A Method for Optimizing Water Quality of the Aquafarm Using Application Independent Digital Twins

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Abstract— **Land-based aquafarm is a method of farming fish on the ground, and the quality of the water has a great influence on the mortality of farmed fish, so the condition of the water in the tank is an important factor. Therefore, it is necessary to maintain the optimal condition of water quality through the analysis of various sensor and control data in the tank. To this end, attempts to improve water quality in land-based aquafarms based on digital twins have recently appeared. In this paper, a systematic interworking mechanism between real and virtual environments is provided to optimize water quality in land-based aquafarms. This systematic interworking mechanism acquires the information of virtual and real space under the digital twin basis using an application-independent common interface. In this paper, a common interface is proposed to enable mutual interworking between virtual simulation and the real world so that it can be used for any application. The information obtained from the virtual and the real space allows the simulation results of the virtual space to be reflected in the real space, and the results are analyzed and fed back to the virtual space so that the real and virtual spaces are optimized.**

Keywords— **Digital Twin, Aquafarm, Optimizing water quality, Application-Independent**

I. INTRODUCTION

Land-based aquafarm is a method of farming fish on the ground and includes a circulation filtration aquaculture method in which water in a tank is circulated and filtered, and a flow-through aquaculture method in which sea water flows and is cultured. Regardless of which farming method is used, the quality of the water has a great influence on the mortality of the fish being farmed, so the condition of the water in the tank is an important factor. Therefore, various sensors (water temperature, DO, CO2, ammonia sensor, etc.) and controllers (oxygen generator, flow meter, etc.) are installed in the tank to maintain the optimal water quality through analysis of the tank environment and control data.

To this end, as part of the recent precision fish farming techniques, attempts are being made to improve water quality in land-based aquafarms based on digital twins. Compared to land-based aquaculture using the existing non-digital-twin, by using the digital twin for water quality, precise aquaculture and economical effects can be achieved by more appropriate frequency of flow or more appropriate oxygen supply

A digital twin is generally defined as technology that identifies the current state of a physical object, responds to changes, improves operations, and imposes value. When applying these technologies to create application systems such as water quality optimization in aquafarms, a dynamic software model in which physical and virtual objects are optimized through real-time synchronized simulations must ultimately be derived.

Achieving this goal is difficult to build with simple individual element technology, and there may be many difficulties in actual implementation with a convergence technology based on various intelligence information and systematic mechanisms. Even if the implemented system is based on the digital twin, there is a difference in implementation level depending on the technology stage.

Currently, it is proposed that the water quality improvement system of many land-based aquafarms is built based on digital twins. However, the actually implemented technology level is mostly a mirroring that replicates a physical object as a digital twin or a monitoring level [1][2] that controls through physical object monitoring and relationship analysis. In addition, even if the physical target is optimized by applying the simulation result, it is difficult to optimize the real environment in real time due to the repeated application of the simulation by static human intervention.

Therefore, a systematic interworking mechanism between the real and the virtual environments is required to optimize the water quality of aquafarm in real time based on the digital twin.

In this paper, a systematic interworking between real and virtual environments is provided to optimize water quality in land-based aquafarms. For the interworking mechanism, an optimal autonomous control engine that can organically reflect the information of the virtual environment to the real environment has been established to autonomously monitor and control the real and virtual environments and optimize the water quality in the real environment.

The systematic interworking mechanism acquires information of virtual and real space through the digital twin that accommodates an application-independent common interface. The common interface (API: Application Programming Interface) in this paper is proposed to make the virtual simulation and the real world interoperate so that it can be used for any application. The information obtained from the virtual and the real space allows the simulation results of the virtual space to be reflected in the real space, and the results are analyzed and fed back to the virtual space so that the real and virtual spaces are optimized.

We describe the related work and the proposed system architecture for optimizing water quality in Section II and Section III respectively. Main components and whole procedure of the proposed mechanism are described in Section IV. Experimental results are also described in Section V. At last, we make the conclusions in Section VI.

II. RELATED WORKS

Currently, it is proposed that many land-based aquafarms water quality improvement systems are implemented based on digital twins, but even if the implemented system is digital twin-based, the level of implementation varies depending on the technology stage. Most of the actual implemented technology levels are mirroring or monitoring levels that replicate physical objects as digital twins. These systems do not consider the digital twin automation mechanism for optimizing the digital twin prediction model.

In the paper [3], a conceptual digital twin was established for DO control, feed control, and fish population management for the purpose of fish growth in a land-based recirculating aquaculture system. The digital twin was applied using a trout farm located in the Trentino-Alto Adige area of northern Italy as a test bed. In order to realize the digital twin, observation, interpretation, decision and action management were aimed. And feed, oxygen and biomass control according to fish growth were targeted. Time series of fish weight gain and oxygen consumption were predicted and applied. However, this method is only a series of procedures for fish growth, and it does not consider the automation mechanism corresponding to digital step 4 for optimizing the growth prediction model by performing it repeatedly.

In the paper [4], an AIoT (Artificial Intelligence based Internet of Things) system was proposed for intelligent fish farming. In order to provide efficient management and remote monitoring of fish farms based on this system, the requirements of a digital transformation infrastructure consisting of a 5-layer digital twin were analyzed. However, this paper is a prototype of a cloud-based digital twin system built based on requirements analysis. Digital automation mechanisms for cost-effective optimization of digital twin predictive models were not considered.

The paper [5] describes the digital transformation problems of companies contributing to the aqua biotechnology industry. In this study, as the first step, due diligence of actual aquaculture industry companies based on closed water circulation technology was conducted. Second, digital models and twins have been developed for biotech plants. Finally, in the field of aquaculture, digital transformation concepts have been developed for different aspects of the functioning of high-tech enterprises. However, this paper only presented a digital transformation model based on the digital twin concept for intensive aquaculture, and did not consider the digital twin for optimizing the digital twin prediction model.

In the paper [6], as part of the iFishienci project, a method was presented to handle the complex digital twin process in the context of a recirculating aquaculture system (RAS) using the Next Generation Service Interfaces Linked Data (NGSI-LD) specification. More specifically, the digital twin for feeding enables the execution of various scenarios, and the simulation system predicts the fish's spontaneous behavior and food intake. Continuous feedback enables decisions to be made in response to the internal and external environment. However, although this paper suggested that the simulation system predicts fish's spontaneous behavior and food intake, it did not consider the digital twin automation mechanism for optimizing the digital twin prediction model.

The paper [7] addressed whether it would be possible to deploy a virtual digital replica of the farm to control essential water quality parameters including temperature, dissolved oxygen (DO), pH, turbidity and ammonia. It uses the monitoring function of the existing IoT system and requires real-time control-based operation. The proposed Planetary Digital Twin uses an AI-powered control loop to monitor, simulate and optimize aquaculture processes and assets. The present experimental results demonstrate the feasibility of a water quality control system that delivers data to an online platform for real-time operation. However, the digital twin automation mechanism for optimizing the digital twin prediction model was not considered.

III. PROPOSED SYSTEM ARCHITECTURE FOR OPTIMIZING WATER QUALITY

A. Proposed System Conceptual Diagram

Fig. 1 is a conceptual diagram of digital twin water quality optimization in land-based aquafarms. It consists of a real space application domain in a real environment, a virtual space application domain in a virtual environment, and optimal autonomous control system that provides a mechanism for optimizing water quality by organically interworking these two spaces. Various types of sensors and controllers that provide information to optimize water quality are installed in the water tank in the real environment to be optimized for water quality.

The virtual space application domain performs a simulation so that the water quality in the tank in the real environment can be optimized in the virtual space using sensors and control information of the tank in the real environment. The optimal autonomous control system proposed in this paper ensures that the environment in the real environment is optimized as the simulation results in the virtual environment are intended for water quality optimization, so that there is no difference between the two environments.

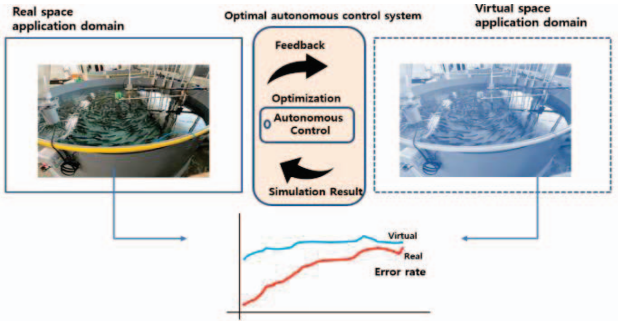


Fig. 1. Digital twin water quality optimization conceptual diagram of aquafarms

B. Application-independent common interface

Fig. 2 is a common interface configuration diagram for systemic interworking between real and virtual environments. The optimal autonomous control engine predicts the real space through simulation of the virtual space application domain and transmits this result information to the optimal integrated autonomous through API (transmission information includes sensor prediction value, controller control request, period, etc.). This information is received and analyzed by the optimal integrated autonomous engine, then mapped to information to be provided to the real space domain and transmitted to the real space domain through the API.

Information received in the real space domain includes sensor values actually measured in real space and control values to be controlled. Information to be mapped is composed of elements in which information in virtual space and information in real space can be interlocked with each other.

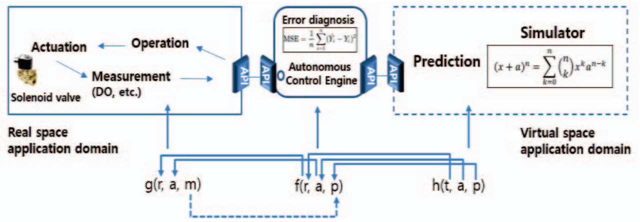


Fig. 2. Configuration of common interface for interworking between real and virtual environments

As shown in Fig. 2, the values that can be obtained as a result of the simulation are the predicted sensor values (p: predicted sensor value, e.g., predicted DO value, etc.), and the controller value (a: actuator (adjustment of the oxygen supply amount of the oxygen supplier) request for solenoid valve control)), and the time (t: period (time series)) of these series of result values.

These values are used as input values for the optimal autonomous engine where interworking mechanisms are performed to reduce environmental errors between the real world and the virtual world. The optimal autonomous engine maps t with real time (r: real time series), and receives a control request, controlled control value, and measured sensor value (m: measured sensor value) in the real world. In this way, the digital twin can be operated using a common interface between the real world and the virtual world and optimal autonomous control that links them.

IV. MAIN COMPONENT AND WHOLE PROCEDURE OF THE MECHANISM

A. Application-independent common interface information flow

Fig. 3 is a common interface information flow diagram between the real environment and the virtual environment. The common interface for systemic interworking between the real and the virtual environments in Fig. 2 can accommodate various applications (i.e., simulation for application #1 (sa #1)) as shown in Fig. 3, so each simulation to be able to do it independently.

Targets for application of digital twin technology for land-based aquaculture include aquaculture optimization of the relationship between food and growth of fish, water quality optimization to improve water quality, and energy optimization to optimize energy in the farm. Other applications in livestock farming, greenhouses, and other industries can build a digital twin using this common interface.

In the case of water quality optimization applications, there are several tanks in the farm, which can be represented as a unit (i.e., unit #1) in the application, and each tank has several sensors and controllers to perform simulations in virtual space. The result of the simulation result, the total time of the time control(t_n), and the predicted sensor value for each period are derived. This information (application number, tank number, controller number and value) is transmitted to the optimal autonomous engine through API.

The optimal autonomous analyzes this information and transmits the information to the real space, which is the controller of the relevant tank (i.e., Oxygen generator) generation value. Oxygen generator is activated or stopped at the corresponding time as requested by the control. This change in the actual space, oxygen is insufficient, then is immediately supplied, and the oxygen concentration is stabilized.

The results in the virtual space are reflected in the real space so that the water quality situation in the tank is optimized, which allows the process of monitoring this situation and feeding back to the virtual space in the optimal autonomous control.

B. Systemic interworking mechanism between real and virtual environments

Fig. 4 is a flow diagram showing the systemic interworking mechanism between the real and virtual environments.

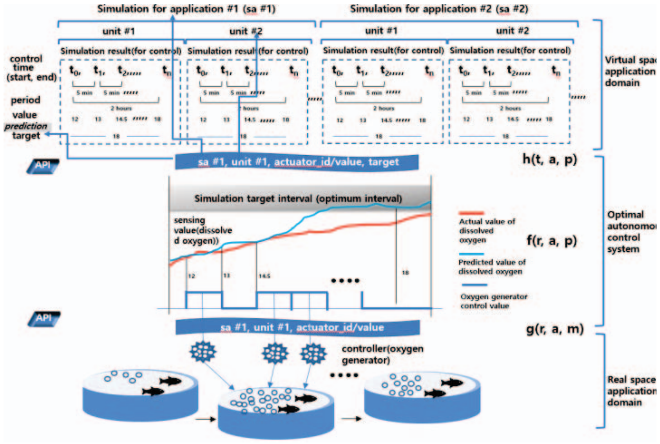


Fig. 3. Common interface between real and virtual environments

In order to minimize the gap between the real and virtual environment, the digital twin delivers simulation results to the optimal autonomous control block in the application domain in the virtual space (Fig. 4 (1)).

In the optimal autonomous system, through the analysis of the result information, it is applied to the actual space (Fig. 4 (2)), and the information of the applied result (Fig. 4 (3)) is obtained and analyzed. As a result, if the actual value and the predicted value of the virtual space exceed the presented threshold range, the result is fed back to the virtual space (Fig. 4 (4)) to perform the simulation again to obtain better results. In this way, the optimization of the real and virtual environment is achieved through a series of systemic interworking mechanisms.

The simulation result is defined by the protocol that transmits the content of the API. It consists of the registration number (register_number), which can be called the identifier of the water quality model, the tank identifier (water_tank_id), and the simulation result (simulation_result). The simulation result consists of the name of the equipment to be controlled (actuator_id) and the control period. When the simulation result is analyzed and delivered to the real space, it is delivered by the protocol that delivers the contents of the API. This includes the control method of the controller of the target water tank.

After the control in the real environment is performed, the actually measured control information and sensor values are transmitted by the protocol, and the feedback to the virtual space for simulation again informs that there is a gap between the simulation result and the real environment by the protocol, and the current feedback information is provided to re-simulate by reflecting the situation.

V. EXPERIMENTAL RESULTS

To test the operation of the systemic interworking mechanism between the real and virtual environment in Fig. 4 above, the test bed was configured as shown in Fig. 5.

For 2000 halibut in a tank with a diameter of 4m, DO sensors and other water temperature and pH sensors are installed, and an oxygen generator is installed next to the tank as a controller. Fig. 6 includes details of the information tables shown in Fig. 5.

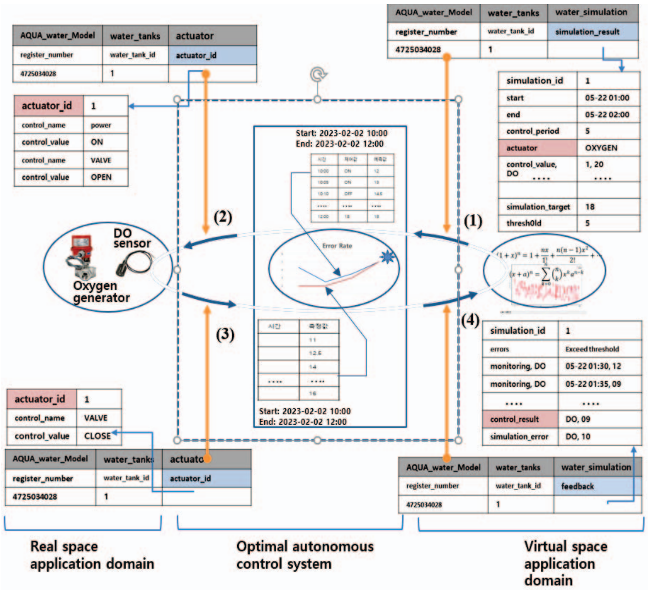


Fig. 4. Flow diagram of the system interworking mechanism between the real and the virtual environments

When the water quality simulation result is received, information is stored in tb_water_sim_result (Fig. 5 1)), which includes, as shown in Fig. 6 1), the time when the simulation result occurred, the controller to be controlled, and the processing status (1: received, 2: processing, 3: processing completed, 4: processing failed, 5: diagnosis completed, 6: feedback), etc. Depending on the simulation results, water quality simulation diagnosis settings are made to diagnose how much the simulation results match the actual site.

The table named tb_water_sim_error_detection_setting (Fig. 5 2)) is a water treatment simulation diagnosis setting information table. As shown in Fig. 6 2), this includes simulation and field match analysis methods (1: DIFF, 2: MSE, 3: MAE), sensor type (1: CO_2, 2: water temperature, 3: pH, 4: DO, 5: ORP, 6: SS, 7: COND), simulation application type (1: water quality, 2: positive, 3: energy, 4: structure), etc.

Table named tb_water_sim_result_controls (Fig. 5 3)) is an information table that controls controllers installed in actual sites according to simulation results, and obtains and stores control and sensor values generated at that time.

As shown in Fig. 6 3), the predicted value and actual measured value of the sensor type according to the control value are stored here, and information about the control result (1: RECEIVED, 2: CPMPLETED, 4: FAIL) is stored.

In this paper, an automatic control request is transmitted through Raspberry Pi relay (Fig. 5 3.1)) to control the oxygen generator, and the actual controller (Fig. 5 3.2)) turns on or off the oxygen generation. Accordingly, oxygen generation in the tank (Fig. 5 3.4)) and generation stop (Fig.

5 3.3)) are executed. The DO value according to this control variation is displayed on the instrument in (Fig. 5 3.5)).

The table named tb_water_sim_error_detection_result (Fig. 5 4) is a water treatment simulation diagnosis (error analysis) result information table. As shown in 4) of Fig. 6, the simulation type (1: water treatment, 2: benign, 3: energy, 4: structure), error analysis method, threshold error value feedback (1: feedback, 0: feedback not) are included.

As shown in Fig. 5 and Fig. 6, the test environment for the systemic interworking mechanism between the real and the virtual environments to optimize the water quality of the land-based aquafarm, which is the purpose of this paper, was configured, and the information data flow through the test is obtained.

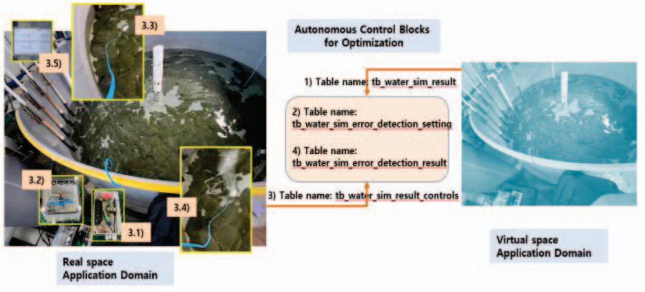
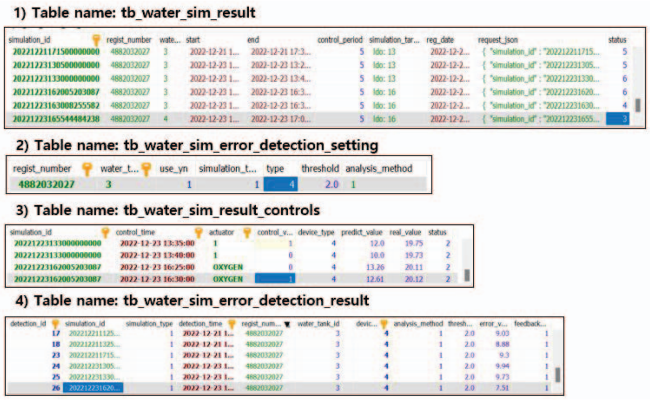


Fig. 5. Real and virtual environments interworking mechanism test bed



1) Table name: tb_water_sim_result

simulation_id	regist_number	wate...	start	end	control_period	simulation_tar...	reg_date	request_json	status
20221221171500000000	4882032027	3	2022-12-21 1...	2022-12-21 17:3...	5	ldo: 13	2022-12-2...	{ "simulation_id" : "202212211715...	5
20221223130500000000	4882032027	3	2022-12-23 1...	2022-12-23 13:2...	5	ldo: 13	2022-12-2...	{ "simulation_id" : "202212231305...	5
20221223133000000000	4882032027	3	2022-12-23 1...	2022-12-23 13:4...	5	ldo: 13	2022-12-2...	{ "simulation_id" : "202212231330...	6
20221223162005203087	4882032027	3	2022-12-23 1...	2022-12-23 16:3...	5	ldo: 16	2022-12-2...	{ "simulation_id" : "202212231620...	6
20221223163008255582	4882032027	3	2022-12-23 1...	2022-12-23 16:3...	5	ldo: 16	2022-12-2...	{ "simulation_id" : "202212231630...	4
20221223165544484238	4882032027	4	2022-12-23 1...	2022-12-23 17:0...	5	ldo: 16	2022-12-2...	{ "simulation_id" : "202212231655...	3

2) Table name: tb_water_sim_error_detection_setting

regist_number	water_t...	use_yn	simulation_t...	type	threshold	analysis_method
4882032027	3	1	1	4	2.0	1

3) Table name: tb_water_sim_result_controls

simulation_id	control_time	actuator	control_v...	device_type	predict_value	real_value	status
20221223133000000000	2022-12-23 13:35:00	1	1	4	12.0	19.75	2
20221223133000000000	2022-12-23 13:40:00	1	0	4	10.0	19.73	2
20221223162005203087	2022-12-23 16:25:00	OXYGEN	0	4	13.26	20.11	2
20221223162005203087	2022-12-23 16:30:00	OXYGEN	1	4	12.61	20.12	2

4) Table name: tb_water_sim_error_detection_result

detection_id	simulation_id	simulation_type	detection_time	regist_num...	water_tank_id	devic...	analysis_method	thresh...	error_v...	feedback...
17	202212211125...	1	2022-12-21 1...	4882032027	3	4	1	2.0	9.03	1
18	202212211325...	1	2022-12-21 1...	4882032027	3	4	1	2.0	8.88	1
23	202212211715...	1	2022-12-21 1...	4882032027	3	4	1	2.0	9.3	1
24	202212231305...	1	2022-12-23 1...	4882032027	3	4	1	2.0	9.94	1
25	202212231330...	1	2022-12-23 1...	4882032027	3	4	1	2.0	9.73	1
26	202212231620...	1	2022-12-23 1...	4882032027	3	4	1	2.0	7.51	1

Fig. 6. Real and virtual environment interworking mechanism result data tables

VI. CONCLUSIONS

In this paper, a systemic interworking mechanism between the real and the virtual environments was provided to optimize the water quality of land-based aquafarms. To this end, an optimal autonomous engine was built to autonomously monitor and control the real and virtual environments to optimize water quality in the real environment. Through the test bed, the operation of the systemic interworking mechanism between the real and the virtual environment was tested, and the information data flow was obtained through the virtual simulation of information and the mutual interworking test of the real world's site through the common interface.

In relation to this paper, it is currently being tested whether optimization of aquafarm water quality can be achieved through an application-independent digital twin. In the water quality simulation, the simulation results are given, and based on the results, the integrated autonomous block acquires the field controller control and sensor values. Through this, we are testing to minimize the difference between the actual sensor value and the predicted sensor value. Through this, it will be possible to prove that the proposed mechanism is an excellent technology in terms of performance.

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