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Smart Aquaculture Design for Vannamei Shrimp Farming Based on Quality Function Development

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***Abstract*—In the fishery industry, Indonesia's large water area has the potential for developing and cultivating fisheries such as vannamei shrimp. For this reason, aquaculture, particularly vannamei shrimp farming, can play a crucial role in Indonesia's economy and food supply. However, challenges such as fluctuating water quality, disease outbreaks, turbidity levels, and irregular shrimp feeding schedules in ponds can affect the productivity and sustainability of shrimp farming. The smart aquaculture system integrates technologies, such as IoT-based sensors, automated feeding mechanisms, and real-time water quality monitoring to optimize the farming process. The research proposes a smart aquaculture design for vannamei shrimp farming based on the Quality Function Development (QFD) method. It starts by creating questionnaires to identify stakeholders' level of interest. The questionnaire results are used as a reference for system redesign using the QFD method to improve the quality and quantity of shrimp harvest, cultivating effectively and efficiently and helping and facilitating the supervision of pond managers on pond water quality, feeding, and feed availability. The result highlights the application of QFD in creating a tailored, technology-driven solution that supports better decision-making, resource optimization, and improved shrimp health. The system reduces human error, enhances farm management, and promotes higher yields by providing real-time data and automation. The evaluation results show that the proposed design can achieve high stakeholder satisfaction. It also achieves better scores compared to the other two competitor's designs.**

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I. Introduction

RECENTLY the developing Industrial Revolution 4.0 is no longer talking about tool automation but rather about cyber-physical systems or the Internet of Things (IoT), where the Internet world is connected to the physical world. Many experts have identified nine leading technologies supporting the Industry 4.0 era. Four of the nine significant technologies require connectivity. Those are the cloud, big data, industrial IoT, and system integration [1] in Fig. 1.

In the Industry 4.0 era, every device is connected to the Internet to collect and analyze data, helping businesses run without problems using reliable networks and infrastructure in the IoT field [2]. Technology integration with IoT can optimize existing technologies. The ability to record data for 24 hours makes the resulting data very dense with a broader sample. The IoT can automate every stage of various work cycles. Users can manage their infrastructure and assets in real time [1]. The IoT market was estimated to grow to reach Rp444 T in 2022, whereas, for the development of IoT devices, approximately 400 million IoT sensor devices were installed in 2020. For this reason, many sectors in Indonesia must be ready to face the era of Industrial Revolution 4.0, including the fisheries sector [3].

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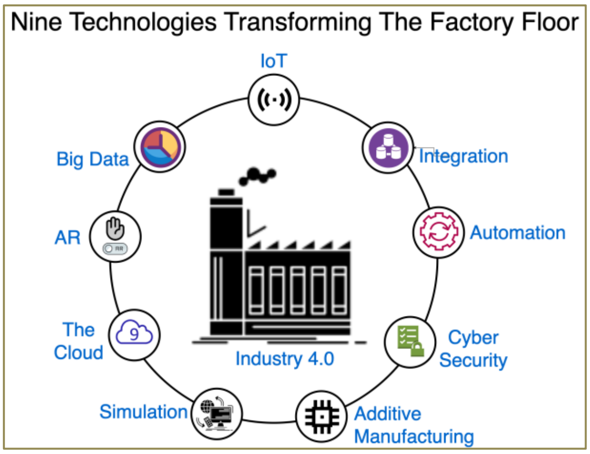

Fig. 1. Nine technologies transforming the factory floor.

Previous research on smart feeding for IoT-based fishponds with the concept of automatic fish feed [4]. This prototype allows remote control of feeding and monitoring pond conditions, such as water temperature, pH levels, and water clarity levels, so that fish growth can be maximized using Arduino. IoT-based smart feeding is a concept that combines architectural and mechanical-electrical designs to provide speed/mobility, ease of control, and access from any direction and at any time, which can ease farmers' tasks in fish cultivation. However, it is constrained because it does not use a Global System for Mobile Communications (GSM) module for data communication. In another research, a research system that focuses on water quality control systems using actuators is proposed. However, it does not discuss the monitoring system based on the IoT in detail [5].

In the research, brief interviews regarding problems usually encountered in the ponds with one of the vannamei shrimp pond employees at PT Delos Teknologi Maritim Jaya are conducted. From the interviews, it can be understood that there are currently several problems in cultivating vannamei shrimp. The main problems are poor water quality during maintenance and the manual monitoring method for aquaculture in ponds. Therefore, managing and monitoring air quality during maintenance is necessary, such as checking the air temperature, salt content, pH, and level. However, there are several obstacles to manual monitoring of ponds. It is constrained by the distance and time. Real-time monitoring is difficult to implement because the pond's location is far from the settlements. The following are some facts from the interview results:

1) There has been a decrease in the quality and quantity of vannamei shrimp harvested.
2) The IoT-based smart aquaculture concept is yet to be widely applied to vannamei shrimp farming.
3) Many vannamei shrimp have died because of unhealthy water quality.
4) Water quality checks and shrimp feeding in ponds are still performed manually by farmers.
5) There is a lack of an Internet network in the shrimp pond area.
6) There is no data or history monitoring.
7) The current system is not yet automated.

From the existing literature and journal references, it is necessary to create a system or method that can bring together shrimp ponds by utilizing a faster and more practical system, namely, an IoT-based system. The research aims to provide a solution by designing a smart aquaculture monitoring system. It utilizes IoT to improve the quality and quantity of vannamei shrimp in the aquaculture industry to make it more efficient and effective. The IoT can help to monitor ponds. This monitoring system monitors pond water quality, such as water temperature, turbidity, and acidity, while the smart feeder system monitors the level of shrimp feed elevation.

This IoT-based smart aquaculture method is designed using several sensors such as temperature sensors, turbidity sensors, pH sensors to measure the acidity and alkalinity of a solution, ultrasonic sensors to measure the water level, and an automatic feeder system to serve food automatically. Then, the captured data are processed by the microcontroller and sent wirelessly using radio waves or radio frequency with LoRa technology to the data transmission center gateway. Then, it is sent to cloud computing as a data server and data processing system in the administrator's web dashboard view. These data also display a real-time mobile application so the user or administrator can combine real-time data from the shrimp ponds. This method is supported by wireless technology. This system is expected to be one of the applicative technological developments, which is expected to provide results to improve the quality of vannamei shrimp that live in ponds.

In addition, the Quality Function Deployment (QFD) method is used, which is a method for planning and developing products that suit consumers' needs and desires [6]. The results of the questionnaire evaluation show that based on the analysis of the answers given by the respondents, the created questionnaire can be used as a reference so that the proposed system design can be used to unite vannamei shrimp ponds to improve the quality and quantity of vannamei shrimp harvest, cultivate effectively and efficiently, and help and facilitate the supervision of pond managers on pond water quality, feeding, and feed availability.

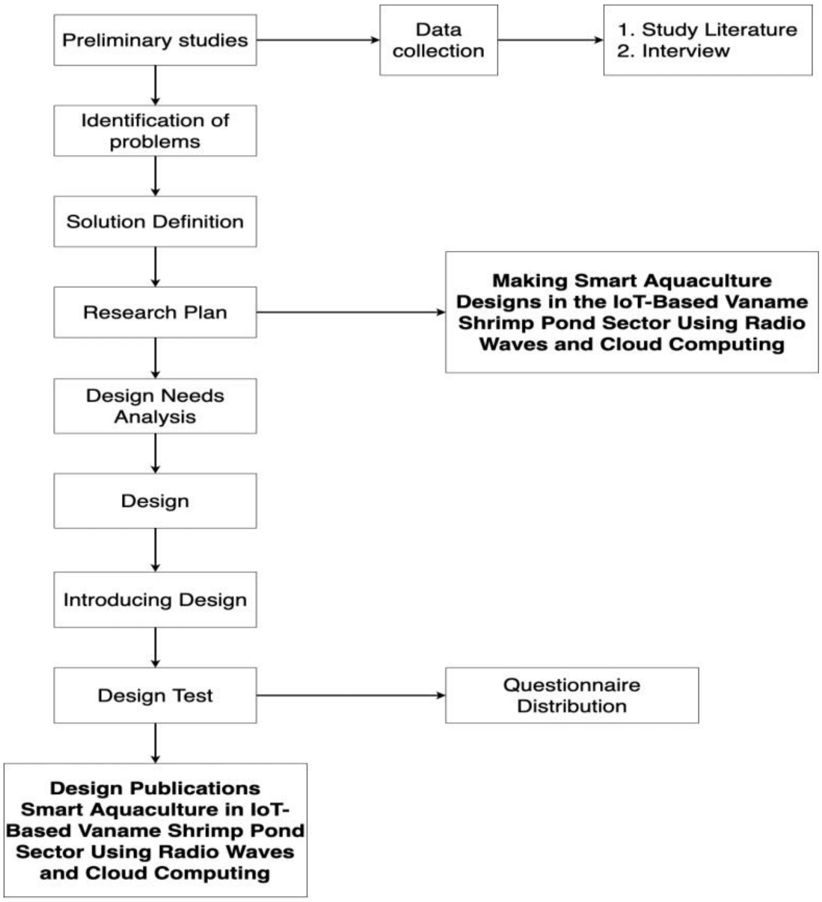

Fig. 2. Research stages.

II. Research Method

A. Research Stages

The research broadly consists of three stages of implementation. The first stage is a preliminary study, which is an assessment of the theories that underlie the process of making smart aquaculture designs in the IoT-based vannamei shrimp pond sector using radio waves and cloud computing. The use of wave radio and cloud computing methods forms the basis for building an IoT-based smart aquaculture system for the vannamei shrimp pond area [7, 8]. Furthermore, various surveys have been conducted on farmers, administrators, and owners of vannamei shrimp ponds. The second stage involves planning an IoT-based smart aquaculture design using radio waves and cloud computing as an application that can be used as a medium for monitoring the pond area in real time [9, 10]. The design of this system is based on the needs analysis of the results of the preliminary study, and the stages are carried out according to the method used. The last stage is the system design testing phase with a questionnaire on the user side: farmers, administrators, or owners of vannamei shrimp ponds and the community. Following the method used, the Design Science Research Methodology (DSRM) is used. The DSRM presents an amalgamation of procedures, principles, and practices [11]. As described, the research details are shown in Fig. 2.

B. Preliminary Studies

In accordance with the DRMS method, it is necessary to conduct a preliminary study that includes the techniques used to collect the required data, which will be used several times, such as interviews and journals. As shown in Fig. 2, the DSRM process includes six steps.

1) Problem identification: This stage defines the basis of a specific problem.
2) Defining goals for solutions: This stage concludes with the goal of completing solutions to problems.
3) Design and development: At this stage, the design and development of the solutions are performed.

The research design describes each object which has a contribution from the researcher in the form of a design.

4) Demonstration: In this stage, researchers will introduce IoT-based smart aquaculture designs using radio waves and cloud computing methods to farmers, administrators, and owners of vannamei shrimp ponds [12–14].
5) Evaluation: In this stage, the researcher conducts the evaluation process with observations to solve problems.
6) Communication: At this stage, the publication of IoT-based smart aquaculture design research will be carried out using radio waves and cloud computing methods with empirical research stages in the research process, including problem definition, literature review, hypothesis development, data collection, analysis, results, discussions, and conclusions that have been made by researchers in the form of journals for publication.

C. Identification and Research Solutions

At this stage, the researchers study the problems encountered during the preliminary study and conduct brief interviews with the PT Delos Teknologi Maritim Jaya. The respondents state the need for companies to overcome problems that are often experienced. In turn, the companies will present the solutions to the farmers’ needs as customers, who will later use the system designed by researchers.

The following are the identification of problems, needs of farmers, and solution plans provided by researchers for these problems. First, there has been a decrease in the quality and quantity of vannamei shrimp harvested. The farmers require an aquaculture concept to improve the quality and quantity of vannamei shrimp harvest. As a solution, the concept of smart aquaculture is needed in IoT-based vannamei shrimp ponds so that they can be monitored in real-time to increase the quality and quantity of vannamei shrimp harvest.

Second, the IoT-based smart aquaculture concept has not been widely applied in vannamei shrimp farming. The farmers require a workshop regarding the application of the smart aquaculture concept. As a solution, the workshop on the application of the smart aquaculture concept is conducted with farmers, administrators, and owners of vannamei shrimp ponds.

Third, many vannamei shrimps have died because of unhealthy water quality. The farmers require tools to check water quality with technology to make it more accurate because it is still manual. As a solution, sensors are required, such as a temperature sensor to measure water temperature, a pH sensor to measure the acidity level of water, a salinity sensor to measure water salinity, and an ultrasonic sensor to measure water level. These sensors are used to determine the water quality.

Fourth, the method of checking the water quality and feeding in ponds in Indonesia is still performed manually by fish farmers. The farmers require a tool to check water quality and automatic feeding because, currently, it is still manual, and the feeding schedule is still not appropriate. As a solution, a system is needed to check the water quality, which will be carried out by installing IoT-based sensors, for which an automatic feeder will be installed.

Fifth, there is a lack of an internet network in the shrimp pond area. The farmers require a stable Internet network if the IoT-based smart aquaculture concept is applied. As a solution, LoRa technology is required as a medium for transferring data from end devices to cloud computing so that the pond area becomes a stable network.

Sixth, there is no data or history monitoring. The farmers require easier monitoring of data storage media because, currently, it is still manual with a checklist and then copied back on a PC or laptop. As a solution, researchers will use cloud computing as a storage medium for monitoring data, and any data required can be downloaded.

Seventh, the current system is not yet automated. The farmers require a smart aquaculture system with novel technology. As a solution, researchers will use the IOT system so that farmers do not work twice to obtain data for monitoring ponds.

D. Implementation of the Quality Function Development (QFD) Method

The following are the research steps that the researcher will carry out to apply the QFD method. First, it is the identification of variables. It has two stages. Firstly, in questionnaire identification, the research questionnaire is divided into two parts. The first questionnaire contains several sections, including the respondent characteristic data section, instructions for filling in the questionnaire, several questions regarding vannamei shrimp ponds, and a statement section. The respondents’ characteristics include their name, gender, and age. The statement section describes the design of smart aquaculture. The second questionnaire is divided into two parts, containing respondents’ satisfaction with the design of IoT-based smart aquaculture and their interests in IoT-based smart aquaculture. Secondly, in the identification of samples, the samples used in the research are employees working at PT

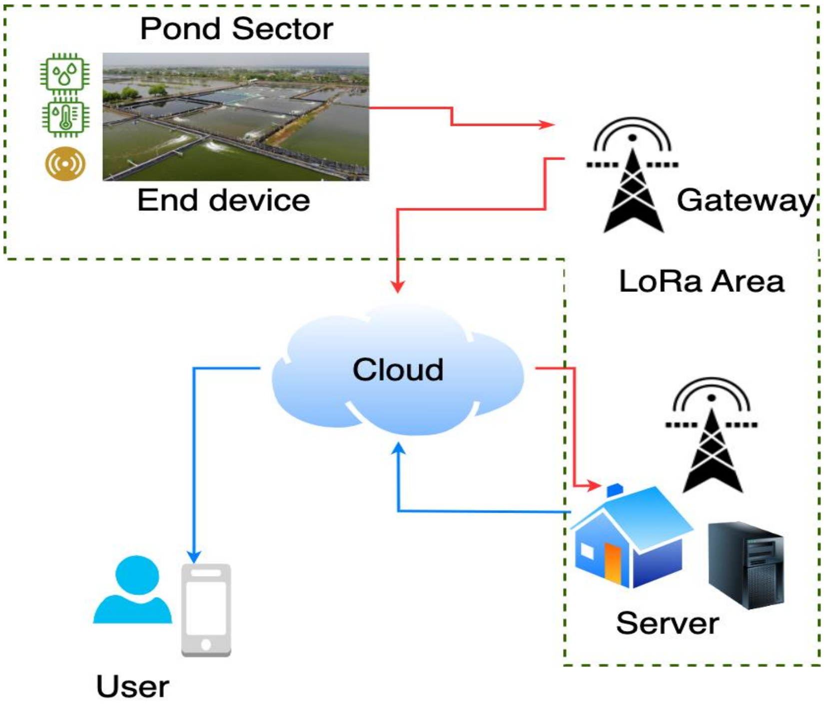

Fig. 3. Overall system diagram.

Delos Teknologi Maritim Jaya, as many as 25 people directly involved with vannamei shrimp ponds.

Second, it is making a questionnaire. Customer satisfaction and interests are determined based on the needs of vannamei shrimp farmers. Third, employees who work in PT Delos Teknologi Maritim Jaya, who participate in the introductory socialization of smart aquaculture design in IoT-based vannamei shrimp ponds, fill out the questionnaire. Fourth, data collection uses the questionnaire that is explained above.

Fifth, it is data processing. The results of the first questionnaire are used to determine the attributes for creating the second questionnaire. Next, based on the results obtained from the second questionnaire, data processing is conducted regarding the level of interest and satisfaction of respondents/users. It is used as the basis for system redesign using the QFD method. Then, a QFD design is conducted. It begins by sequentially forming House of Quality (HOQ) diagrams and translating consumers' needs into operational steps. The operational steps are as follows:

- Identify all the needs and desires of farmers against existing designs.
- Identify the farmers' level of interest in each of the characteristics of existing farmers.
- Translate all needs and desires of farmers (whats) into design characteristics (hows).
- Determine the relationship between each characteristic of the farmer with the design characteristics.
- Form a correlation matrix that shows the relationship between the existing design characteristics.
- Assign values in the form of numbers to the matrix of the relationship between farmers' desires and design characteristics. Assessments can be made based on the relative importance of each consumer's needs and desires.

Last, the researchers create a system design based on the developed characteristics.

E. System Design

System design is the development stage after the analysis of the design requirements. The design stage is carried out to design the solutions created in the analysis stage. The design can be adjusted until the correct design is obtained. Figure 3 shows a diagram of the overall system. The overall system design consists of the following stages: block diagram, flowchart, hardware, system packaging, Unified Modeling Language (UML), and software design for applications. Each stage is described in more detail as follows.

First, block diagram design is a concise picture of the combination of cause and effect between the input and output of a system. A block diagram is shown in Fig. A1 in Appendix. The system has two major parts: the end device and cloud computing. The end device consists of sensors, a microcontroller, a smart feeder, and a LoRa wireless transmission. Cloud computing consists of a cloud server and a LoRa access point.

Second, a flowchart describes problem-solving stages by presenting symbols that are easy to understand, easy to use, and standardized. A flowchart describes the problem-solving stage in a simple, unraveled, neat, and transparent way using standard symbols. The flowchart in Fig. A2 in Appendix shows a designed smart aquaculture system workflow in the IoT-based vannamei shrimp pond sector using radio waves and cloud computing. The workflow of the designed system is described as follows [15, 16].

- If the water temperature is > 30°C, the monitoring application will display a notification to the user that the pump will automatically turn on to neutralize the water temperature.
- If the pH of the water is between 7.5 and 8.5, it indicates normal pH. If the pH of the water drops or rises from 7.5–8.5, the monitoring application displays a notification for the user to increase the alkalinity level manually in the pond immediately [17].
- If the level of salt or salinity is between 15 and 25 ppt for shrimp ponds aged 1–2 months, it indicates normal salt levels. If the salt level drops or increases from 15 to 25 ppt, the monitoring application will display a notification for the user to come to the office immediately. The pond provides manual action.
- For smart feeders, the ultrasonic sensor notifies the monitoring application if the feed height in the feed reservoir is less than 3 cm so the user can immediately go to the pond to refill the feed reservoir. If the feed is readily available or exceeds a height of 3 cm, it will be automatically dispensed according to the user’s predetermined schedule.

Third, in hardware design, smart aquaculture design in the IoT-based vannamei shrimp pond sector consists of various hardware, such as a microcontroller, LoRA module (transmitter and receiver), circuit sensors (DS18B20 sensor, SEN0161, salinity sensor), and automatic feeder circuit (HC-SR04 Sensor). The smart aquaculture design series in the IoT-based vannamei shrimp pond sector also consists of a monitoring circuit system with several sensors for monitoring. Figure A3 in Appendix shows a monitoring system circuit consisting of a series of sensors, microcontrollers, LoRa modules, and ultrasonic sensors on an automatic feeder and power supply. This system measures water temperature, pH, and salt content in water. Ultrasonic sensors placed in the automatic feeder container function to measure the shrimp feed content. Then, the data obtained from the sensor circuit are processed by the microcontroller from analog data to digital data to be sent by the LoRa module to the LoRa Access Point to the cloud.

The smart aquaculture system in the IoT-based vannamei shrimp pond sector is designed to use Acrylic Teflon material as a packaging system because it is resistant to water and bad weather. Materials such as these are considered suitable with the specifications needed as system protectors in the middle of vannamei shrimp ponds.

Fourth, in Unified Modeling Language (UML) design, it explains a user application system for the creation of a smart aquaculture system in the IoT-based vannamei shrimp pond sector using radio waves and cloud computing. This design consists of designing a use case and activity diagrams. Figure A4 in Appendix shows an image of a user-use case design on an Android application for a smart aquaculture system. It shows that the system consists of several functions: login/logout, monitoring, feed availability, and automatic feeder features.

In this activity diagram design, various flows of activities in the system are described. How each flow begins, the decisions that may occur, and how the activity flow in the system ends are the workflow or activity of a system or menu in the system software. This activity diagram is also used to define the order or grouping of views of the user interface system, where each activity is considered to have a display interface design, and a menu design displayed in the software. Activity diagrams are shown in Figs. A5–A9 in Appendix. Some activities defined in these diagrams are data viewing, automatic feeders, download history, and logout.

Fifth, in software design for applications, the software on the computer is created by utilizing the Database Management System (DBMS), which is an application that processes databases and user applications used in the cloud computing method to transmit data to gadgets. Next, in cloud computing design, this system has two access levels: server and user. The server level has functions to input data and view and manage users. The user level only monitors the situation in the pond area. In this program, there is a table record menu in the admin section. Monitoring data includes the number, name of equipment, date, time, temperature data, pH data, salt content data in

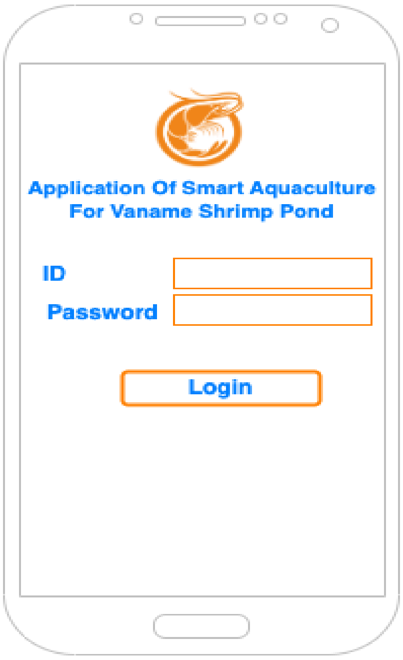

Fig. 4. Login page design.

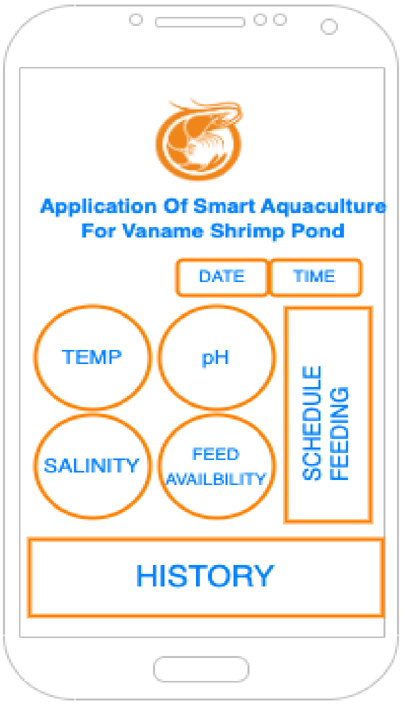

Fig. 5. Menu page design.

water, feed content data, and feeding schedule data.

Moreover, in user application design, the researchers also design a user application. This UI design is carried out in four stages using the User-Centered Design (UCD) process, understanding the context of use, specifying user requirements, designing solutions, and evaluating requirements. The steps taken in designing the user interface and user experience are described as follows. The page structure includes the login page and the dashboard, which is designed to display sensors and schedules and the amount of feed in the pond. History page is used to download the monitoring results. Figure 4 shows the login page. A form is displayed on the login screen to fill in the user ID and password. If the user has successfully logged in, the user enters the main menu page to view the data on the state of the pond. Figure 5 shows the menu page. It displays the date, time, temperature, pH level, salt level, feed content, feed schedule, and history. The history display is designed to show the history of the sensor states and shrimp feeding. A historical page is shown in Fig. 6.

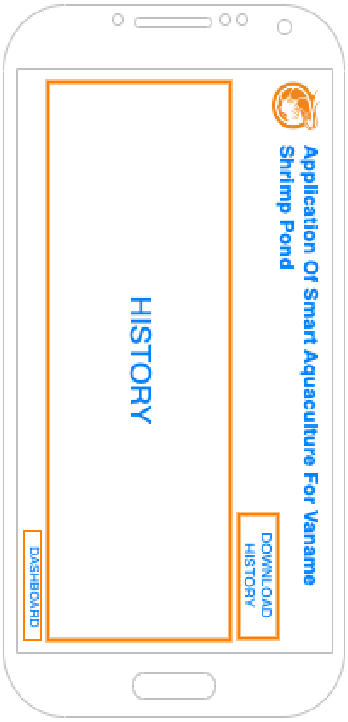

Fig. 6. History page design.

Sixth, in data collection, the questionnaires in the research include the preparation of a grid of instruments that have been designed by researchers and distributed to obtain responses from users, namely farmers, managers, and owners of ponds. On this basis, a grid of instruments is made, composed of several indicators needed to explore the respondents’ opinions. This system is also validated through validity and reliability tests, such as instrumental arrangement,

TABLE I
RESULTS OF QUESTIONNAIRE DISTRIBUTION.

No	Description	Quantity
1	Distributed questionnaire	25
2	Non-returning questionnaire	3
3	Returned questionnaire	22
4	Questionnaire that cannot be processed	3
5	Questionnaire that can be processed	22

TABLE II
VALIDITY TEST RESULTS.

Variable	Item	N	R-Count	R-Table	Description
Statement	P1	22	0.75853981	0.432	Valid
	P2	22	0.60487687	0.432	Valid
	P3	22	0.81601436	0.432	Valid
	P4	22	0.75521718	0.432	Valid
	P5	22	0.87395693	0.432	Valid
	P6	22	0.90578502	0.432	Valid
	P7	22	0.66453628	0.432	Valid
	P8	22	0.90961538	0.432	Valid
	P9	22	0.95625465	0.432	Valid
	P10	22	0.92242686	0.432	Valid
	P11	22	0.85738114	0.432	Valid
	P12	22	0.65907824	0.432	Valid
	P13	22	0.91720331	0.432	Valid
	P14	22	0.9178172	0.432	Valid
	P15	22	0.92891756	0.432	Valid
	P16	22	0.90274012	0.432	Valid
	P17	22	0.88557352	0.432	Valid
	P18	22	0.92719734	0.432	Valid
	P19	22	0.96955906	0.432	Valid
	P20	22	0.88408644	0.432	Valid
	P21	22	0.91092825	0.432	Valid
	P22	22	0.73320876	0.432	Valid

validity, and reliability tests.

III. RESULTS AND DISCUSSION

A. Respondents' Distribution

The questionnaires are distributed to 25 respondents who are employees of PT Delos Teknologi Maritim Jaya. The questionnaires are distributed after obtaining research permission from the company. The number of questionnaires distributed is limited to 25 questionnaires. Because at the time the socialization is carried out, PT Delos Teknologi Maritim Jaya employees who are allowed to attend the socialization are limited to only 25 employees. The questionnaire is distributed directly by the researchers via Google Forms. The questionnaire data are collected for 11 days (from 12 to 22 August 2022).

The researchers summarize the results of distributing the questionnaires in Table I. It shows the number of questionnaires that can be used in the research. Overall, a total of 25 questionnaires are distributed, and from that number, a total of 22 questionnaires are filled in. Based on this, the total number of questionnaires that can be processed and analyzed is 22. Table I presents the questionnaire distribution results.

TABLE III
RELIABILITY TEST RESULTS.

Variable	Fixed Value	Cronbach's Alpha	Description
Statement	0.6	0.982269318	Reliable

B. Validity Test

The results of the validity test are shown in Table II. It shows that all the indicators used to measure the statement variables in the research have a significance level of less than 0.05 or 5%. It means that all indicators and statements on each variable are valid. Hence, they can be used as data collectors and analyzed further.

C. Readability Test

The results of the reliability test are listed in Table III. It shows that all variables used in the research have an alpha value greater than 0.6. Hence, all variables are reliable. All questions can be trusted and used for further research.

D. Normality Test

The normality test aims to test whether the dependent variable, independent variable, or both have a normal distribution in the regression model. Figure 7 shows that the points are spread near the diagonal line. Therefore, the data are normally distributed.

E. Analysis of Questionnaire Research Results

From the questionnaire results, several things need to be paid close attention to in order to improve the quality and quantity of vannamei shrimp.

1) The system needs reliability and accuracy when analyzing water quality.
2) An application must have downtime. It should be noted that during downtime. The monitoring system can remain optimally monitoring pond water quality.
3) This tool will later be placed in vannamei shrimp ponds where the location is right in the water. It is necessary to pay attention to the selection of materials for the packaging of the device to protect the sensors inside.
4) Later, a trial of use and a workshop are needed to explain the system to employees who are used to checking manually and switching automatically.

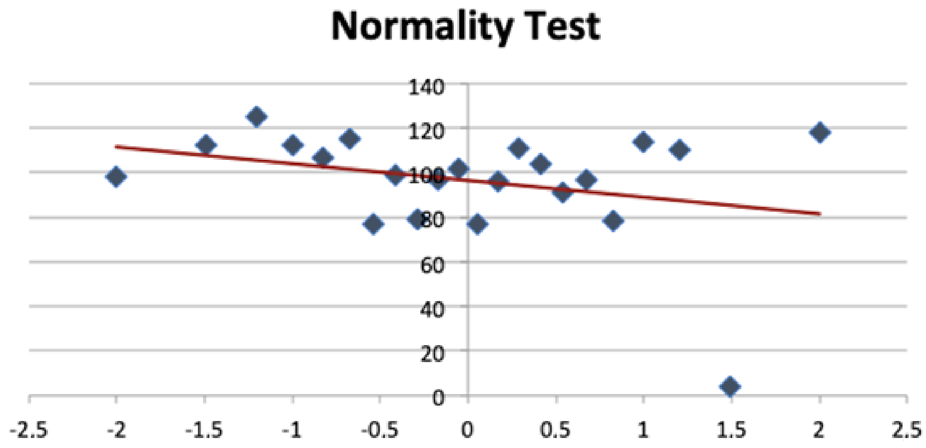

Fig. 7. Normality test results of dependent and independent variables.

F. Analysis of Design Requirements

Requirement analysis is carried out to determine what is needed in the research, the output to be produced by the system, and the scope of the process used to process input into output and control the system. At this stage, the researchers analyze hardware requirements, system architecture, data communication, and software requirements used in the smart aquaculture system in the IoT-based vannamei shrimp pond sector.

In an analysis of hardware requirements, the selection of the sensors is based on a study conducted by researchers conducting interviews with respondents from PT Delos Teknologi Maritim Jaya. From the results of these interviews, researchers identify problems and provide solutions to problems faced by vannamei shrimp ponds by selecting hardware consisting of a pH sensor, salinity sensor, temperature sensor, ultrasonic sensor, smart feeder, microcontroller, LoRa module, LoRa access point, aerator, relay, jumper cable, and smartphone.

In an analysis of system architecture, the system architecture is the system that will be built. The smart aquaculture application for vannamei shrimp ponds based on IoT will communicate with a microcontroller, which is bridged by LoRa communication using data storage media using cloud computing. Figure A10 in Appendix shows an image of the system architecture analysis.

Figure 8 shows an explanation of the architectural description of smart aquaculture development. This description is defined as follows. First, Android applications will be used by users such as farmers, administrators, or owners of shrimp ponds. Users can automatically see the state of water pH, water salinity, water temperature, feed content, and feed. Second, cloud computing is used as a data-storage medium for web servers and Android applications. Third, the LoRa access point will send data to cloud computing. Fourth, LoRa transmits data from the microcontroller to the access point. Fifth, the microcontroller is used as a server, and the main control of the system is a data processor generated from sensors. Sixth, SEN0161 is used as a water pH sensor. The sensor data are used to measure the pH of the water in the vannamei shrimp ponds. Seventh, salinity is used as a water-salt level sensor. The sensor data are used to measure the salt level of the water in the vannamei shrimp ponds. Eighth, DS18B20 is used as the water temperature sensor. These sensor data are used to measure the water temperature in the vannamei shrimp ponds. Ninth, ultrasonic HC-SR04 is used as a sensor to determine the feed content by measuring the height of the feed in the automatic feeder of the vannamei shrimp ponds. Tenth, automatic feeder functions to provide feed automatically on vannamei shrimp ponds.

In an analysis of data communication, LoRa is used as a data communication medium with end devices through microcontrollers and cloud computing for user applications. Figure 8 shows the data communication flow. First, all sensors send data to the microcontroller. The microcontroller then sends data from the sensors via LoRa communication to cloud computing in real time. Cloud computing, as a data storage server, sends it to the Android application in real time. On the other hand, owners can set water quality thresholds in vannamei shrimp ponds and feed the shrimps automatically. Finally, the microcontroller sends an early warning through the Android application if the minimum system detects water quality beyond the threshold set by the user at any time.

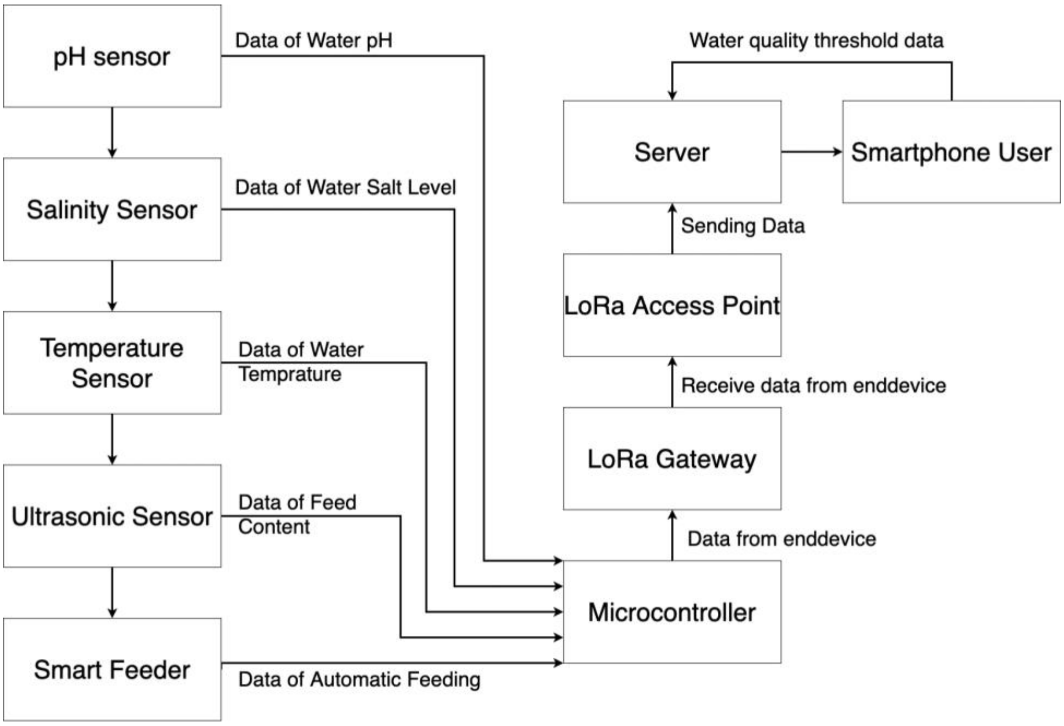

Fig. 8. Data communication flow analysis.

TABLE IV
MINIMUM SMARTPHONE SOFTWARE SPECIFICATION.

No	Software	Minimum Specification
1	System Operation	Android v. 5.0
2	Signal	H+
3	RAM	512 MB

In an analysis of software, the analysis of software requirements is an analysis process for the aspects of software utilization. The software required to create a Smart Aquaculture system is the Arduino Integrated Development Environment (IDE), database server, and Blynk application. Table IV lists the specifications for the minimum software requirements of smartphones that use the system.

G. Quality Function Deployment (QFD) Test Results

In questionnaire research data, the data obtained in the form of result data from distributing the first questionnaire are used to determine the attributes in the second questionnaire regarding the interests and satisfaction of potential IoT-based smart aquaculture users. Data from the first questionnaire, which consists of 25 statements, are used as a basis for determining the characteristics of the needs of smart aquaculture users and consists of eight attributes: waterproof packaging design (A), ease of operation (B), ability to maintain water quality (C), ease of pond monitoring (D), stable network (E), automatic feeding (F), affordable price (G), and placement position in the middle of the pond (H) [18].

TABLE V
AVERAGE LEVEL OF SATISFACTION AND INTEREST OF RESPONDENTS.

No	Attributes	Interest Level	Satisfaction Level
1	Waterproof packaging design (A)	4.6	4.0
2	Ease of operation (B)	4.6	4.0
3	Maintaining water quality (C)	5.0	4.9
4	Making it easier to monitor ponds (D)	5.0	4.2
5	Having a stable network (E)	4.8	4.3
6	Automatic feeding (F)	4.4	4.1
7	Affordable price (G)	4.4	4.2
8	Placement position in the middle of the pond (H)	4.2	4.4

This attribute is used to create the second questionnaire. The results are obtained by the average value of the level of satisfaction and importance of respondents according to Table V. It shows that it achieves high interest and satisfaction levels. It achieves more than 4.0 interest and satisfaction level (out of 5).

The next stage is preparing a HOQ. In this stage, a HOQ or product planning matrix is prepared to create a

TABLE VI
RESULTS OF ABSOLUTE IMPORTANCE AND RELATIVE IMPORTANCE.

No	Attributes	Absolute Interest	Relative Interest
1	Waterproof packaging design (A)	4.6	12.52
2	Ease of operation (B)	4.6	12.39
3	Maintaining water quality (C)	5.0	13.50
4	Making it easier to monitor ponds (D)	5.0	13.50
5	Having a stable network (E)	4.8	12.88
6	Automatic feeding (F)	4.4	11.90
7	Affordable price (G)	4.4	11.90
8	Placement position in the middle of the pond (H)	4.2	11.41

TABLE VII
RESULTS OF IMPROVEMENT RATIO, SALES POINT, RAW WEIGHT, AND NORMALIZED RAW WEIGHT.

No	Atr	SL	AG	R	SP	RW	NRW
1	(A)	4.0	4	1.0	1.5	18.77	0.126
2	(B)	4.0	4	1.0	1.2	14.87	0.100
3	(C)	4.9	4	1.2	1.5	24.62	0.165
4	(D)	4.2	4	1.1	1.5	21.40	0.144
5	(E)	4.3	4	1.1	1.5	20.64	0.139
6	(F)	4.1	4	1.0	1.5	18.46	0.124
7	(G)	4.2	4	1.1	1.2	15.09	0.101
8	(H)	4.4	4	1.1	1.2	14.94	0.100

Description: Atr: Attribute, SL: Satisfaction Level, AG: Average Goal, R: Ratio, SP: Sales Point, RW: Raw Weight, and NRW: Normalized Raw Weight.

product planning matrix that needs to be considered in the steps. The steps in creating an HOQ are as follows. First, the researchers determine the level of interest and satisfaction based on Table VI. It determines the value of absolute interest in accordance with the results of the interest level data from users. The magnitude of the relative importance value can be obtained according to Table VI. It shows that it achieves a high level of absolute interest and relative interest. It achieves more than 4.0 on the absolute interest level and more than 11.0 on relative interest level.

Second, the researchers determine goals (targets). The goal is related to satisfaction with smart aquaculture design to overcome the problems faced by vannamei shrimp farmers. It is also related to the performance target for each indicator of the farmers' needs to provide a competitive advantage for writers and users of smart aquaculture. As shown in Table VI, the goal (target) value for the smart aquaculture design quality indicator has an average value in the range of 4 to 5. It means that the goals can be achieved.

Third, the researchers determine the improvement ratio, sales point, raw weight, and normalized weight. This ratio gives weight to the needs of smart aquaculture users, who require the most development. The development ratio is a comparison between goals and customer satisfaction (satisfaction level). The sales points are determined by the authors. This value reflects the level of importance that can be obtained if the relevant indicator is improved and refined. After performing the calculation, it can be seen that the user's level of interest in each element varies, with a total raw weight of 148.79. The normalized raw weight is obtained from the raw weight for each attribute. This stage aims to ensure customer needs and determine customer performance goals. Table VII shows the ratio, sales point, raw weight, and normalized weight data. Table VII shows that the product quality attributes with a percentage of normalized raw weight above 10% consist of five attributes: being able to maintain water quality (C) by 17%, facilitating pond monitoring (D) by 14%, having a stable network (E) by 14%, waterproof packaging design (A) by 13%, and automatic feeding (F) by 12%.

The next stage is to create a relationship matrix to determine the relationship by assigning weighted values. It will later be carried out on the relationship between the needs of farmers and technical specifications. Subsequently, the technical correlation is determined. Technical correlations show the interaction between the technical response and the symbol for the direction of change in technical characteristics. The next stage is to determine the priority of the technique or technical matrix, which is sorted based on the normalized contribution from the highest to the lowest value. The HOQ matrix is shown in Fig. A11 in Appendix. It shows that the proposed method can achieve a higher score in five criteria compared to two other competitors. The most significant difference is in the ability to monitor ponds just by looking at the applications.

H. System Benefits

The benefits obtained from the smart aquaculture design in the IoT-based vannamei shrimp pond sector are as follows. First, it can effectively and efficiently improve the quality and quantity of harvested vannamei shrimp. Second, it can assist and facilitate the supervision of pond managers on pond water quality, feeding, and feed availability. Third, it can monitor vannamei shrimp farming in real time. Fourth, it can be monitored using a smartphone. There is warning information about water quality values when they are not up to standard, shrimp feeding, and feed availability.

IV. CONCLUSION

In the research, a smart aquaculture design in the IoT-based vannamei shrimp pond sector has been proposed. This design follows the wishes and needs of farmers using the QFD method to increase the quality and quantity of vannamei shrimp harvest. The farmers’ desire for smart aquaculture is to maintain water quality, facilitate monitoring of ponds, and have a stable network, waterproof packaging design, ease of operation, automatic feeding, affordable prices, and placement position in the middle of the pond. Based on the results of the questionnaire, a smart aquaculture design comprising an end device and a cloud computing component has been proposed. Communication between these components is conducted using LoRA wireless communication. In the design, stakeholders can monitor the vannamei shrimp situation in real time. The proposed design achieved a high level of satisfaction for stakeholders. The HOQ evaluation results show that the proposed design achieves a better score than the other two competitors’ designs.

In the future, the potential for Indonesian aquaculture resources, especially vannamei shrimp, will become even more significant. It certainly needs to be supported by increasingly sophisticated cultivation technology to optimize shrimp harvest by producing the best-sized vannamei shrimp. In the future, the research can be equipped with several technologies, such as the addition of an IoT-based waterwheel innovation, which can cause water movement in ponds and produce high Dissolved Oxygen (DO). Nanobubble technologies can also be considered in the future. Nanobubble technology results in more optimal water quality in ponds because it produces tiny air bubbles that balance the oxygen in pond water.

Author Contribution

Writing—original draft, B. S.; Methodology, B. S. and N. S.; Investigation, B. S.; Supervision, N. S. All authors have read and agreed to the published version of the manuscript.

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Appendix

The Appendix can be seen in the next page.

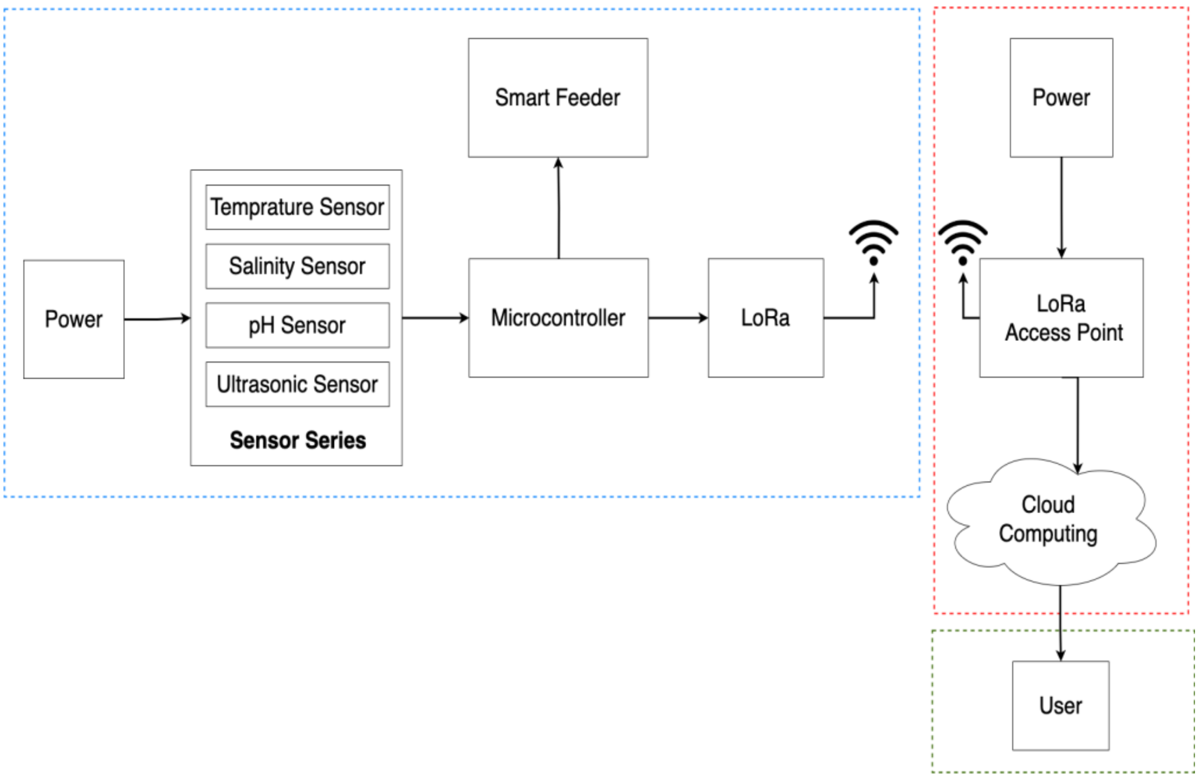


Fig. A1. Block diagram design.

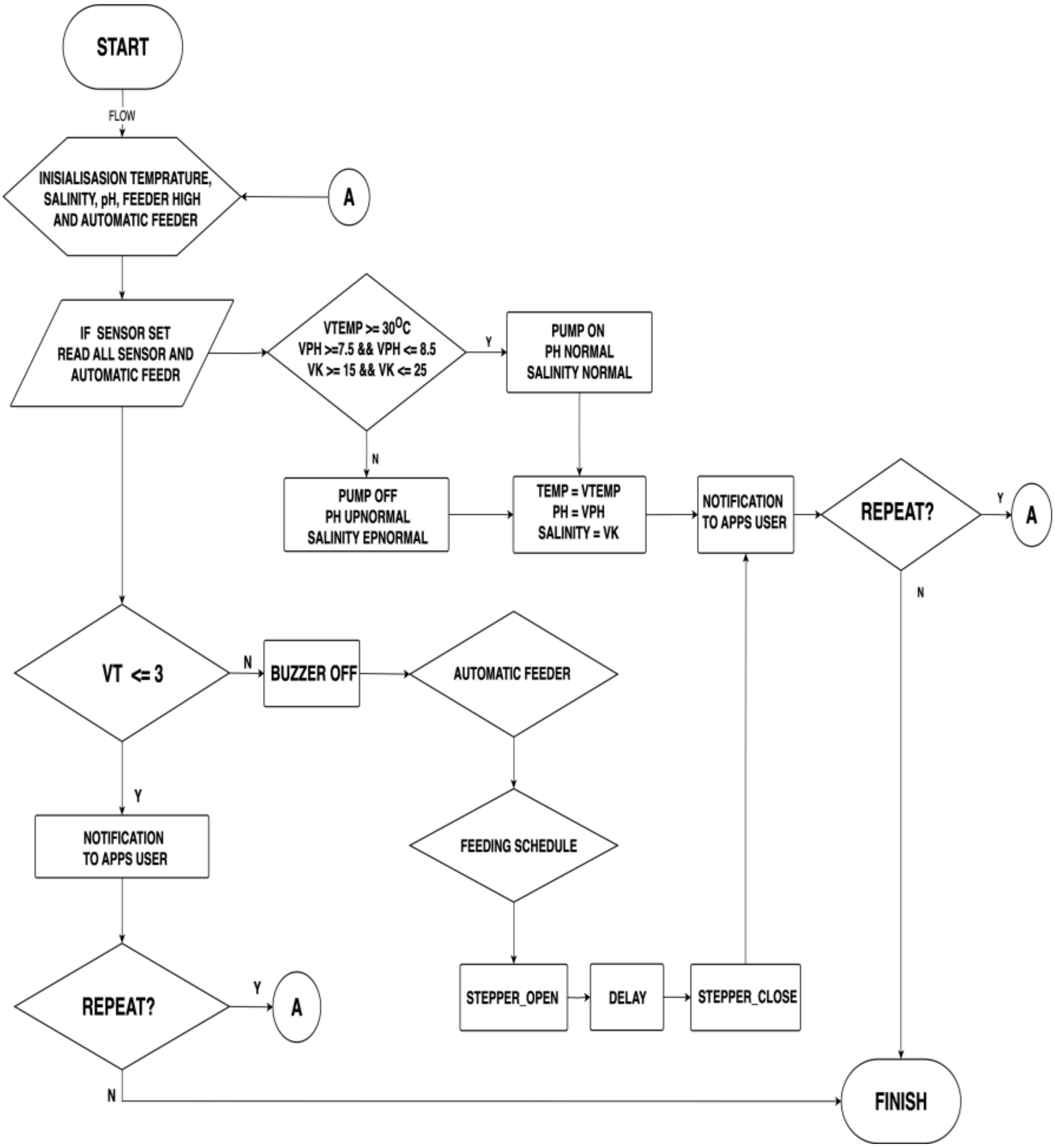


Fig. A2. Flowchart system design.

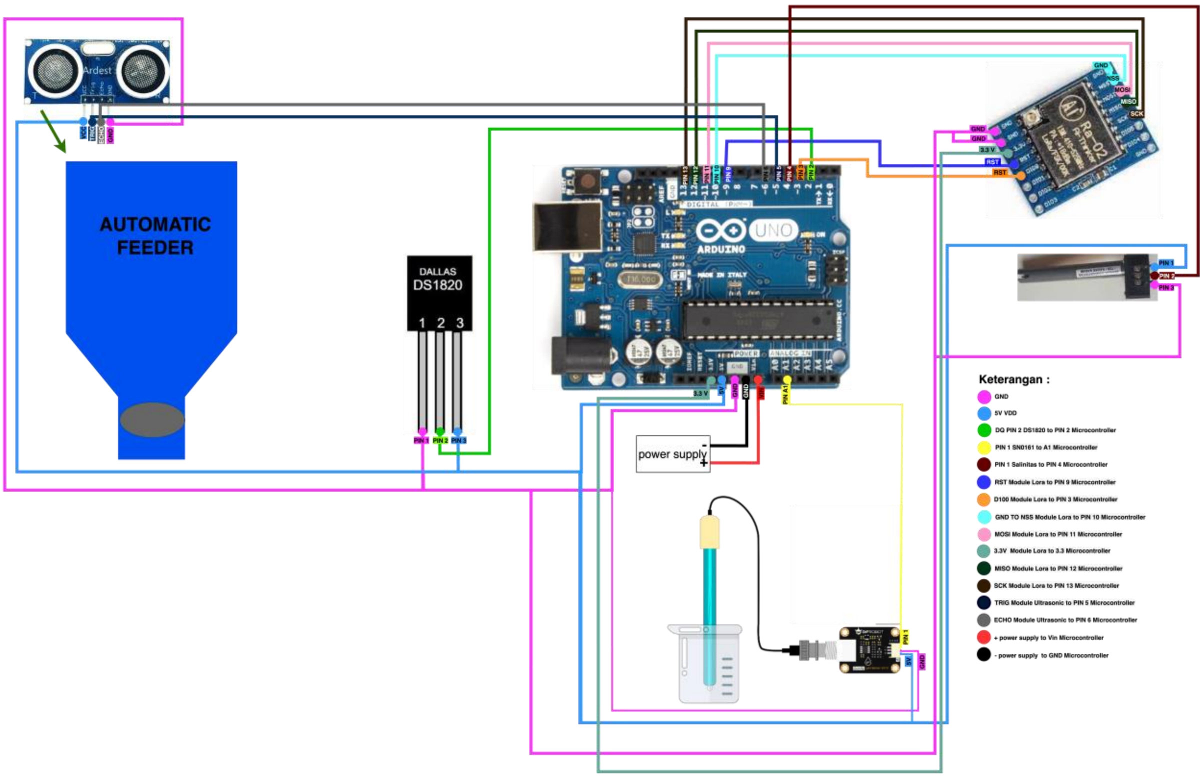


Fig. A3. Monitoring system circuit design.

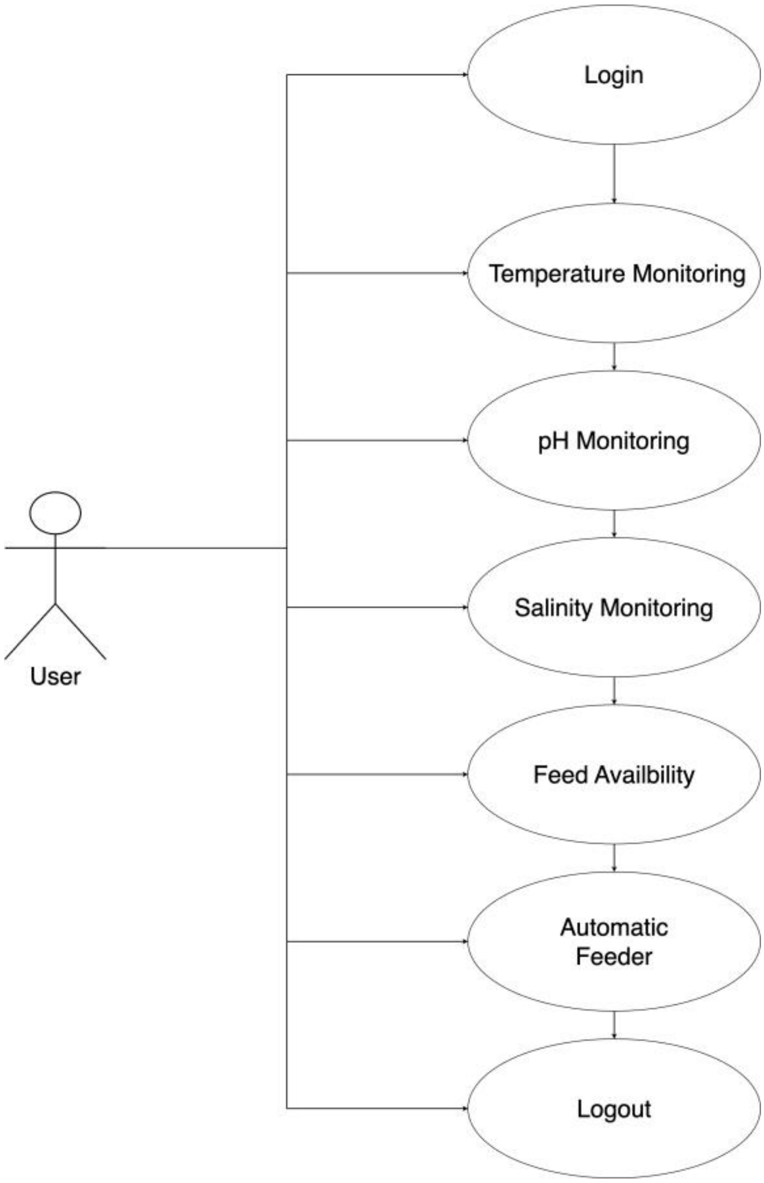


Fig. A4. Use case diagram.

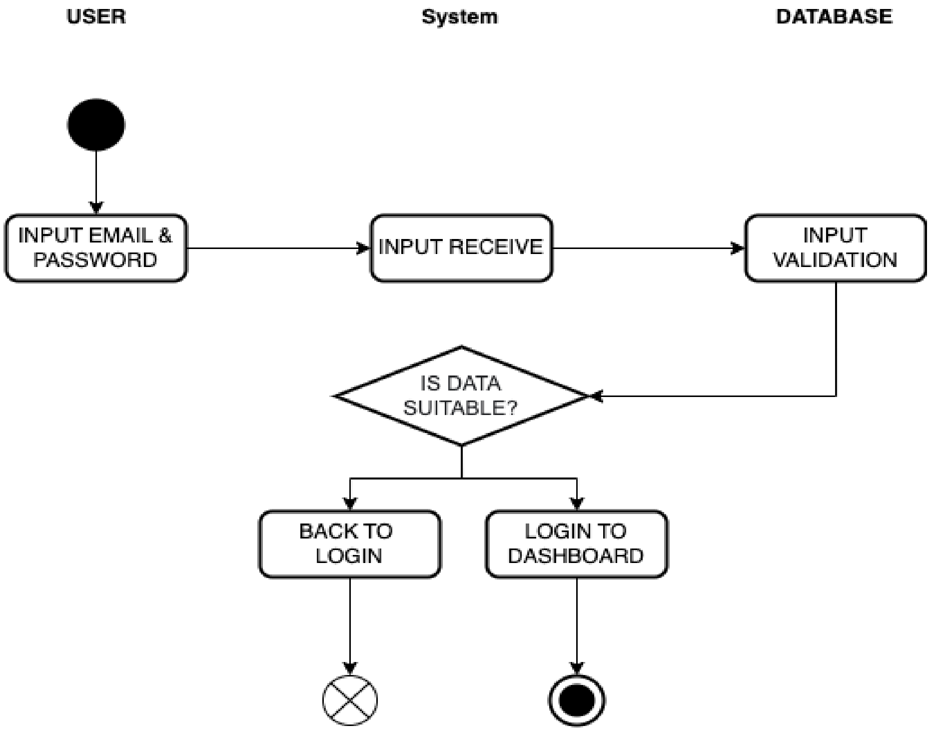


Fig. A5. Activity diagram of Login menu.

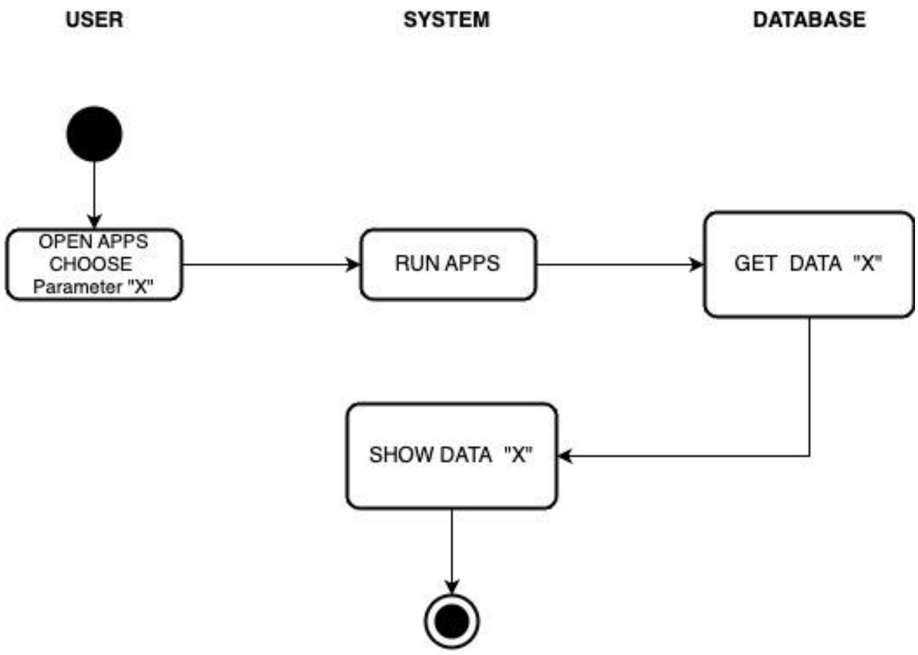


Fig. A6. Activity diagram of data viewing.

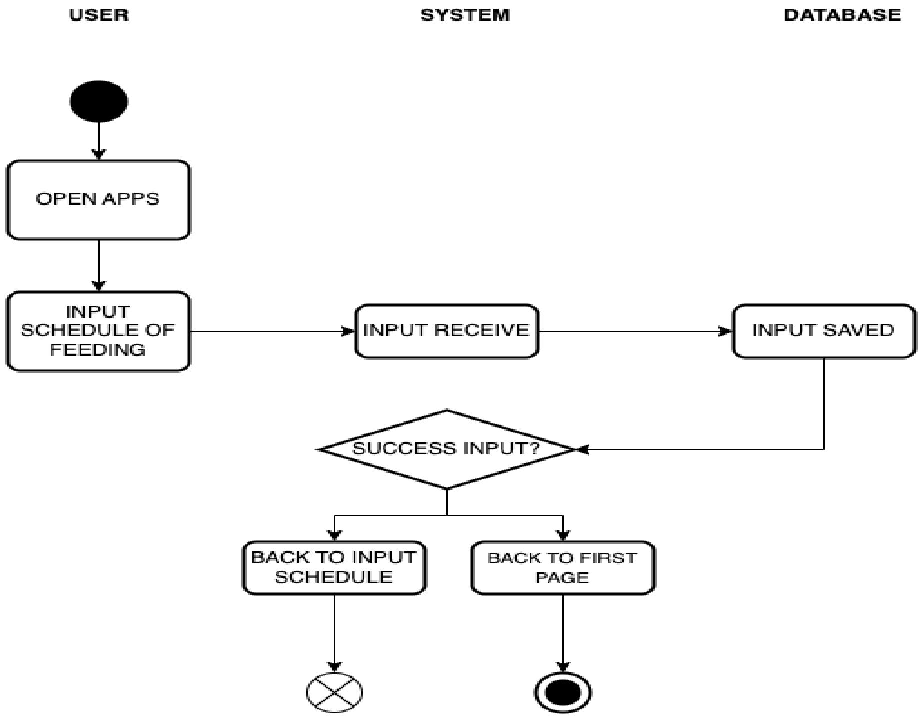


Fig. A7. Activity diagram of the automatic feeder.

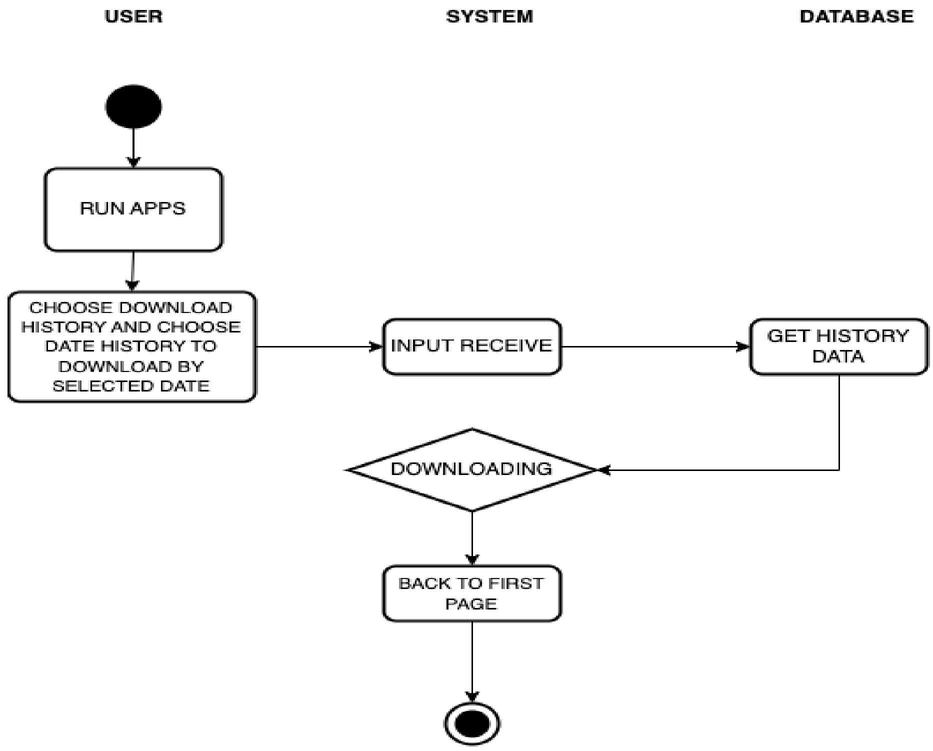


Fig. A8. Activity diagram of download history.

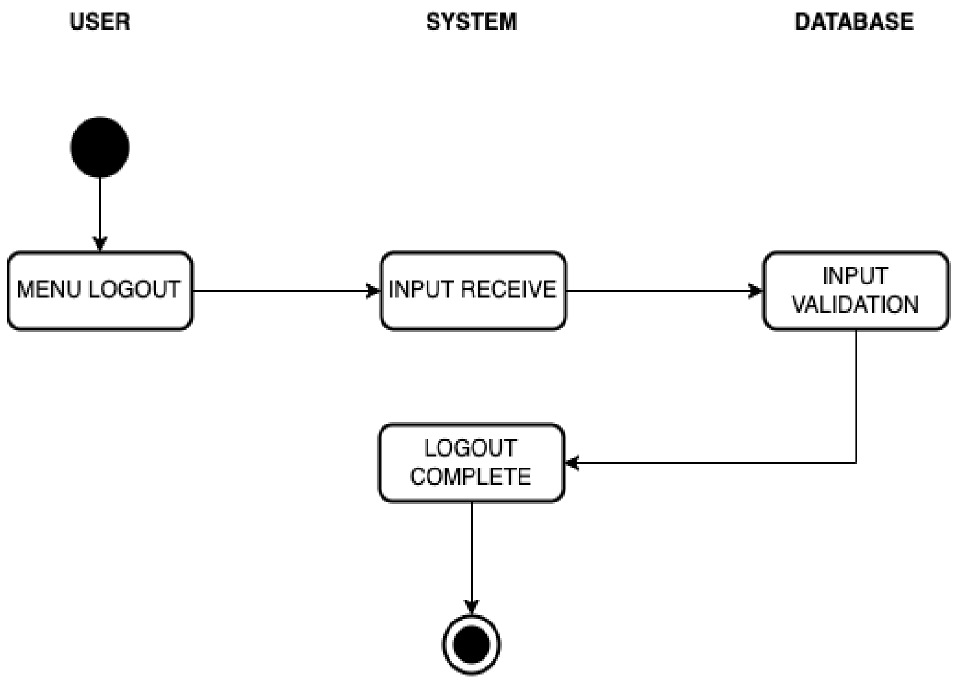


Fig. A9. Activity diagram of the Logout menu.

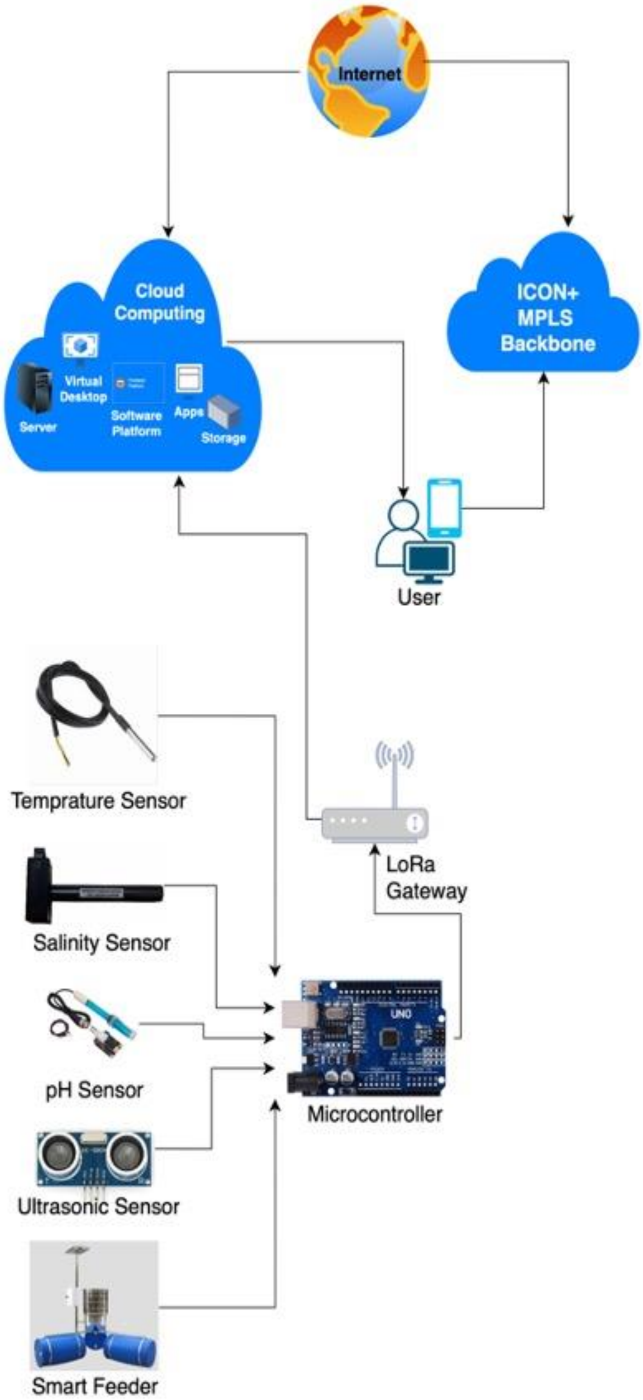
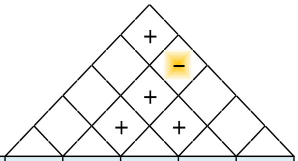
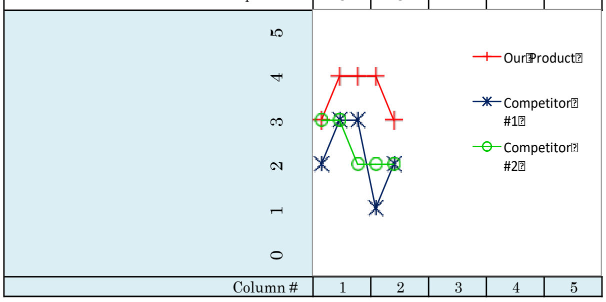


Fig. A10. Analysis of system architecture.



Weight	Column # / Customer Requirements (Explicit and Implicit) \ Functional Requirements	1 The strength of the package materials	2 Sensor Reliability	3 Quality of Application Functions	4 Time efficiency	5 Placement Position Quality	Competitor #1	Competitor #2
7	Water Resistant Packaging Design	●					P	F
5	Easy to Use			●			F	P
6	Maintain Water Quality		●	●		○	F	F
8	Facilitate Monitoring of Ponds			●	●		F	F
3	Having a Stable Network			●	○		P	P
4	Automatic Feeding		●		●	○	P	F
1	Affordable Price	▽	▽	○	●		G	F
2	Placement Position in the Middle of the Pond	○				●	F	P

	1	2	3	4	5
Target	Strong, protects the sensors inside	Able to maintain water quality	Able to monitor ponds in real time	Able to monitor ponds just by looking at the application	Easy to reach when refilling feed or tool maintenance
Importance Value	70	91	201	129	48
Difficulty Level	4	4	5	3	2
Relative	4	3	1	2	5
Our Product	3	4	4	4	3
Competitor #1:	2	3	3	1	2
Competitor #2	3	3	2	2	2



Correlations	
Positive	+
Negative	–
No Correlation	

Relationships	
Strong = 9	●
Moderate = 3	○
Weak = 1	▽

Competitor's Value	
GOOD	G
FAIR	F
POOR	P

Fig. A11. Result of House of Quality (HOQ).