dimensions: 120 *x* 10 *x* 5 cm) used as the sensor pile (Figure 21a). Soil pressure transducers were fixed on the body of the sensor pile. Two Kyowa BED-A-200KP transducers were installed side by side at a position 20 centimetres from the pile tip, as depicted in Figure 21b. For this installation, one BED-A-200KP transducer was attached to the Sensor unit, and the other one was connected to the Kyowa measuring instrument consisting of the EDX-10B compact recording system and an EDX-11B strain measuring unit (Kyowa). This configuration allows us to gather and compare the soil pressure data measured at the same location using the designed system and the Kyowa instrument (Figure 22).

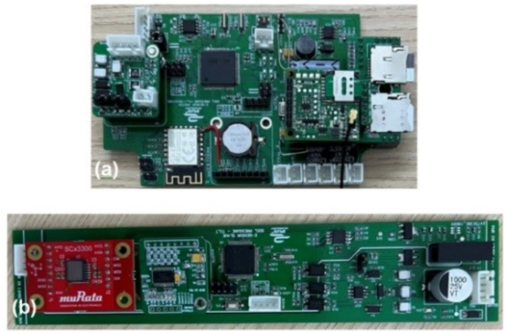

Figure 20. Electronic circuits of the Sensor node: (a): Master unit and (b) Sensor unit

Figure 21. Installation of sensors on the metal pile: (a) Sensor unit is housed in a protective PVC enclosure; (b) Soil pressure transducers installed on the body of the sensor pile

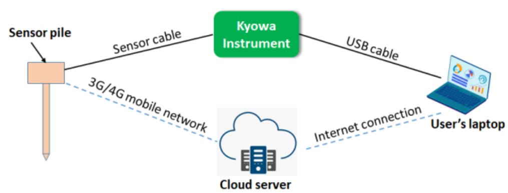

Figure 22. System configuration for gathering soil pressure data from the two BED-A-200KP transducers

In this study, the experimental area was a short canal (dimensions: 25 *x* 3 m) dug next to Cai Sau riverbank, Can Tho City, to simulate the geological conditions of the riverbank (Figure 23). The soil in this area is soft clay and has the following physiomechanical parameters: soil cohesion C = 8.1 kPa, generic friction angle φ=3°16', bulk unit weight γ_w = 1.571g/cm^3, and void ratio e = 1.808. The canal bed was designed with a depth of 2 meters and the slope had a coefficient of H=0.5, V=2. The sensor pile was positioned 0.1 meters away from the edge of the canal bank. Soil pressure transducers were located at a depth of 0.2 to 0.4m. The sandbags are used as a strip load to make pressure on the ground surface around the sensor pile. Their arrangement was made on a 0.6 x 1.4 m steel plate, placed 0.2m away from the sensor pile, as shown in Figure 23a. A rainfall generator was used to saturate the test area's soil with water. Wave generators produced waves and altered the water level of the canal to form a scour hole at the bottom of the slope. The strip load was progressively raised until the landslide happened, each load level was 3.5 kPa. During the test, data on soil pressure and pile tilt angle were obtained. Users can also observe the instantaneous changes of measurement data on the software interface.

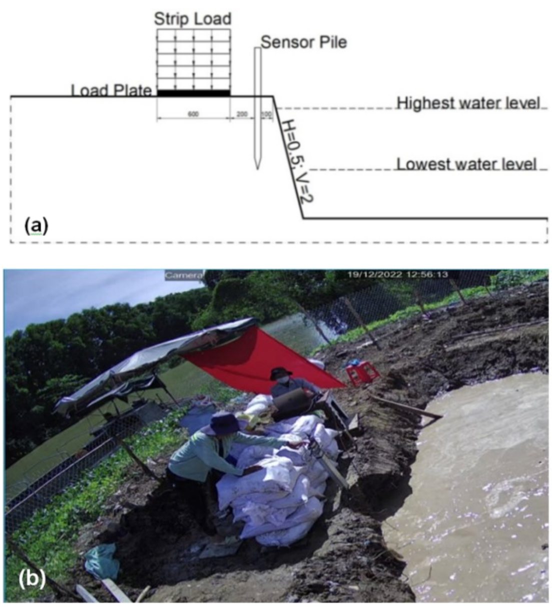

Figure 23. Test area

(a) Dimensions of the experimental canal; (b) Image taken at the experimental site

Figures 24 and 25 display the tilt angle and soil pressure measurement data obtained during the destructive deformation of the ground at the pile position, respectively. It can be seen that the landslides occur in only a few minutes since the landslide mechanism is abrupt deformation. At the time 12:43:37, the slope collapsed when the strip load value increased to about 17.5 kPa. In Figure 24, the tilt angle in the X direction (perpendicular to the canal bank) experiences a sharp increase at 12:43:27 due to the rapid sliding of the soil mass towards the canal. The angle of inclination in the Y direction then increases sharply at 12:43:37. Since the sensor pile is moving with the sliding soil mass, the tilt angle values in the X and Y axes are different in both magnitude and time.

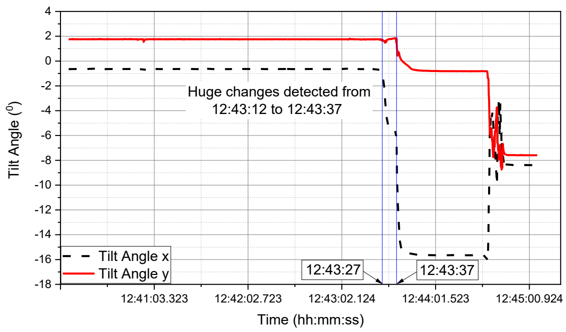

Figure 24. Graph shows the measured tilt angle data

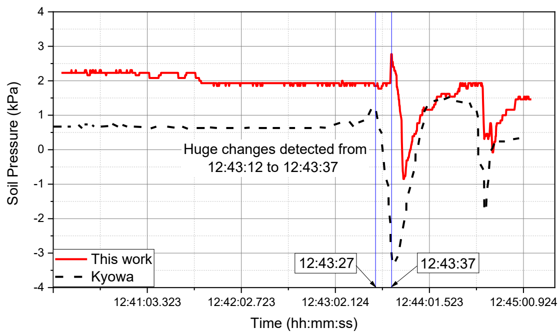

Figure 25. Graph shows the measured soil pressure data

Figure 25 shows that the measurement data of the horizontal soil pressure varies synchronously with the tilt angle data. The maximum value of the horizontal soil pressure recorded by the designed system is 2.77 kPa occurring at the time 12:43:37. The maximum value of the horizontal soil pressure recorded by the Kyowa instrument is 1.25 kPa occurring at the time 12:43:27. The differences in the soil pressure magnitude between the two systems could be due to the soil heterogeneity. Besides, it can be seen that the data recorded by the designed system has a latency of about 10 seconds compared to the Kyowa instrument. This delay can be attributed to the longer data processing and transmission time of the IoT system. The experimental results show that the data of the horizontal ground pressure in the sliding mass measured by the proposed system agree well with those measured by the Kyowa measuring instrument. The results obtained in this study can be used to build landslide prediction models and early warning systems for riverbank failure in the Mekong Delta region.

5. CONCLUSIONS

This paper presented some applications of IoT technology for agriculture and riverbank landslide monitoring in the Mekong Delta. These research projects utilized the potential of IoT technology and applications to enhance the efficiency of rice cultivation and aquaculture, and support the development of riverbank landslide early warning systems for the region. IoT technology and applications are proliferating and will hold an important role in the fight against climate change in the Mekong Delta.

REFERENCES

Thu, P. (2023). Sustainable development of the Mekong Delta – Part 1: Facing risks. *Foreign Relationship Information Page*. https://ttdn.vn/nghien-cuu-trao-doi/ly-luan-thuc-tien/phat-trien-ben-vung-dbscl-bai-1-doi-mat-voi-nguy-co-85473 (in Vietnamese).

Bui, N. H. (2023). Complete the policy system for sustainable development of the Mekong Delta. *Communist Review*. https://www.tapchicongsan.org.vn/web/guest/nghien-cu/-/2018/828804/hoan-thien-he-thong-chinh-sach-de-vung-dong-bang-song-cuu-long-phat-trien-ben-vung.aspx (in Vietnamese).

Salam, A. (2020). Internet of Things for Environmental Sustainability and Climate Change. In: *Internet of Things for Sustainable Community Development. Internet of Things*. Springer, Cham.

Ullo, S. L., & Sinha, G. R. (2020). Advances in smart environment monitoring systems using IoT and sensors. *Sensors*, *20*(11), 3113.

Xu, J., Gu, B., & Tian, G. (2022). Review of agricultural IoT technology. *Artificial Intelligence in Agriculture*, *6*, 10-22.

Precedence Research. (2023). *Internet of Things (IoT) Market.* https://www.precedenceresearch.com/internet-of-things-market

Tin, N. H., Nhan, D. K., & Phuong, T. L. (2014). Effectiveness of alternate wetting and drying (AWD) technique rice production adapting to saline intrusion and water shortage in the Mekong Delta, Vietnam - Case study in Soc Trang Province. In *International Rice Congress* (pp. 51-52).

Allen, J. M., Sander, B. O. (2019). The Diverse Benefits of Alternate Wetting and Drying (AWD). *Los Baños, Philippines: International Rice Research Institute* (IRRI). https://ccafs.cgiar.org/publications/diverse-benefits-alternate-wetting-and-drying-awd

Nguyen, H. T., Luong, V. Q. D., Tran, N. K. H., Hong, M. H., Ho, C. T., Chau, M. D., Huynh, V. H., & Le, A. T. (2020). An IoT-based monitoring and control system for rice cultivation using alternate wetting and drying irrigation method. *The University of Danang Journal of Science and Technology*, *8*(8), 7-12 (in Vietnamese).

Siopongco, J. D. L. C, Wassmann, R., & Sander, B. O. (2013). Alternate wetting and drying in Philippine rice production: feasibility study for a Clean Development Mechanism. *Technical Report*, IRRI, 2013.

Giang, H. (2016). *World aquaculture in the period 2003 – 2014* (in Vietnamese).

Mai, T. (2017). *The fisheries industry has made many contributions to the economic development of the Mekong Delta*. https://baophapluat.vn/nganh-thuy-san-co-nhieu-dong-gop-phat-trien-kinh-te-vung-dbscl-post261170.html (in Vietnamese).

Luong, V. Q. D., Dang, V. M. D., Tran, H. D., & Nguyen, C. N. (2020). Design and Deployment of an IoT-Based Water Quality Monitoring System for Aquaculture in Mekong Delta. *International Journal of Mechanical Engineering and Robotics Research*, *9*(8), 1170-1175.

Nu, N. T., & Thinh, P. H. (2020). Soft soils in the Mekong Delta of Vietnam. *Actual Science*, *4*(1), 10-16.

Vietnam News Agency. (2020). *Land erosion worsens in the Mekong Delta*. https://en.vietnamplus.vn/land-erosion-worsens-in-the-mekong-delta/189425.vnp

Dang, T. A., Luong, V. Q. D., & Nguyen, C. N. (2023) Design of an IoT-based System for Prefailure Deformation Monitoring of Riverbank Landslides in Mekong Delta. In *Proceedings of the 8th International Conference on Micro-Electronics, Electromagnetics and Telecommunications (ICMEET)*. To be published by Springer on June 20th 2024.

Kyowa. (n.d.). *EDX-10 Series Compact Recording System*. EDX-10 Series Manual. https://product.kyowa-ei.com/en/products/data-loggers/type-s_edx-10_series