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PLC-based design of monitoring system for ICT-integrated vertical fish farm

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Abstract
The common cause of the mass mortality of fishes in a fish farm is a power failure. There can be many reasons for the power failures but most of them are the result of natural disasters, systematic faults, ill-willed sabotages, or mistakes of employees. Such incidents usually have a bad influence upon small or medium-scale farmers. To deal with unexpected power failures, this research proposes a status monitoring system utilizing both PLC and ICT. Consistent supply of electric power in Fish Farms is essential for the operation and management of farm facilities regardless of them being indoors or afloat. The statistics show that the power failure and the red tides are the major causes of ruining farmer's earnings. The proposed system is autonomous and simple enough for the employees to operate such that prompt actions can be taken in times of crisis. There have been some concerns about applying the PLC technology as it often involves loss of transmission signals. To minimize signal losses, use of RUDP in the transmission layer was proposed as well. At the same time, a GUI-based operational mode has been embedded in the Android application to enhance user convenience for observing and managing farm's activities such as controlling of seawater and farm accesses and checking locations, photoperiods, withdrawal periods, and system's batteries. The proposed design can be quite suitable for the Vertical Fish Farm.

Keywords: Energy harvesting, PLC, Vertical fish farm, Fish farm, Solution

Background

Establishing a fair market order is essential and a priority to achieve 'Creative Economy', which is a current main policy direction of the government of the Republic of Korea (ROK). This idea is to give small and medium-sized companies the opportunities to compete fairly with larger firms and be successful. Such coexistence will encourage those companies in an unfavorable situation to exert their best efforts. Implementation of the idea involves elimination of unfair practices, traditional bureaucracies, and demands a new way of thinking. Despite of recent rapid growth of the ROK's aquaculture industry, such an idea is yet to be realized as there are still many administrative restrictions and the mindset of farmers is too conservative so that they are reluctant to deviate from the old way of operating their farms. 'Creative Economy' requires a creative thinking. Although the government is trying to support small farms by enforcing more favorable policies, they wouldn't be effective if these supporting measures are not based on feasible and practical plans. Use of an advanced technology can be a solution. In this case, using the PLC (Power Line Communication) and ICT (Information and communications technology) technologies for fish farms will be one of the most efficient ways of improving out-dated operation and management systems at the farms. This study focuses on the power management. Electric power is vital for the farms as they use much power for culturing so that power failures can be devastating and often farmers suffer a great loss. Power management is especially critical for the indoor vertical fish farms as they have to continually re-circulate seawaters or pump them into their tanks [1, 2] to prevent mass mortality. The proposed system will be able to deal with every operation and emergency at the farm as far as electric power is concerned. Continuous power monitoring and warning system will be used effectively to prevent possible future accidents. RUDP was used as a standard transport layer protocol to minimize signal losses resulting from the noises often generated in the PLC systems.

Related research

Power line communication

The commercialized PLC systems exert a speed up to 1 Gbps for both home and multimedia use [2–6]. However, the problem of noise due to electromagnetic waves still remains as a major demerit of these systems such that in most cases, transformers are used to solve the problem. The PLC technology is being adopted the IoT-oriented homes to control household appliances by using telephone or power lines. The major advantage of using this technology is that not much additional works are required to install the PLC system, which means no extra installation of communication circuits. Two of the exemplar components in such a system are the attachable/external PLC modems developed by Energy Korea Co., Ltd. (ROK) for the watt-hour meters and the PLC-based broadcast module developed by Korea Electro Technology Research Institute. Both products demonstrate convenient and accurate performances. There is no doubt that the PLC technology will be used more widely in the future but the problem of noise has not been solved completely yet. Therefore, use of RUDP in a transport layer was proposed in this study to increase reliability of communications by reducing noise generation.

Reliable user datagram protocol

Reliable User Datagram Protocol (RUDP) was used in the transport layer to minimize transmission failure and data loss due to noises consistently present in the PLC systems [7, 8]. RUDP exhibits stable and relatively faster performances when used for the PLC systems. To validate its effectiveness, simulations were carried out in the preceding study along with performance evaluations [9]. The results are shown below.

$$\sum_{t=0}^{n} \frac{\partial P_{TCP}}{\partial T} = 0.99 \tag{1}$$

Sum of the time-derivatives against received packet volume when TCP is used.

$$\sum_{t=0}^{n} \frac{\partial P_{UDP}}{\partial T} = 0.97 \tag{2}$$

Sum of the time-derivatives against received packet volume when UDP is used.

$$\sum_{t=0}^{n} \frac{\partial P_{RUDP}}{\partial T} = 0.98 \tag{3}$$

Sum of the time-derivatives against received packet volume when RUDP is used.

Although TCP (Transmission Control Protocol) has the best speed, UDP (User Datagram Protocol) is used often instead as TCP has some vulnerability in security. The speed of RUDP has been improved recently so that RUDP has been proposed to compensate noise-oriented transmission losses.

Vertical farm

"Vertical Farm" is an alternative farming system invented by Prof. Dickson Despommier [10–14], Columbia University in 1999 [10] to solve the problems of shortages of food and farmlands. This system allows farmers to grow their products regardless of weather conditions by controlling lights, water, temperature and humidity. It's often referred to as a "Plant Farm" as well. For the agricultural sector, the test bed experiments were completed in Japan, US and Europe, where some of their firms have entered into the business stages whereas the livestock sector is actively studying the system together with some pharmaceutical companies.

Figure 1 shows an example of vertical farm. This paper considers selection of a suitable site. In theory, Prof. Despommier's system [10–14] can crop thirty times a year in the city area and grow plants as much as one needs no matter what the weather conditions are (e.g., droughts, floods and typhoons, etc.).

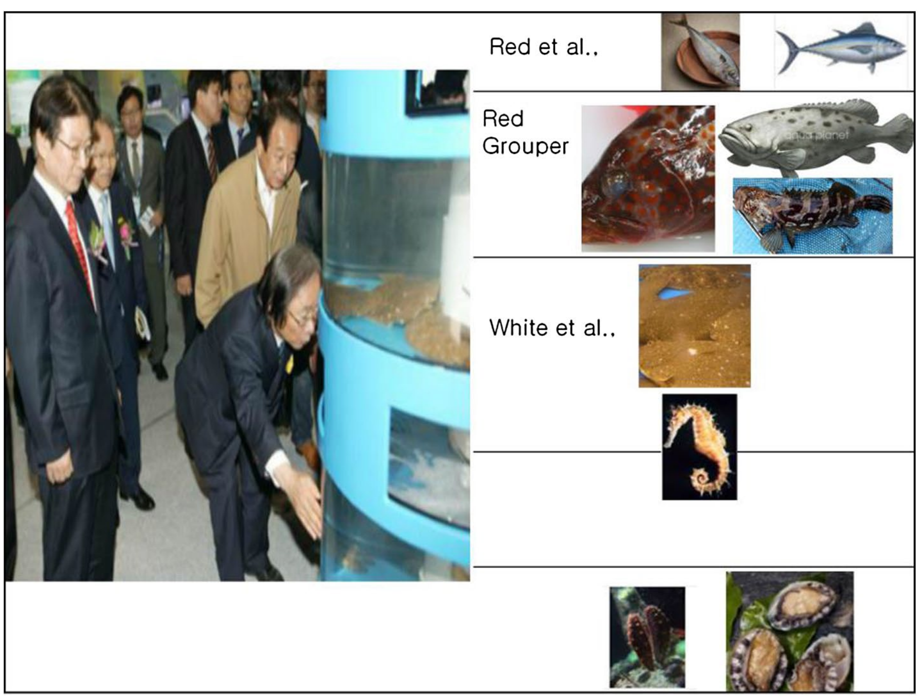

Fig. 1 Example of vertical fish farm

This "Future Farming" in times of abnormal climate changes uses LED lights instead of sunlight and sprinkles nutrient-mixed sprays on the roots instead of soaking them in the water. According to the simulations, it is possible to grow enough foodstuffs to feed around fifty thousand people with a thirty-story farm.

System design for ICT-integrated vertical fish farm monitoring and its solution

The system design and its Android application have been developed by integrating ICT on a PLC network. The study proposes a framework for the monitoring system as well. These two tasks were carried out based on the author's preceding researches [15–20]. As shown in (Fig. 2), the test bed was constructed based on the scenarios in four layers among seven OSI layers.

In datalink and physical layers, two scenarios have been respectively implemented during the period of 2 years to devise a more reliable 220 V (Korea's standard voltage)-PLC system. Their performances have been tested through the test bed experiments. In the application layer, a Java-based application was developed to monitor each section of the farm. For the application, the algorithm used in author's previous study (cf. Medicine-Intake Notification System) has been embedded. In parallel with the release of this journal article, a patent will be applied and the technical details will be disclosed as an open-source technology.

Overall configuration of the proposed system is presented in (Fig. 3). For the vertical fish farms, human-oriented mistakes and intentional obstructions are the major causes of financial loss, bringing much more damages to the small-scale farms. Such a risk can be reduced by introducing the ICT in their farms for continuous monitoring and equipments control purposes.

Employee monitoring

The farm management can monitor the performance of their employees by providing the personal tags for them. The tags were originally developed for a theft-prevention purpose but they have other functions as well. For example, they can be used to track whereabouts of their employees, how they are performing their tasks, or what are their attendances

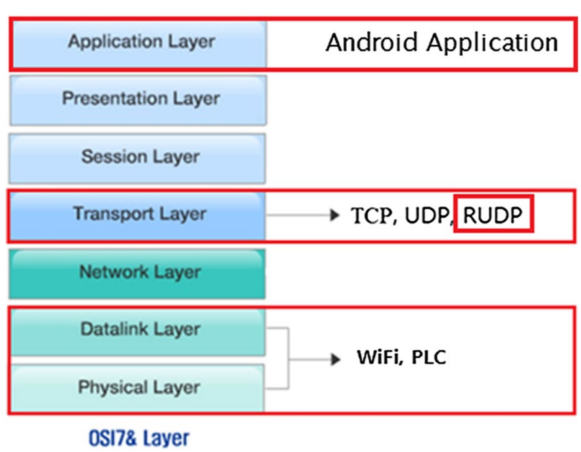

Fig. 2 An android application and the framework for monitoring system

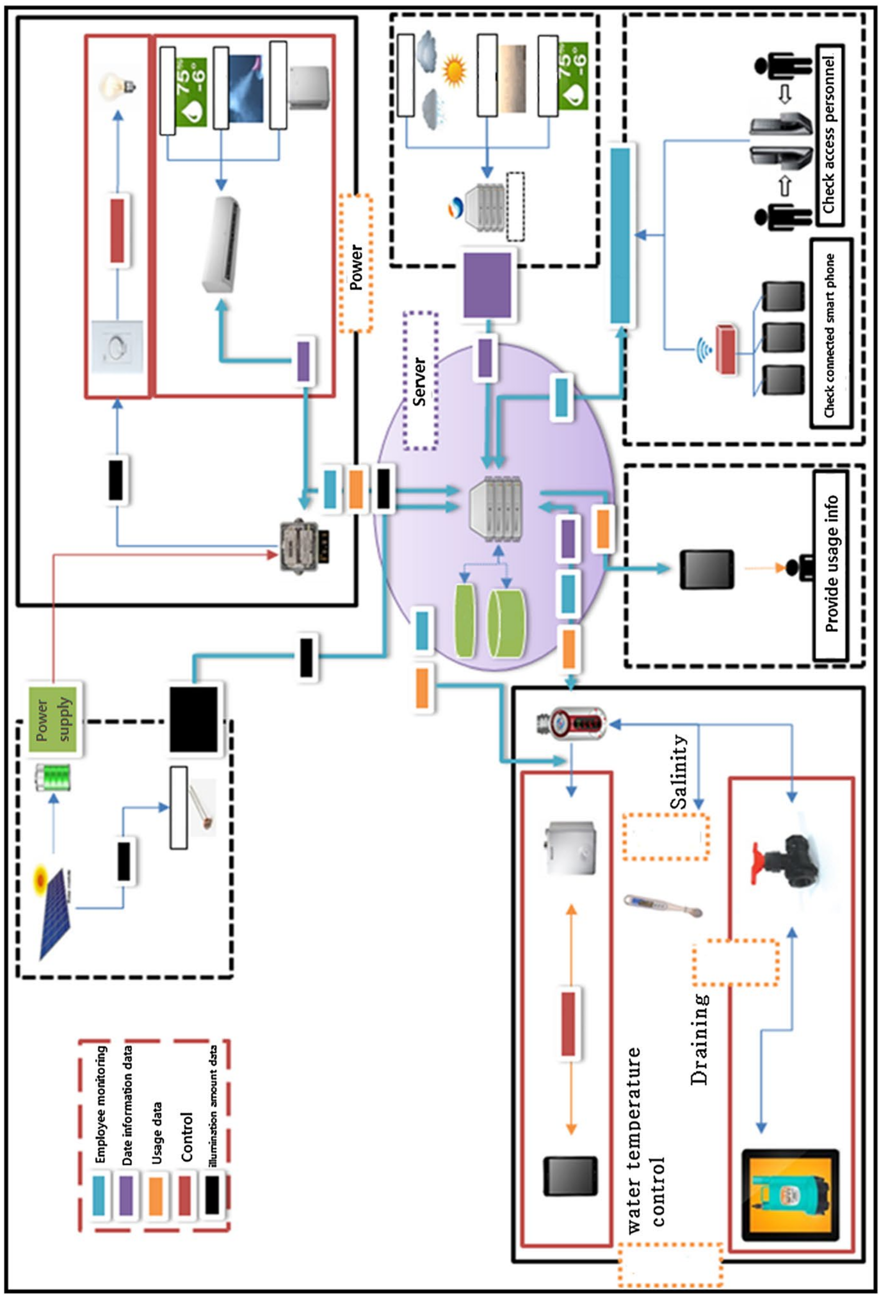

Fig. 3 A system design for ICT-integrated fish farm monitoring and its solution

are. While the management can have such advantages, employees will also have some benefits as well. That is, they can be warned of emergencies, check their working days or absences conveniently to calculate their wages. This can reduce monetary complaints and also secures the safety of employees. A part of technologies used for the proposed system was originally designed for the electronic auto-lock system where wireless AP (Access Point). Considering the reliability and efficiency of the system, RUDP was used as a transfer protocol. Both C and C++ languages were used for coding while Java was used for the implementation. One of the distinctive features of this system is that the communications between equipments are established solely on a power line(s) so that additional device (or circuits) installation works can be minimized. Now that almost all the fish farms can use the electric power supplied by the Korean Electric Power Corp. (KEPCO), they can also construct an individual PLC network conveniently without much cost. Figure 4 describes the main algorithm of this employee monitoring system.

Embedding the employee monitoring algorithm in a positioning system will allow convenient monitoring of individual employee's performance while preventing accidents and thefts in the farms. At the same time, such a system can secure employees safety by assessing present danger or anticipating imminent disasters and informing them to take some adequate preventive measures. System's monitoring process is described in Fig. 5.

As the population in most fishing villages is aging rapidly, most of the workers in the nearby fish farms consist of relatively old people who could fall into some dangerous situations more easily than the younger workers as they lack endurance. This is true especially during the summer time when the number of heat-oriented illnesses usually

A_p: Address accessed in the past

A_n: Current address being accessed

$$f(x) = (\sum Number(A_p) - \sum Number(A_n))$$

//Comparison of the numbers of the past and current addresses approached

if $f(x) = 0$ //If the numbers are identical

  if $\sum Time(A_n) \geqq 1Hour$ //If the current approach time exceeds 1 hour

   Then Warning Message transmission to the User's phone

   Not $Return(f(x))$ //Return to f(x) comparison

Not $(= f(x) \neq 0)$ // If the numbers are not identical

  if $\sum Number(A_n) \geqq 2(= g(x))$ //Assume that the number of current //approaching address is 2 or more

  Then $Return(g(x))$ //Return to g(x) comparison

  Not

  if $\sum Time(A_n) \geqq 0.5Hour$

//If the current approach time exceeds 0,5 hour

   Then Visitation request message transmission to the User's phone

   Not $Return(f(x))$ //Return to f(x) comparison

Fig. 4 The core algorithm of employee monitoring system

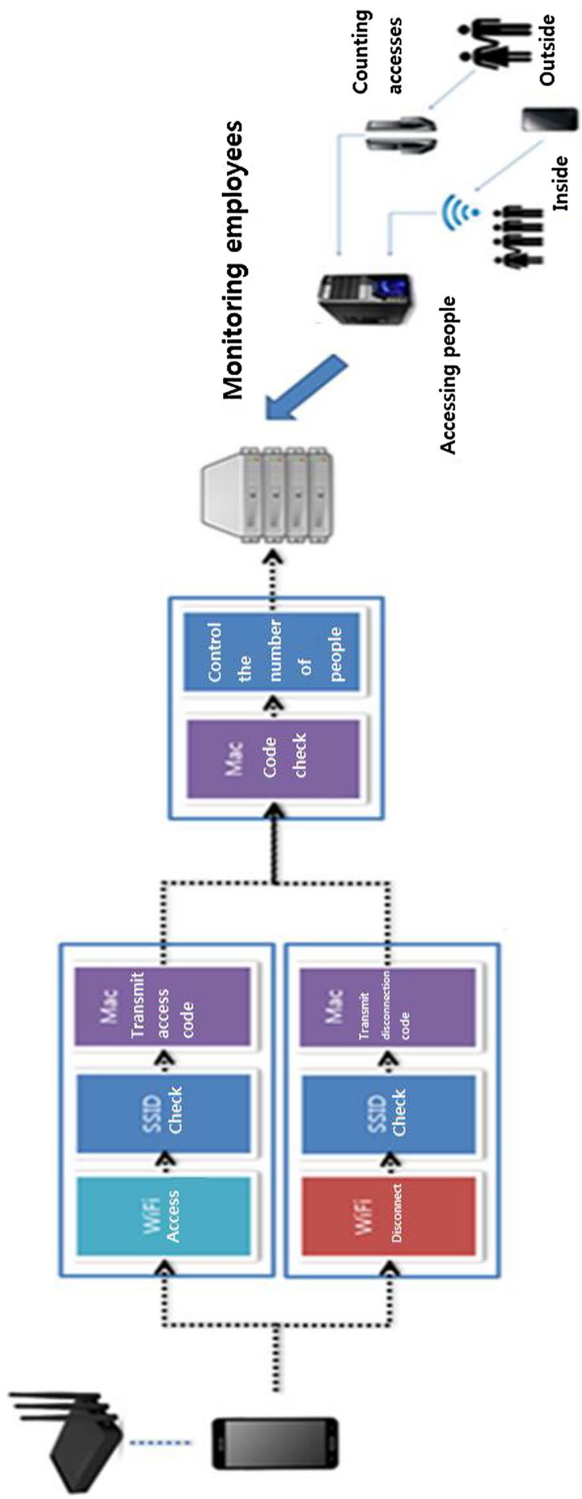

Fig. 5 A method of monitoring employees

increases. The system with the proposed algorithm can prevent such indents as it can routinely check their movements. Once the system determines that a worker is not shifting his/her present position for a certain period of time, it assumes that he/she is either taking a rest or in danger.

Full-grown marine products at fish farms are shipped out to markets seasonally to get better profits but these periods could be the most vulnerable time as the major portion of thefts or accidents occur during these periods, resulting in a great loss for the farmers. The traditional theft prevention systems used by the farmers require expensive installation costs as they include many system devices or equipments and can be installed by the experts only. On the other hand, the PLC-based systems like the one proposed in this study require a relatively small installation cost and offer better performances. The authorized employee (or visitor) tags allow farm managers to check their employees' access situations so that they will be informed of accesses of ones with unauthorized tags immediately through smart phones or other portable devices. Then, the precautionary measures can be taken to prevent possible theft.

Farming environment monitoring

Various factors must be balanced within an appropriate environment when culturing marine products. For the ocean cage-fishing farms, seawater temperatures, weathers, currents and tides should be considered while for the land-based farms, water temperatures, pH and salinity are the important factors. Especially the latter is often influenced by the temperature changes caused by nearby factories who use seawater as a coolant or by the changes in salinity within the tanks resulting from salty substances carried from the seaside, leading to mass mortality of fishes and shells. Since these changes cannot be recognized visually, it is difficult for the small and medium-sized fish farms to check them. Even a little change can present much risk and if they accumulate, a greater damage can be expected [1]. Figure 6 shows a farming environment monitoring process.

However, it is possible to check these changes immediately with the proposed application and by setting the checking categories to issue an alarm, farmers will be able to prevent damages and reduce manpower for a monitoring task. At the same time, by creating a database for the fish diseases and intelligently operating the system, relevant information can be sent to nearby marine disease control center, the Ministry of maritime

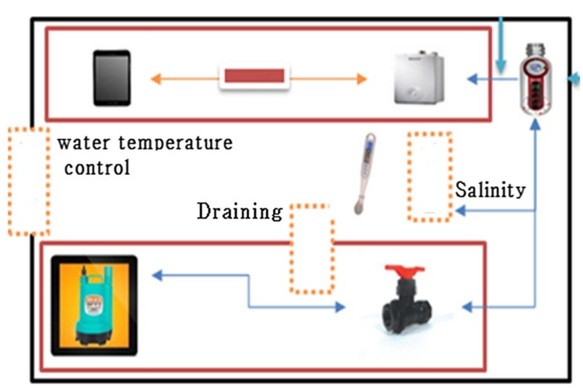

Fig. 6 Farming environment monitoring

Affairs and Fisheries, or National Fisheries Research and Development Institute for speedy feedbacks to prevent damages beforehand.

Management of photoperiod

Spawning and cultivating fishes can be controlled by adjusting the water temperatures and photoperiods. It is possible for the fishes to spawn and grow faster with a "long-day treatment (lengthening of photoperiod with artificial lights)", especially for the flatfish for which the photoperiod is more effective than the temperature. If the photoperiod can be controlled with an automatic light adjustment system through the application, the number of fishes will be multiplied much faster.

Aspects of energy and environmental conservation

Auxiliary batteries and solar cells

As always, typhoons during the summer are the major concern of fish farmers as power interruptions caused by them can be fatal to their farms. Even a short period of interruption can result in entire mortality within the farm so that farmers prepare for the emergency situations once a typhoon alert has been issued. To deal with such a situation, the auxiliary batteries, which can be charged at dawn and used in the daytime during which the same batteries can be re-charged through solar cells, can be considered. Farmers will be able to store the charged power within the batteries 24 h a day to get ready for unexpected or notified power interruptions to reducing damages [1]. Figure 7 shows auxiliary batteries and solar cells.

Controlling withdrawal period

Despite of current developments in the fish culturing technologies, using antibiotics for marine products is still unavoidable. Usually, the safety of these products is secured by making sure that they will be shipped out after their withdrawal time. Nevertheless, it is true that sometimes such a process is being ignored intentionally for the monetary purpose or by mistake as there are many antibiotics being used these days and their usages can be quite confusing, even with a periodical training. One of the distinctive features of

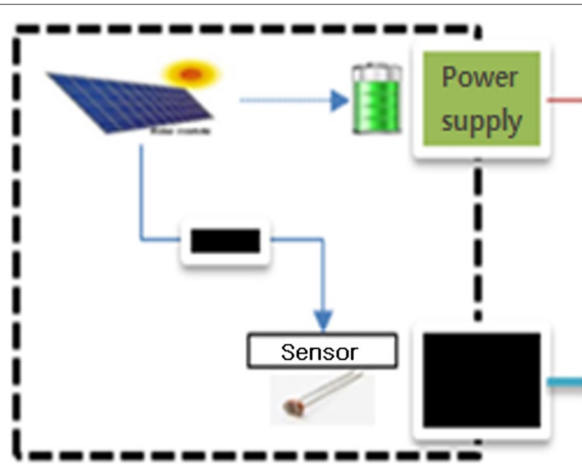

Fig. 7 Auxiliary batteries and solar cells

the proposed system is that the contents of 'A Guide to Medicines for Marine Products' (Korea National Fisheries Research and Development Institute, 2016) are included in a system database as a reference so that the system recognizes what kind of a drug and how much of it has been administered and then notifies the user by alarm after its withdrawal time has passed. This function will surely improve the brand image of farmer's products. The management of seawater temperature and the level of dissolved oxygen in the seawater is critical for the fish farms but the workers or even managers often forget to check these as they have other chores to attend. It is almost impossible for those workers in a small-sized farm to continuously check these two elements so that in many cases, accidents happen abruptly and the responses are usually late. Figure 8 shows a database design for controlling the withdrawal period.

The two most important elements for aquaculture, dissolved oxygen and temperature, should be consistently observed and managed but in many cases, employees at the site are unable to cope with emergency situations associated with these elements. Figure 9 shows a design of proposed Android application.

The menus in this application are Fish Farm Management, Access Control, Positioning, Withdrawal Period Checking and Auxiliary (Ancillary) Battery. The first category is used for the management of photoperiods and seawater elements such as Dissolved Oxygen (DO), pH and temperatures. Access Control monitors and controls farm accesses to prevent theft and accidents. Warnings will be sent to the user's smartphone once an unauthorized person enters the farm. Positioning, which locates the positions of employees in real-time, can be used to issue a warning in times of emergencies or give some working orders. Withdrawal Period Checking informs the user the last day of the withdrawal period through alarm so that he/she can take further working steps. Finally,

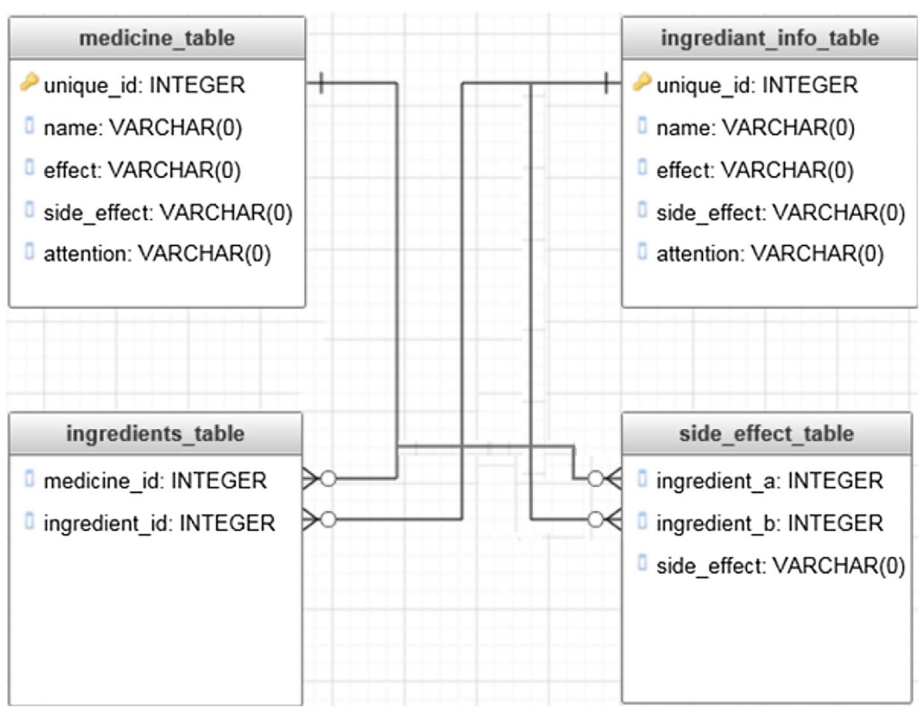

Fig. 8 A database design for controlling a withdrawal period [20]

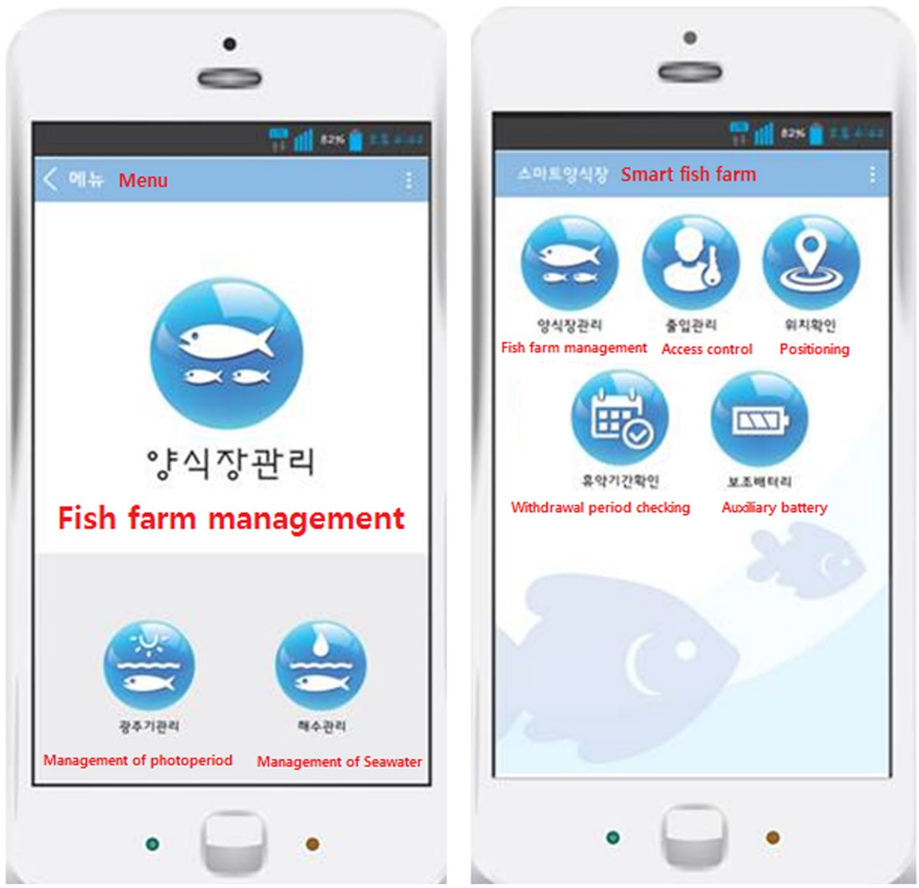

Fig. 9 Design of fish farm android application

Auxiliary Battery lets the user to check remaining battery power so that he/she can recharge it or find an alternative power source to get ready for the emergencies when the farm's power fails.

Comparison with other system

The term 'Blue Revolution', which refers to the revolution of the Aquaculture industry, was first introduced in an UK economic Journal 'The Economist [21]' in 2003 and derived from the original term 'Green Revolution' that had led to a dramatic increase in the output of agricultural produce. Although The Economist has forecasted that the mankind would obtain marine products through aquaculture industry fulfilling the Blue Revolution by 2030, the current aquaculture industry of the ROK is still at the early stage of such a revolution [21, 22].

One of the futurologists anticipated in his report [21–23] that following the rapid increase in global demand of marine products, the aquaculture business would become a high value-added business as other cutting-edge technology-based industries and emerge as one of the major industries in 2018. The report also predicted that the volume of cultured marine products would exceed more than 50% of entire marine products starting from 2015, and due to their continued price increase and demand, the global market size for the these products would reach around one trillion US dollars. Thus, the relevant ROK government agencies have been conducting various researches and pilot projects pertaining to the 'u-Farms' (Urban Farms).

The major methodological difference between the government-oriented researches and our idea is that we have introduced the Power Line Communication (PLC) technology into our proposed system design. The concepts used in this study have been validated through a number of prior articles and theses presented at the conferences and published on journals [15–20].

RFID/USN-based high-quality marine product production support system

Construction of this system started in 2008 for the cage-culturing farms nearby Tongyeong-city, Gyeongsannam-do prefecture, aiming to increase income of aquaculture farmers, merchandise globally competitive marine products, and improve consumer trust. The goal of this project was to convince consumers that what they are consuming is safe and reliable by utilizing the RFID/USN technology to perform an adequate production process management and establish a data linkage throughout entire process [24]. Figure 10 shows a fish attached with the product developed at that time.

Some major contents of the project included a USN-based production management system for the cage-culturing farms, RFID-based traceability management system for fisheries port markets, integrated management system (portal site) for live-fish safety information, trace data, etc.

First, the USN-based cage-culturing production management system performs management of basic overall information of the farm in addition to arrival/shipment information management for both young and full-grown fishes and monitoring of growth/development environments. Second, the RFID-based traceability management system manages production information, reseller's inventories, transaction information of distributors, live-fish arrival/shipment/transport information. Finally, the integrated management system (portal site) performs the activities such as business promotions, management of bulletin boards for consumers and users, as well as data linking with the Ministry of Food, Agriculture, Forestry and Fisheries (MIFAFF).

The results of the project regarding distributors, sales, and consumers can be checked with the system. The benefits for the farmer were as follows.

- A scientific achievement was confirmed with continuous monitoring of underwater and external environments of the cage-culturing site by using the acquired data to improvement productivity.
- It was possible to reduce farmer's facility operation costs based on the records (data) pertaining to production management and facility maintenance status.
- A comprehensive decision making was possible with the data including the record of young fishes purchase, shipment of full-grown fishes, as well as monitoring results of growth environment.
- Farmers' ability to cope with the crisis had increased. For example, a prompt notice regarding the change in seawater with SMS messages helped farmers to handle the situation much faster than before.
- Lastly, farmers were able to check the problems of their farms through underwater cameras and CCTV monitoring.

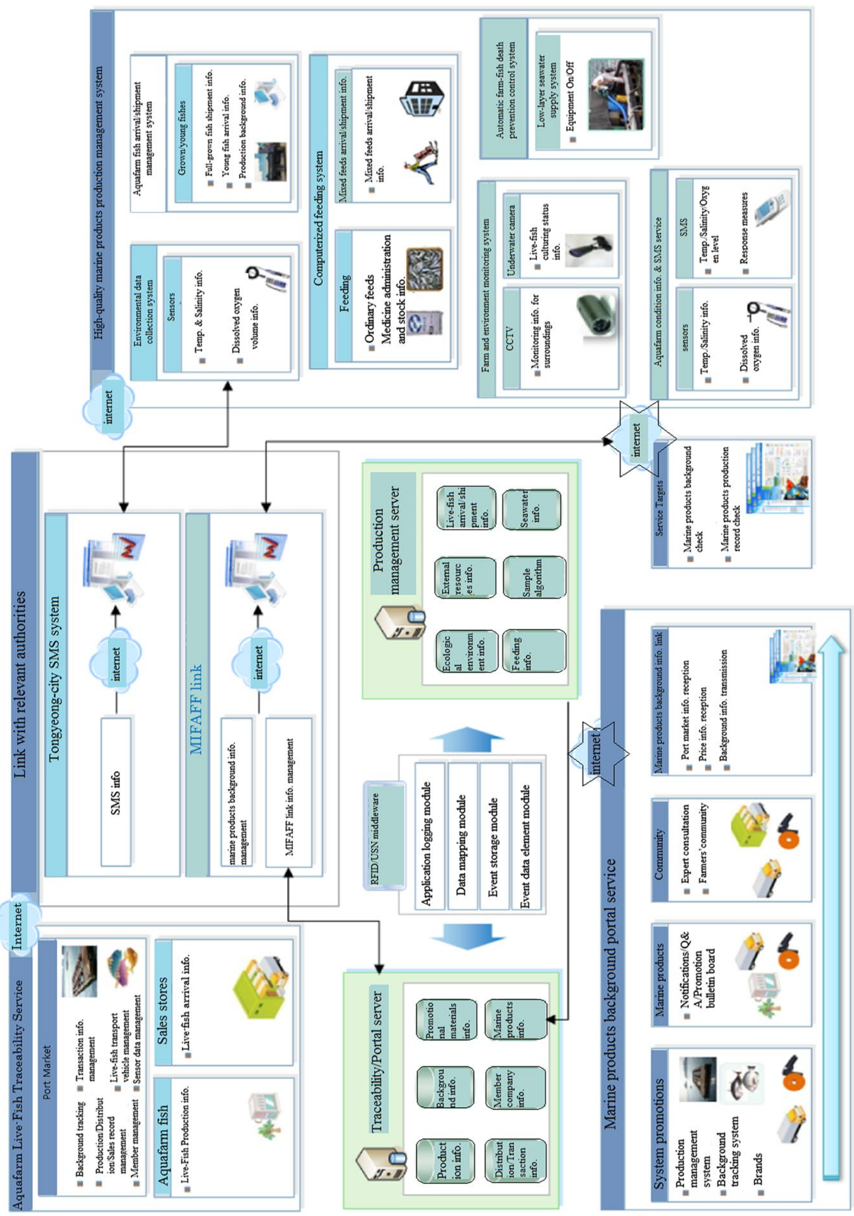

Fig. 10 A fish attached with the product developed at the time

The major benefit for the distributors was an actual increase in their sales volume through demands of high-quality live fishes and transparent distribution process. Their reliability had improved with issuance of credible Country of Origin (COA) for the fishes shipped and it was possible for them to improve their earnings by using the statistics showing them accurate sales volumes and profits. Moreover, farmers were able to check an appropriate time and price by securing current sales and price status of entire nation's port markets though the information linkage with the MIFAFF. Finally, the real-time availability of water temperature and dissolved oxygen of fish-delivery vehicles allowed them to minimize the loss during transportation.

From the resellers' stance, their reliability and sales were improved by providing consumers with high-quality fishes with credible COA's, as well as entire records in distribution process. Such trust-worthy information led to consumers' trust while improving their earnings.

In general, it was expected that consumers would be able to enjoy a healthy diet as the proposed systems could minimize distribution of substandard fishes and offer accurate production/delivery information to promptly cope with crisis.

High-quality u-aquaculture support system in clean waters of Jeju Island

This system, which was constructed in January of 2009 in Jeju Island, is to automatically collect and manage production information including manufacturing of mixed feeds, feeding process, etc. by using RFID/USN technology for the aquaculture industry. RFID tags are attached on the fishes to provide the same information to consumers. The system allows consumers to check the information with attached RFID tags. A real-name production system was implemented to provide production information to consumers and such a measure allowed consumers' confidence on the Jeju-produced aquaculture products to be improved while securing industry's competitiveness following the market-opening pressures from FTA and other trade agreements, promoting the image of clean Jeju globally [25]. Figure 11 shows the high-quality u-Aquaculture support system in clean waters of Jeju Island. Figure 12 shows monitoring tags.

Construction project of u-aquaculture farm in Tongyeong and Maritime Disaster response system

The u-IT pilot project was implemented for six aquaculture farms nearby Tongyeong-city in 2010. The project was comprised of tasks such as improvement of growth and development management system of existing RFID/USN-based high-quality production support system, construction of the farm-protection and emergency alarm service systems using CCTVs and intrusion detection sensors, and establishment of the disaster observation and response system by linking with it weather information and the real-time seawater pollution observation system.

Some of the major performances include improvement of farm management by securing farm's operating information and monitoring theft and disaster events, establishment of disaster protection system with CCTVs, intrusion detection sensors along with the operation of bottom-layer seawater supply system, and construction of real-time monitoring and notification service system using smartphones.

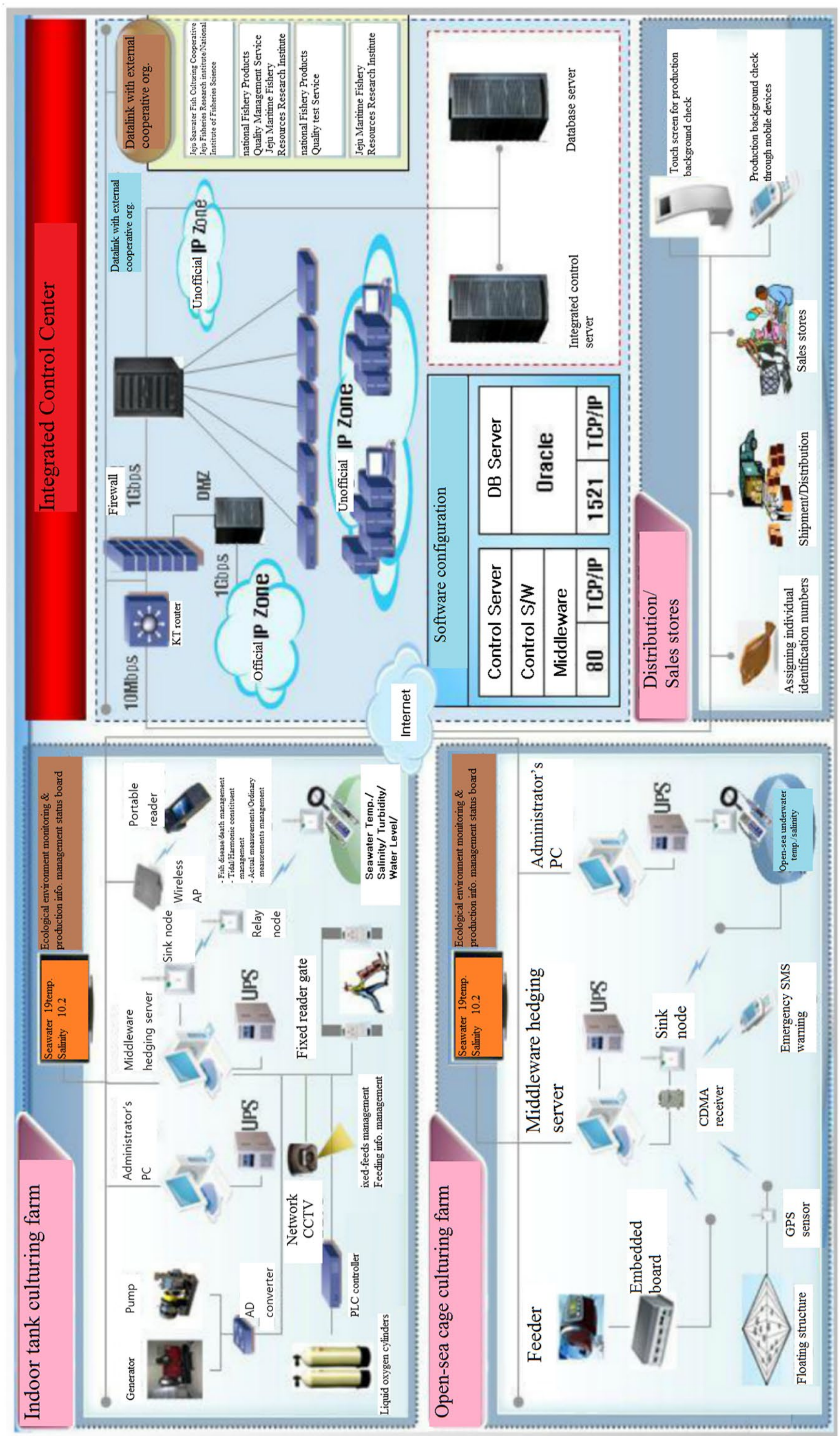

Fig. 11 High-quality u-aquaculture support system in clean waters of Jeju Island

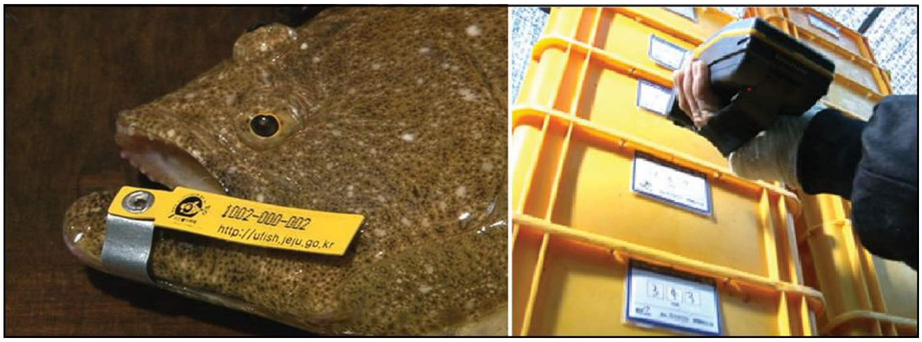

Fig. 12 Monitoring tags

This project was divided into five areas: First, object was to provide farmers with a distribution-model software package which allows an efficient and practical real-time monitoring of seawater environments. Second, the problems in existing growth and development management system were fixed through improvement of u-Farm growth management system software. Third, the real-time intrusion detection and theft prevention system was constructed to protect the standardized u-farms to give warnings. Fourth, by linking all the seawater environment information systems installed at the farms, the real-time farm disaster forecasting/warning system network was constructed. Finally, in order to respond to seawater pollutions, the systems were designed to provide the information regarding the low-layer seawater supply system (equipments) and the possibility of future crisis to the relevant authorities and the farmers.

The resulting effects of the introduced u-IT technology in this project can be found in four areas. First, computerization of farm management process led to the increase in efficiency. The task of managing aquaculture farms was considered as a 3D-work till then as it required much hard physical work and systematic management was not easy. Computerization and automation of management process largely contributed to the farmers' earnings and work efficiency. Figure 13 shows construction project of u-Aquaculture farm in Tongyeong and maritime disaster response system.

Second, construction of an efficient and adaptable farm protection system was possible with a network of CCTVs, intrusion detection sensors, along with low-layer seawater supply equipments. By directly installing the protection system on the Fish farms, those facilities previously unprotected by existing systems were covered. Such a platform system can be utilized for the disasters occurring nearby waters. Much useful information (e.g., real-time images and sensor data) were provided to the relevant authorities and farmers through smartphones and websites in order for them to take some precautionary measures.

Third, the real-time provision of data including seawater temperatures, dissolved oxygen levels, weather information and tides were possible. Supplying such information vital to the farmers through software applications and internet sites in real-time was the first global attempt so that this research might be able to provide an important basis for future application development.

Fourth and last, introduction of the u-IT technology for the Fish farms is quite meaningful that the all the involved systems are ubiquitous. There have been various

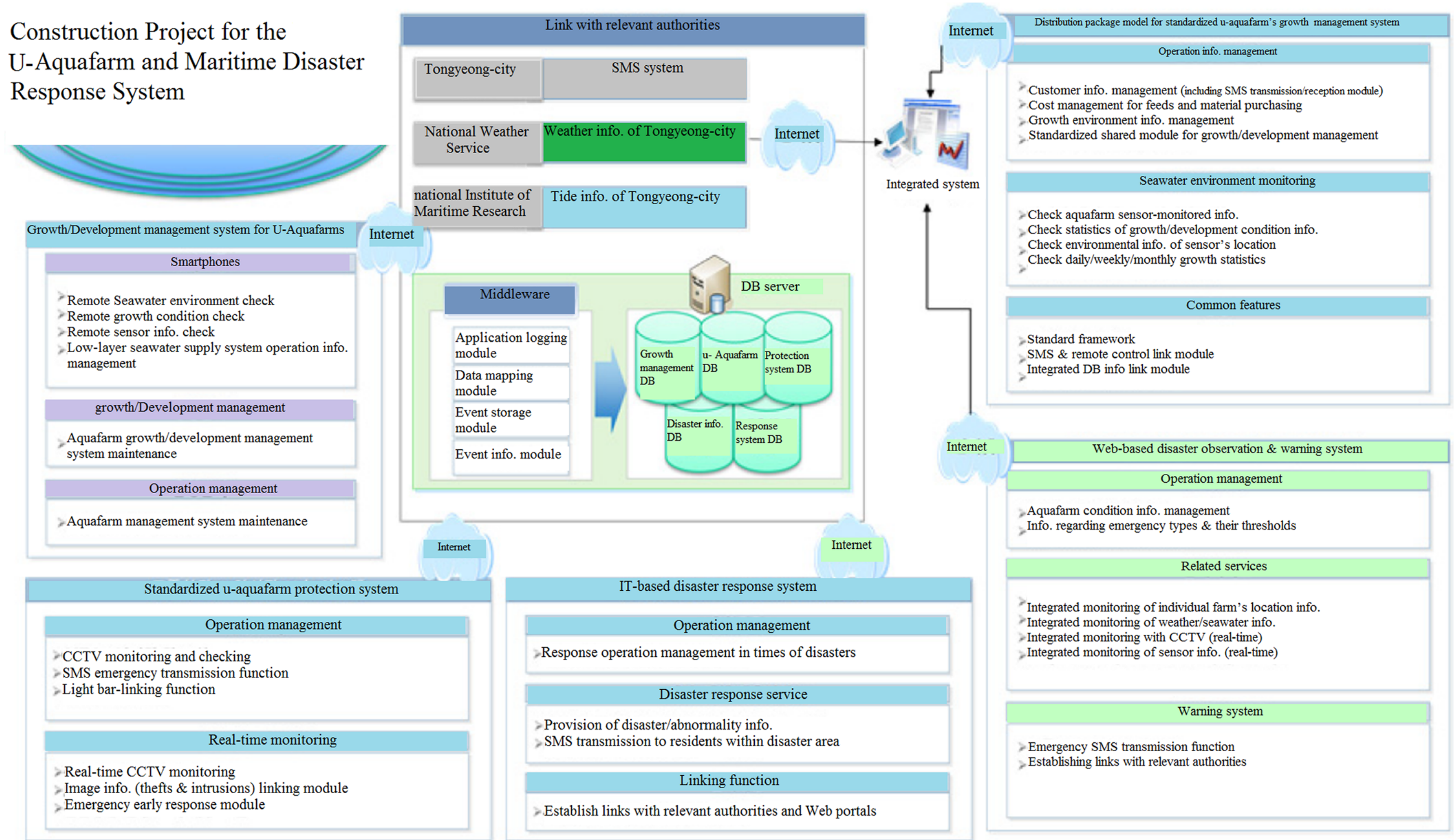

Fig. 13 Construction project of u-aquaculture farm in Tongyeong and Maritime Disaster response system

ubiquitous projects but implementing such a system on the cage-culturing farms is the first attempt and can be the first example that will be able to surmount regional and environmental limitations. Through the system, which the farmers and the relevant authorities can gain an easy access, the effects of u-Services can be maximized and the project described in this study will be exemplary to other researcher or farmers considering similar projects.

Conclusion and future work

Being one of the most important factors in fish farm management, the electric power level must be kept steady during culturing seasons, especially for those indoor fish farmers who need to re-circulate seawaters constantly through their pumps. Otherwise, they will lose entire season's earnings due to mass mortality. The algorithm proposed in this study will be useful to the farmers as it can monitor farm's power status continuously and autonomously. The PLC technology has been applied to the system, and as for the application, RUDP was used in its transfer layer as a standard protocol to compensate transmission loss often caused by the noise generation in a PLC system. This phenomenon is common to most of the PLC-based communication systems as they rely on a power line(s) or telephone line. The proposed Android application has adopted a GUI (Graphical User Interface) to conveniently manage and control tasks at the farm. Application's functions include positioning of employees, checking withdrawal periods, photoperiods, and farm accesses, in addition to controlling the seawater elements. It is expected that the proposed system, algorithm, and application will be adaptable to the Vertical Fish Farms, especially for the small or medium-scale farms as they can be installed and operated at minimal costs. Also, aside from benefit of avoiding the financial damages every year due to power failures and natural disasters, farmers can expect improved product images and reliability by offering anti-biotic-free marine products to the consumers who are deeply concerned with misuse of drugs at the fish farms.

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Competing interests
The author declares that he has no competing interests.

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