TẠP CHÍ KHOA HỌC
TRƯỜNG ĐẠI HỌC QUY NHƠN

Nghiên cứu và ứng dụng mạng truyền thông công nghiệp trong hệ thống xử lý nước thải sinh hoạt tại thành phố Quy Nhơn

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TÓM TẮT

Xử lý nước thải là rất quan trọng đối với các khu vực đô thị để đảm bảo bảo vệ môi trường và sức khỏe cộng đồng. Ở thành phố Quy Nhơn, việc quản lý hiệu quả nước thải sinh hoạt liên quan đến việc thu thập nó từ các khu dân cư khác nhau và xử lý tại một cơ sở xử lý tập trung. Việc tích hợp mạng truyền thông công nghiệp và hệ thống giám sát và thu thập dữ liệu (SCADA), vào quá trình này có thể cải thiện đáng kể hiệu quả vận hành và giảm chi phí. Bài báo này nhóm tác giả đã nghiên cứu áp dụng mạng truyền thông công nghiệp trong hệ thống xử lý nước thải của thành phố Quy Nhơn để giảm chi phí vận hành và nâng cao hiệu quả quản lý trong việc xử lý các sự cố vận hành. Kết quả thực nghiệm tại Phòng thí nghiệm Mạng truyền thông công nghiệp và SCADA (314A7), Trường Đại học Quy Nhơn đã cho thấy hiệu quả rất cao.

Từ khóa: *Mạng truyền thông công nghiệp, SCADA, trạm bơm, hệ thống xử lý mước thải, thành phố Quy Nhơn.*

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Research and application of industrial communication networks in the domestic wastewater treatment system for Quy Nhon city

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ABSTRACT

Wastewater treatment is crucial for urban areas to ensure environmental protection and public health. In Quy Nhon city, effective management of domestic wastewater involves collecting it from various residential areas and treating it at a centralized treatment facility. Integrating industrial communication networks and Supervisory Control and Data Acquisition (SCADA) systems into this process can significantly improve operational efficiency and reduce costs. This paper examines the application of industrial communication networks in the wastewater treatment system of Quy Nhon city to reduce operational costs and enhance management efficiency in handling operational incidents. Experimental results from the Industrial Communication Network and SCADA Laboratory (314A7) at Quy Nhon University have shown very high effectiveness.

Keywords*: Industrial communication networks***,** *SCADA, pumping stations, wastewater treatment system, Quy Nhơn city.*

1. INTRODUCTION

Wastewater management is a fundamental aspect of life and development in modern societies. The collection and treatment of wastewater significantly affect both the environment and the economy, on local and global scales. Thus, it is essential to engage in activities that guarantee proper wastewater management. This is especially true in urban and densely populated areas, where finding optimal solutions for sewage systems, including wastewater treatment plants, is crucial.[1,2]

The primary objective of a wastewater treatment plant is to treat water from various sources by eliminating its pollutants.[3,4] Typically, this process is carried out in four or five stages, as depicted in Figure 1.

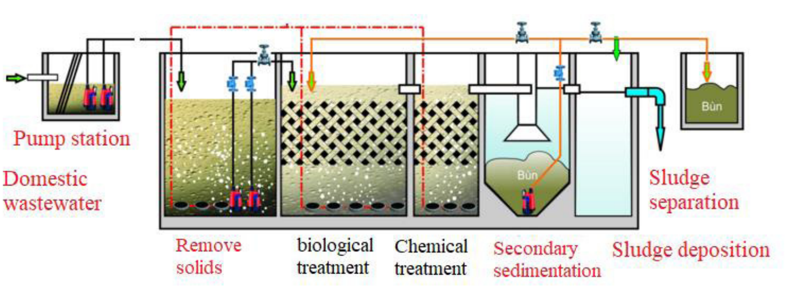

Figure 1. Wastewater treatment process.[3]

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• Pre-treatment, or mechanical treatment, involves removing solids and larger papers from the water.

• Following pre-treatment is biological treatment.

• Chemical treatment occurs after the biological treatment.

• The subsequent step is secondary sedimentation, which entails gathering all the waste and sludge from the treatment process and separating it from the purified water.

• Lastly, the sludge is collected and dried through various methods.

The wastewater treatment system in Quy Nhon city, operational since 2014 following significant investment, has markedly enhanced the city's environmental sanitation. Wastewater is collected and conveyed to the Nhon Binh Treatment Plant, which has a capacity of 14,000 cubic meters per day.

In recent years, a significant number of centralized wastewater treatment plants have been established in both large and medium-sized urban areas, including Hanoi, Bac Ninh, Vinh, and Can Tho, with the support of the Vietnamese Government and various international organizations.

Consequently, the presence of toxins in wastewater poses a significant health hazard to operational personnel. Therefore, the adoption of automated or remote control methodologies emerges as a critical necessity in the management of wastewater pumping and treatment processes.

Presently, the Binh Dinh Civil and Industrial Project Management Board has recommended that the Provincial People's Committee enter into an agreement with URENCO and UDC for the management and operation of the facility and 12 wastewater pumping stations, employing on-site personnel.[5]

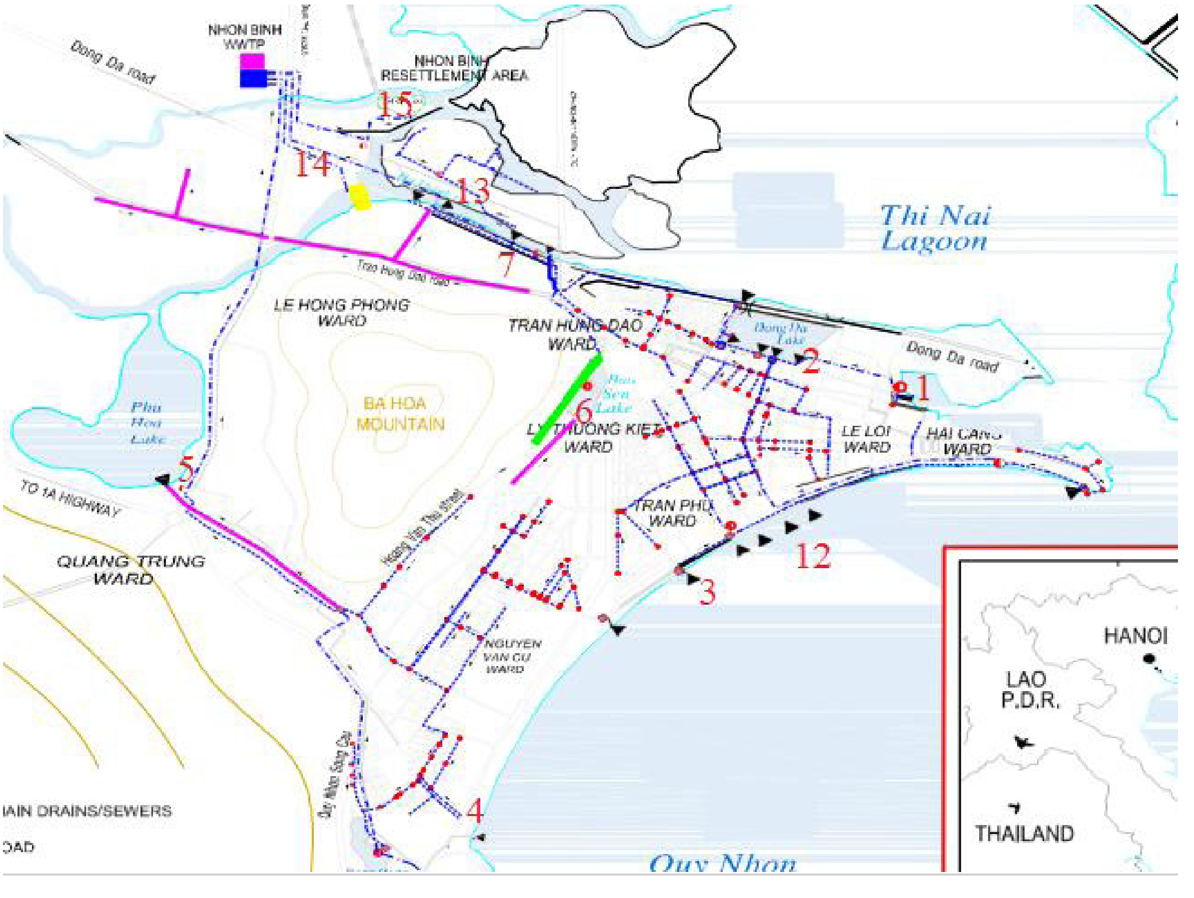

Figure 2. Diagram of Quy Nhon city wastewater pumping and treatment system.

Wastewater treatment systems globally collect water from various stations and transport it to treatment centers. There is an increasing emphasis on implementing remote management solutions to reduce issues encountered during system operation, particularly concerning pipelines and pumping stations.[6,7] The City of Seattle's wastewater collection system ranks among the largest in Washington State, encompassing sanitary, combined, and partially separated combined sewers. In areas served by sanitary sewers, stormwater runoff is channeled into a storm drainage system, while sewage is transported through city sewers to extensive pipelines and treatment facilities. These larger infrastructures are owned and operated by the King County Department of Natural Resources and Parks (DNRP).[6,8]

The Nhon Binh Wastewater Treatment Plant is a component of the Quy Nhon City Environmental Sanitation Project, financed through non-refundable aid from the global environmental fund. Officially inaugurated in 2017, the plant utilizes advanced negative filtration technology, incorporating air and biological trickling filtration processes.

Currently, the new technology application solution (OPC UA) has not been applied to the water treatment system in general, and Quy Nhon city in particular. The authors' proposal will bring many technical and economic benefits.

The authors propose the adoption of Supervisory Control and Data Acquisition (SCADA) for the wastewater treatment system of Quy Nhon city (Figure 3).

Data is stored in the SCADA database and preprocessed to eliminate outliers and fill in missing values. The process monitoring and control functions are collectively organized, demonstrating their ongoing and collaborative use in the system. This preprocessed data is crucial for detecting and identifying sensor faults, as well as for monitoring the operational processes of the plant.[9,10]

Significant advancements in computer technology have led to the development of both wireless and wired communication protocols, such as MODBUS, OPC DA, and OPC UA. These innovations make it feasible to collect and compile extensive datasets. Consequently, this provides operators, engineers, and maintenance staff with sophisticated analytical tools, facilitating cost reduction, the avoidance of unnecessary repairs, and improved time and plant management. Importantly, these advancements also contribute to safeguarding the health of operators.[11,12]

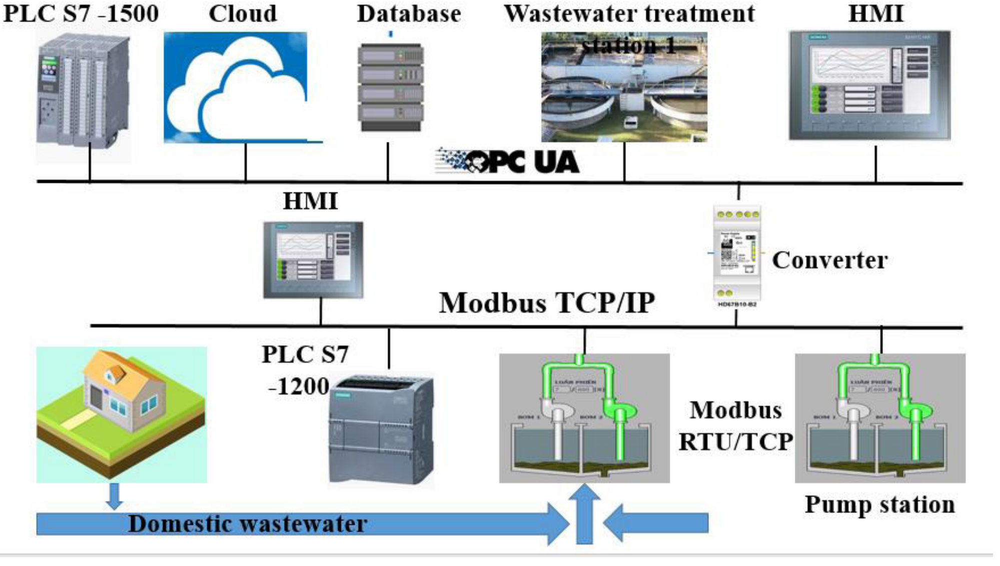

Figure 3. Applying industrial network to manage wastewater treatment system of Quy Nhon city.

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- Benefits of wastewater treatment from the SCADA system are:
- Reduce chemical exposure
- Control the amount of wastewater and treat it appropriately
- Economic efficiency
- Integrated control of environmental and weather impacts
- Record the history of the entire process
- Monitor the status of remote pumping systems

2. IMPLEMENTATION

2.1. Management solution for wastewater collection station in Quy Nhon city

In certain scenarios, wastewater treatment systems are established directly at the discharge location. Within the scope of this study, the oversight of the Wastewater Treatment Plant falls under the jurisdiction of the Department of Power and Utility. The outcomes of the treatment process include water that has been neutralized to a pH level devoid of hazardous and toxic substances, and sludge that is prepared for disposal at a designated site for hazardous and toxic materials.[3] In the city of Paraty, collection systems utilize piping networks. A significant challenge associated with the vacuum system was the anticipated operational and maintenance costs, given the city's limited experience and expertise with such collection systems. It has been determined that for Paraty, adopting a uniform, consistent, and straightforward collection system would be the most suitable approach.

Implementing a comprehensive wastewater management solution for Quy Nhon city entails the integration of monitoring systems, the optimization of collection infrastructure, and the assurance of efficient treatment processes. Collaboration with local authorities, the deployment of sensor networks, and the application of data analytics are key strategies to improve operational efficiency and the assessment of environmental impacts. To manage the wastewater collection station system effectively, the authors utilize the Modbus communication network (Figure 4).

Modbus is a Client/Server protocol. In simple terms, this means that the server, often a PLC, does not send any data until the client, in this case, the SCADA, requests it. In other words, there is no way for a PLC to send data to the SCADA if a sensor has a change in value. In practice, this means that the SCADA will have to request data from all PLCs to look for a change in the data, even if the data might have been unchanged since the last time. An exception to this is OpenMbus, where the client is able to subscribe to the server which then sends an update every time a value changes.

First, the program from the computer connects via an ethernet network through a switch including PLC, HMI, and computer to upload the program to the PLC. This program controls the motor through the inverter using Modbus RTU communication.

Then, data at the pumping stations will be sent to the wastewater treatment center via the industrial communication network (Ethernet) by fiber optic cable.

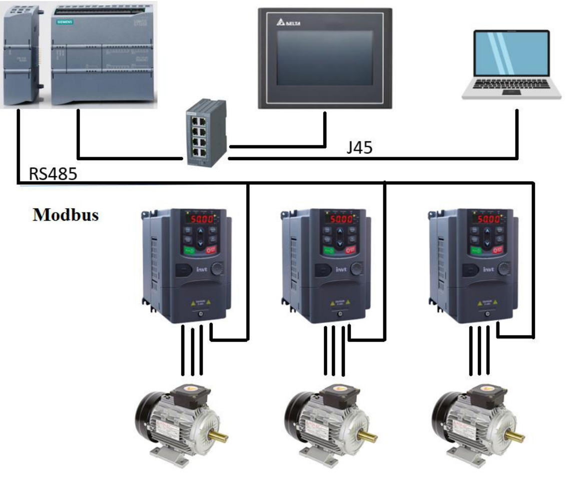

Figure 4. Wastewater collection station management system.

2.3. Communication solutions for the system

To exchange data between pumping stations and processing centers, we create a communication system. They supervisory control and data acquisition. The radius of Quy Nhon city's wastewater pumping and treatment system is about 10 km, suitable for applying Ethernet network based on OPC UA platform.

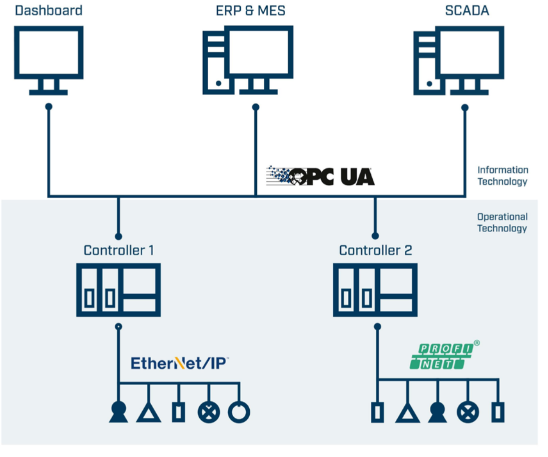

Figure 5. Ethernet industrial communication protocol.

OPC-UA was previously OPC Classic, based solely on technologies developed by Microsoft. Although useful and efficient, the system's reliance on Windows has prevented its development in the modern factory. Released since 2015, OPC UA retains all the functionalities of OPC Classic, except that it is 100% independent of the platform used, simplifying the implementation and maintenance of information systems. Unlike its predecessor, OPC UA can be used on Linux, Mac OS, Microsoft Windows, iOS or Android. Figure 5 is an OPC UA protocol in industrial communication.

Having an increase in determinism within the network will help to perform real-time data transmission. Within the WWTP facilities, measurement devices, control and communication equipment are required to report real-time date to the SCADA system, but other equipment like VoIP or surveillance cameras will not require this. An industrial managed Ethernet switch with network management software built-in is required in order to increase determinism for all field equipment data transmission.

Set the IP Address with the BOOTP/DHCP Tool. The BOOTP/DHCP tool is a standalone server that you can use to set an IP address. The BOOTP/DHCP tool sets an IP address and other TCP parameters.

The EtherNet/IP Address Commissioning Tool provides additional functionality than the BootP/DHCP tool.

Access the BOOTP/DHCP tool from one of these locations:

• Programs > Rockwell Software® > BOOTP-DHCP Tool > BOOTP-DHCP

• Tools directory on the Studio 5000® environment installation CD.

Add the Device to the Controller Organizer:

After installing a device and setting the IP address, add the device to the Controller Organizer in a programming software project. This addition establishes I/O control.

Before initiating operation, it is essential to download the project to the host controller. Once the controller starts, it establishes a connection with the device, and the device's configuration dictates its behavior. To construct the I/O configuration for a standard I/O network, adhere to the following steps:

1. Add the device.

2. Add the remote device for distributed I/O.

3. Add the I/O modules. This graphic shows the I/O configuration of the consumer controller after distributed I/O modules are added.

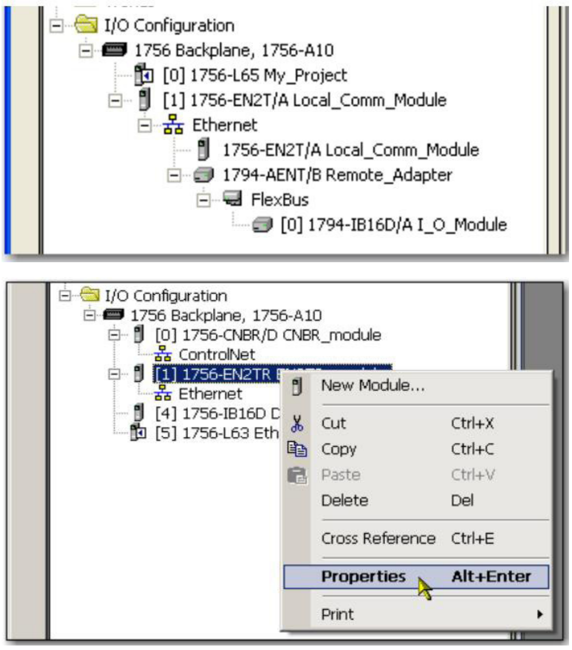

Figure 6. The I/O configuration of the consumer controller.

To configure the device, follow these steps.

1. Make sure that the device is installed, started, and connected to the controller.

2. In the Controller Organizer, right-click the device and choose Properties.

2.4. Construction of SCADA system for wastewater treatment center

Wastewater treatment encompasses a range of processes and equipment units, including screening, pumping, aeration, sedimentation, filtration, neutralization, chlorination, residual removal, sludge digestion, and effluent discharge. These processes necessitate an automated monitoring system to verify the proper operation of each equipment unit and minimize worker exposure to pollutants, pathogens, or hazardous chemicals. The adoption of Open Platform Communications Unified Architecture (OPC UA Figure 7) can potentially lower the costs associated with engineering and maintaining an IoT network, as well as bolster data security from the field level to the cloud.[13]

An application architecture was designed by letting the application act as both a SCADA and HMI. Depending on what level of the architecture you place it and to where it stores its data, this becomes possible.

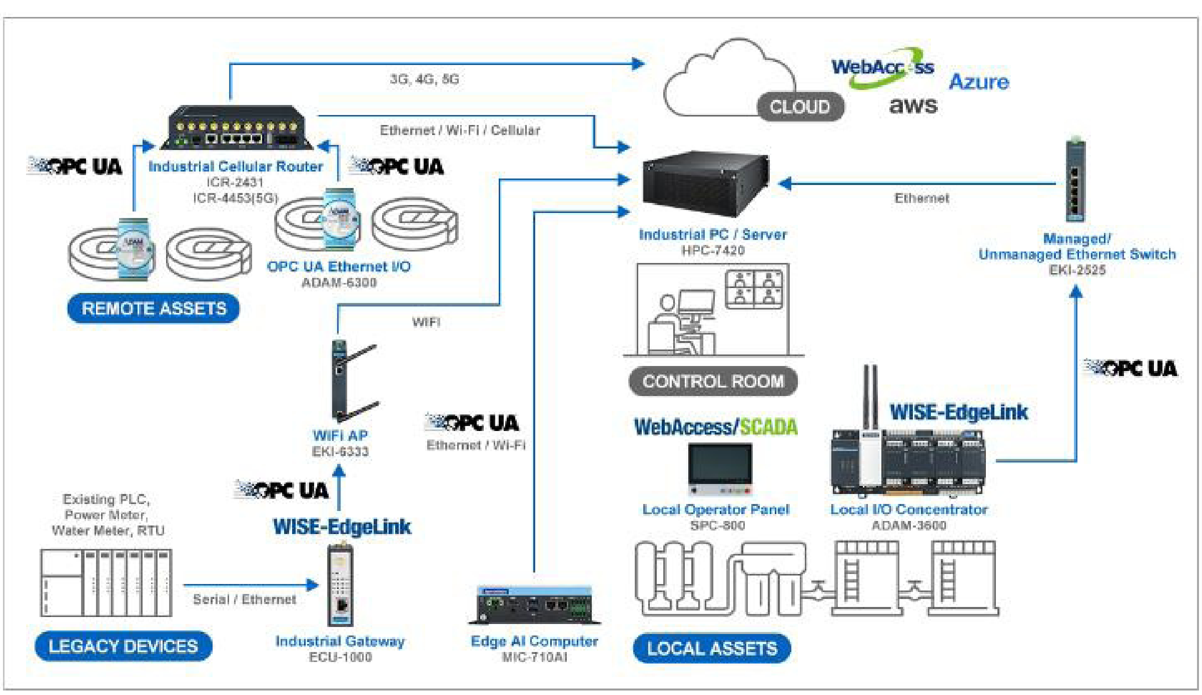

Figure 7. Wastewater treatment plant system diagram.

Take a pump as an example:

- Power consumption (kW)
- Pump flow (m^3/h)
- Setpoint for pump flow (m^3/h)
- Is active (true/false)
- Has any active alarms (true/false)
- Manual mode active (true/false)

2.5. Experimental results and discussion

To evaluate the proposed solution, the authors tested each function of system X in the laboratory. From there, it confirms its feasibility when applied in practice.

The results are divided into three layers where layer one describes the overview of all systems and correlates to level one in the high performance HMI as described section. Layer two correlates to level two in the high performance HMI hierarchy and speaks of sub systems and objects in the workviews. Finally, layer three presents the details of a specific object and correlates to levels three and four of the hierarchy.

- Experimental equipment

The authors introduce some of the main equipment available in the laboratory to serve the experimental process of this research content. The main control unit for the treatment plant is the S7-1500, IoT 2050 Ethernet communication module, the main control of the pumping station is the S7-1200 and the pump control inverter as Figure 8.

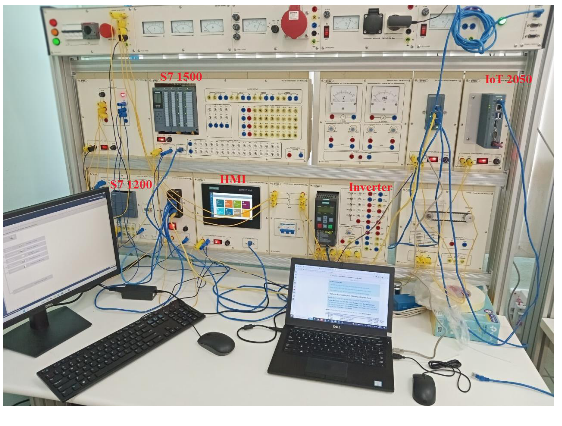

Figure 8. Experimental model of wastewater pumping and treatment system.

- Modbus communication for pumping stations

The model is implemented with three inverters, each linked to a specific wastewater pump responsible for transferring water from the storage tank to the pressure pipeline. The control and programming for this pumping station setup are executed using the PLC S7-1200 (Figure 9).

Figure 9. Pump station monitoring and control model based on Modbus RTU network.

Parameters are within allowable limits and are updated continuously every 1 s, ensuring real-time calculation for shrimp pond monitoring systems. In addition, the above system can provide a common database for scientists, shrimp hatcheries, fishery extension centers and so on. In addition, the above data is also daily, monthly, and yearly graphed to store historical parameters Figure 9, and Figure 10.

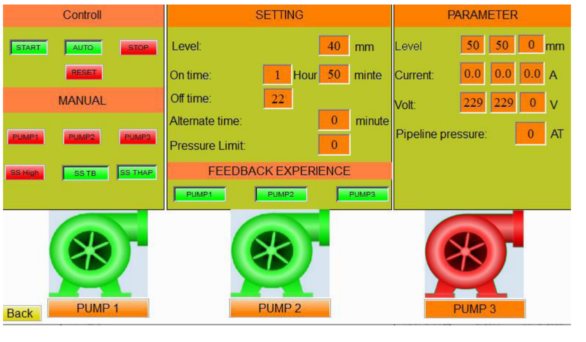

Figure 10. Results of running the model in Auto mode.

Start the system running in Auto mode, and set the system's on/off time, alternating time, and pipe pressure limit. When the low level sensor receives, pumps 1 and 2 run alternately according to the set time and frequency. If the level sensor receives an average value, both pumps 1 and 2 will run at the set frequency.

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If the level sensor receives a high value, all 3 pumps 1, 2 and 3 will run at the set frequency. If the pipeline pressure exceeds the set pressure, the system will stop the pump and warn.

During operation, the system continuously monitors the pump's operating frequency, voltage, and current.

- SCADA system for wastewater treatment plant

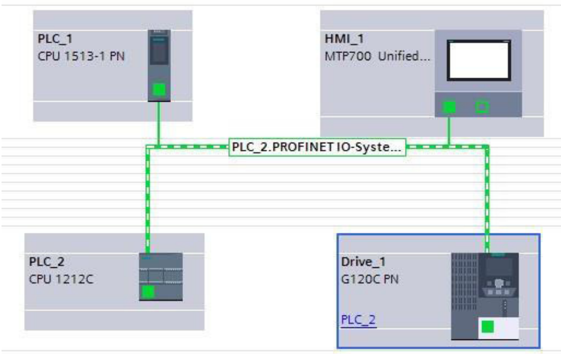

Figure 11. Experimental model of control center.

In wastewater treatment plants, the SCADA system operates in a more complex manner, with the program being implemented on the PLC S7-1500.

Like the pumping station, the treatment plant features a vast array of inputs and outputs, facilitating extensive data exchange. The SCADA system onsite constructs parameters, enabling data communication with 12 pumping stations via the Ethernet network. This setup, grounded in the OPC UA platform, ensures compatibility across all devices and various operating systems. Some parameters were selected to experiment with the research content, to reflect the applicability of the content of this paper (Figure 12).

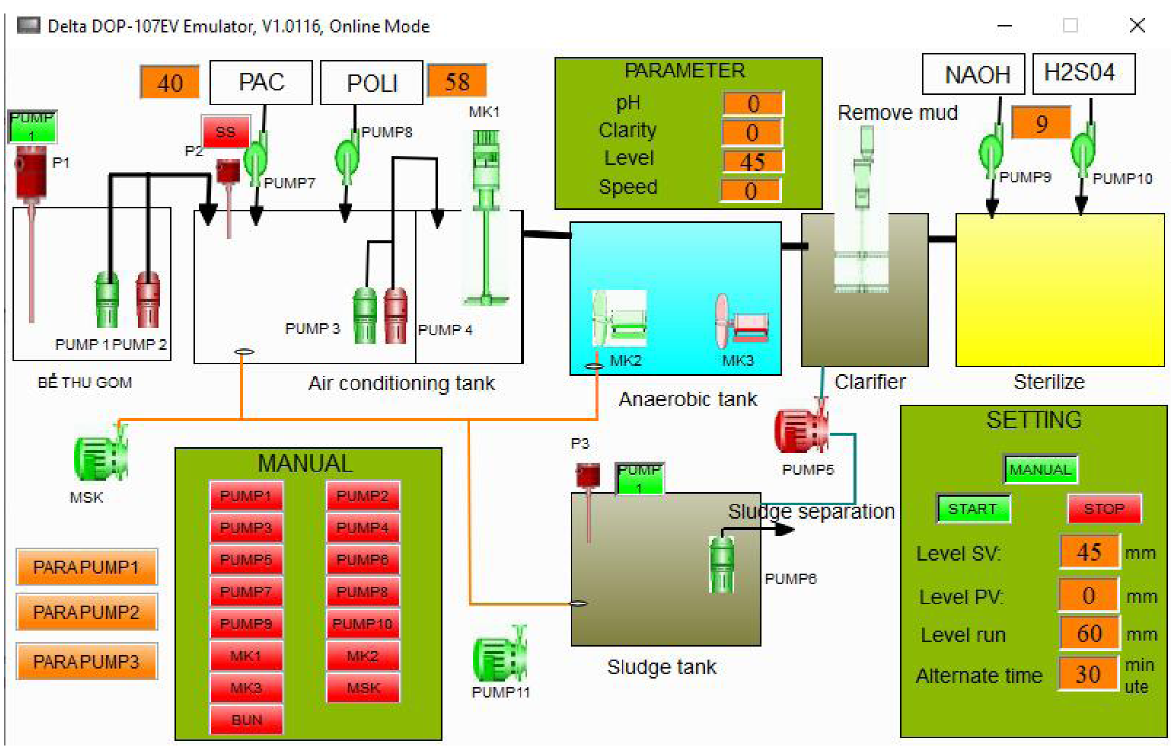

Figure 12. Experimental results of SCADA system at wastewater treatment plant.

If SS P1 is in state 1 (P1=1) and SS P2 is in state 0 (P2=0), then pump 1 and pump 2 are eligible to operate. These two pumps operate alternately according to the set time, progressing. Pump water from the collection tank to the equalization tank to regulate the amount of water. Next, pump 3 and pump 4 in the equalization tank will operate alternately to pump water to the tank where the stirrer is located. If pump 3 or pump 4 operates, MK1 will operate. Pump 7 and pump 8 will operate for x minutes and rest for x minutes (x is the previously set time).

MK2 and MK3 operate alternately. At the sedimentation tank, the sludge scraper will operate for 10 minutes and rest for 5 minutes. The sterilization tank and chemical pumps will operate according to the set time. At the sludge tank, if SS P3 (P3=0) has not yet been activated, pump 5 operates to pump the amount of water and sludge settled at the bottom of the tank to the sludge tank. At the sludge tank, pump 6 operates to pump the unsatisfactory amount of water. The treatment request is returned to the collection tank to continue the treatment process. Otherwise, when P3 (P3=1) is activated, pump 5 stops operating, and at this time, pump 11 operates to pump the sludge to the sludge drying yard for treatment. mud. SS-pH and SS-sludge sensors are two sensors for measuring water pH and turbidity.

At the disinfection tank, pump 9 and pump 10 will pump CLO and NaOH chemicals to disinfect water to meet standards before being discharged into the environment. The aerator operates for 10 minutes and has a 5-minute break to blow air into the tanks in the system.

In case SS P2 is active (P2=1), pump 1 and pump 2 in the collection tank stop operating and stop the process of pumping water to the equalization tank to avoid filling the tank and draining water, when the amount of water is pumped to another tank of the tank. The system reaches the point where sensor P2 is no longer active (P2=0), then pumps 1 and 2 will operate normally again.

In case SS P3 operates, pump 5 stops working and pump 11 operates and will pump the sludge from the sludge tank to the sludge drying tank for treatment…

If an unexpected problem occurs during system operation, the system alarms and the operator presses Stop. After fixing the problem, the system continues to operate again when we press Start.

- IoT communications for wastewater treatment systems

Equipment for selecting experimental configurations in the laboratory is V-BOX H-WF, Server-based https://web.asean.v-box.net

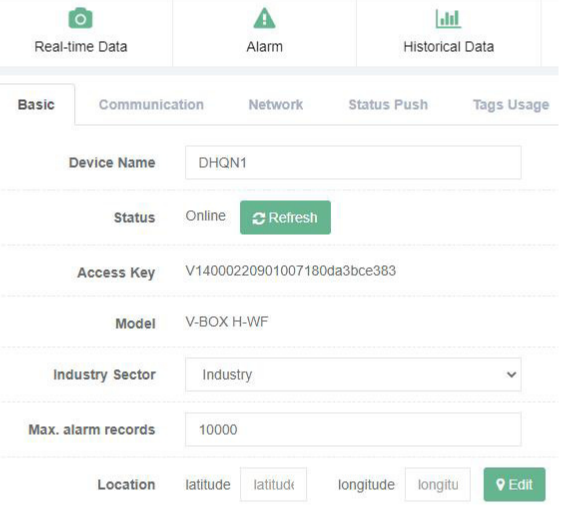

Figure 13. Experimental configuration of IoT communication system.

The monitored parameter is the wastewater level at 12 internal pumping stations. The optimal control algorithm for the pumping system is mentioned in other content. The experimental value is set at 0 - 100 cm, corresponding to the monitored wastewater level and pile pressure so that the control system at the stations can operate 1 - 3 pumps.

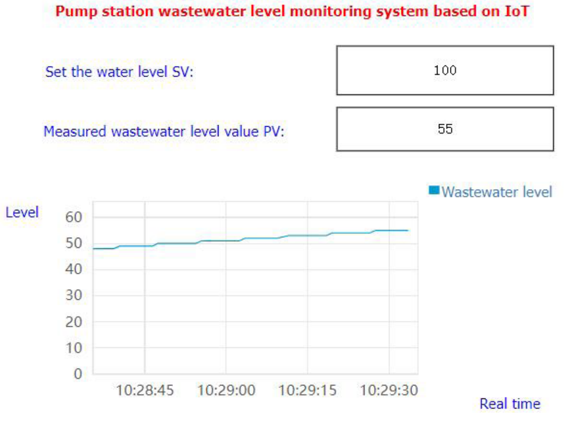

Figure 14. Monitor wastewater levels at pumping stations.

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The results show that controlling remote values through research content works stably. Parameters can be displayed and set remotely via the S7-1200 PLC control system (Figure 14).

3. CONCLUSION

The paper has achieved the following results:

The authors offer a solution to manage the entire wastewater pumping and treatment system for Quy Nhon City.

At pumping stations, the paper proposes to use the Modbus industrial network system to manage pumps and pipeline pressure.

At the central processing plant, the paper proposes to use an industrial Ethernet network system based on the OPC UA platform to manage the processing system and upload data to the Cloud.

It uses industrial IoT communications to link data exchange between the pumping station and the wastewater treatment center.

After the paper's content is deployed, it brings many benefits such as: Increasing system reliability, managing data via Cloud, automatically controlling the amount of wastewater, especially reducing health damage to operators.

Experimental results at the Industrial Network and SCADA Laboratory of Quy Nhon University, the research results of the paper are applicable in practice.

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