Industry Paper

Low Cost Based IoT System in the Paddy Field to Labor-Saving and Feasible Study for Protecting Japanese Rice Terraces

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Abstract - Rice terraces, which are one of the factors that form the traditional landscape of Japan, exist in hilly and mountainous areas. Due to their topographical features and the aging agricultural workers, it is difficult to continue rice cultivation for a long time. Therefore, we focused on water management, which occupies approximately 30% of the working time in rice cultivation and proposed a paddy field water level monitoring system aimed at labor savings using Sigfox communication. We implemented a system that can be used by elderly farmers and conducted an experiment in Otari Village, Nagano Prefecture, to verify the functionality of the proposed system. As a result, we received results from both the quantitative and qualitative evaluations.

Keywords: IoT application, Agriculture, Paddy field, Sigfox, Labor saving.

1 INTRODUCTION

In the field of agricultural IoT, technological innovations in networks, hardware, and software have been progressing. In addition, studies and practical applications have been promoted to develop labor-saving and automation technologies. In this field, the amount of investment and the technological requirements differ greatly between full-time farmers and side business farmers. In addition, since the applicable technology differs depending on the breeding environment, a system that meets the requirements of the agricultural systems is required.

This study focused on labor-saving in water management for part-time farmers in terraced rice fields. Rice terraces are not only valuable as a landscape of Japanese “satoyama”, but are also an important resource in the region because they play a role in disaster prevention by taking irrigated land. However, they are difficult to pave and are not flat. For these reasons, the rice terraces have shrunk, and such a phenomenon occurs in mountainous areas with rice terraces. Therefore, we propose an IoT-based water level monitoring system that can be used by elderly farmers at a low cost for saving labor in rice terraces. Water management accounts for 30% of the agricultural work during rice cultivation, and we aimed to relieve the burden by saving labor. In addition, the proposed system was installed in three farms: the Otari Village, the Kita-azumi District, and the Nagano Prefecture, which are in a mountainous area with terraced rice fields. The usefulness of the system was verified by a quantitative and qualitative evaluation.

The novelties of this paper are (1) the design of supporting paddy field labors and implemented them in a real field as PoC (Proof of concept), (2) revealed the proposed system is reassuring to be able to make decisions on patrols in rainy weather and confirm information from a distance. Later points were important, especially for elderly people who are the main laborers in agricultural fields.

2 RELATED WORK

This section describes water management systems and applications for rice cultivation in the field of agricultural IoT. Before starting the introduction of real products, we describe the IoT-based prototypes for supporting agriculture especially for supporting paddy fields. In the paddy fields, water management is important and there are two types of technologies sense water levels. Former is a sensor to sense water level directly, the other is to utilize image data and analyzed them for sensing water level. Reference [2 and 3] shows IoT sensors can be utilized for sensing water level with inkjet-printed soil moisture and leaf wetness sensor and there are examples of former technologies. The other is showed in reference [4 and 5] and they used the massive image data and machine learning to measure water level in the paddy field.

Our proposed system adopted the former technologies; sensing water level with sensor and networked it for data utilization. Following products shows how IoT-based technologies are utilized for the paddy field management.

2.1 PaddyWatch

This product is a system that automatically measured the water level and temperature required for paddy rice cultivation, which also had a water level sensor in paddy fields sold by Vegitalia Co., Ltd. [6]. This product aims to reduce the number of water patrols and the time required for farmer patrols by providing the water level status on a web application. In addition, it had the necessary functions for proper water management and additional functions for data analysis. The network uses NTT DoCoMo’ SIM. The sensor unit could measure the water level and the water temperature, while optionally acquiring other data. The three series, PaddyWatch, PW-2300, and PW-2400, as of November 10, 2020, have a standard monthly basic charge (use period only) of 1,980 yen.

2.2 Paditch Gate 02+

This product realized real-time remote control of sluice gate management as one of the water management practices provided by Enowa Co., Ltd. [7]. The product has a water level adjustment function, and users could select a time in advance to close a water gate for the paddy fields. Additionally, the product could open and close the floodgate automatically. The sensor unit measures the water level and temperature of the paddy field. In water management, determination, and actions, such as opening the floodgate based on data about water level and temperature could add new water to the paddy field to raise the water level. Hence, if the system sensed that the water temperature would have been lower, the floodgate would have been closed. This product saves labor in water management by remotely controlling and automating the system.

2.3 Position of This Research

The above products for water management in rice cultivation have been expanded and introduced to actual sites. In particular, PaddyWatch performed water management using IoT technology, which was the purpose of this study. NTT DoCoMo’s network and radio waves were relatively stable even in mountainous areas. Therefore, stable operation was expected in the region as well. In addition, paditch gate 02+ could remotely control and automate the necessary water management after water level measurement and provided a service that enabled water management from a remote location. These products could solve the problems that farmers in terraced rice fields had, which will be described later. The novelty of this study was regarding its focus on the attributes of the subjects.

The agricultural population in rice cultivation was reducing, and the population was aging [8]. As mentioned above, there were many terraced rice fields in the mountainous areas, and the area of one paddy field was not as large as agricultural land. Thus, a large-scale yield could not have been expected. In addition, as the location may not have faced the maintained roadway, there were disadvantages in terms of location, such as the difficulty with inserting agricultural machinery [5]. However, terraced rice fields had various functions, and considering the sustainability from the viewpoint of land use in mountainous areas, it was important to incorporate labor-saving and automation technology to protect the terraced rice fields.

To keep the rice terraces as cultivated land, we thought that it was necessary to pay attention to the bearers and to have a system that matched the attributes of the agricultural population. In most agricultural IoT systems, the information provided was from a web application. However, for elderly people, web applications were often not tools that they used on a daily basis. The proposed system will be described below.

3 PROPOSED SYSTEM

The proposed system considered the network environments of the Otari Village, the Kita-azumi District, and the Nagano Prefecture, which cooperated with the proof-of-concept for this study, as well as the characteristics of farmers in rice terraces. The outline of the system is shown below, and then the details are described for each network, hardware, and software.

3.1 System Overview

Figure 1 illustrates the overview of this study. In the following, the technologies for configuring the system are shown separately for networks, hardware, and software. The paddy field water level monitoring system can be seen in a schematic diagram of this system in Fig. 1 for the terraced rice fields in mountainous areas.

The flow from data measurement to information provision shown in the figure is explained. First, the device that measured the water level and the other data in paddy fields had a built-in communication module with Sigfox and sent data at specified time intervals. Then, the data was sent to the Sigfox backend server, which sent it to the data server that we developed in MongoDB. This data server communicated with the web application server prepared for the web application for users and offered a web page that provided data visualization to each user. Hence, the measurement data, including the summarized information, was sent to the specified e-mail address.

The details of the network, hardware, and software, which are the technologies for configuring this system, are described below.

3.2 Network

For the network, we adopted Sigfox, which had been prepared by the local governments of the Otari Village. Sigfox was one of the LPWA (low power wide area) standards and was a global IoT network featuring low cost, low power consumption, and long-distance transmission [9, 10]. Using the frequency band at approximately 920 MHz of this network, the speed of uplink communication from the terminal to the base station was approximately 100 bps, and that of downlink communication was approximately 600 bps. In addition, the maximum data capacity that could be transmitted in one communication attempt was 12 bytes, the

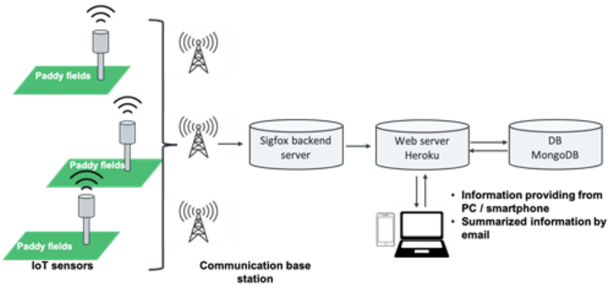

Figure 1 Overview.

Table 1 A list of collected data.

Data	Contents
Water level 1	5 levels (minimum value 3 cm to maximum value 5 cm)
Water level 2	0.5 cm (maximum 12 cm)
water temperature	Paddy water temperature (℃)
temperature	Temperature (℃) approximately 1.2 m from the ground
Humidity	Humidity on the board (%)
Atmospheric pressure	(hPa)
Substrate temperature	Substrate temperature （℃）
Illuminance	0-255 step illuminance
Internal operating voltage	(V)

Table 2 Detailed information of the payload design.

Byte index	Contents
0	Outdoor temperature
1	
2	Water temperature
3	Board temperature
4	Luminance
5	Voltage
6	Air pressure
7	
8	Humidity
9	Water level
10	Empty

upper limit of the number of communication attempts per day was set, and there was a limit of 140 times for uplink and 4 times for downlink.

The details of data selection will be described in the measurement section. This time, the data in Table 1 were acquired, and the payload of the data sent from the hardware to the Sigfox Backend Server was in the format shown in Table 2.

3.3 Hardware

This section describes the network-compatible water level measurement device installed in paddy fields, including the unit of measurement, transmission, and power supply. Figure

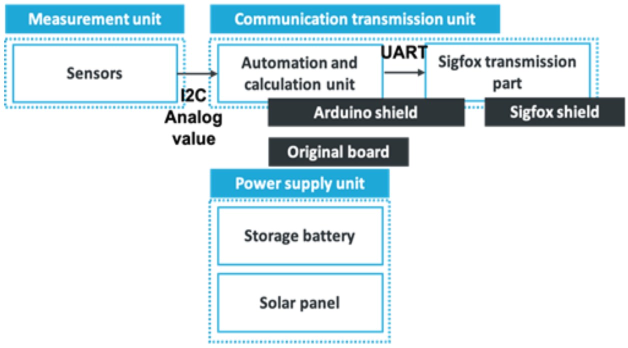

Figure 2 Block diagram.

2 shows a block diagram with the connections between each part and the board.

The hardware was divided into a data communication unit, a measurement unit, and a power unit. The measurement unit mainly measured water level data and environmental data, such as temperature and humidity.

Measurement unit

In this system, the water level and water temperature required for water management in paddy fields were collected as important measurement data. We used two devices with different measurement methods. One was a float switch type water level measurement sensor (hereinafter referred to as a float sensor) that determined the water level position by reacting to the reed switch by raising and lowering the float. The other was a float-less switch type water level measurement sensor that measured the resistance value (voltage) between two poles and determined the presence or absence of water [11].

The former was intended to be adopted in this system because it could be produced with a relatively inexpensive configuration, but the measurement interval depended on the size of the module. Therefore, when designing an existing module, the minimum measurement interval was 3 cm. In general, in the individual farmers' paddy field management, we expected that the resolution would be sufficient and proceeded with production. For the latter, the resolution was sufficient for water level measurement with a float sensor, a water level sensor (ASZ-M0917 [12] made by Aszac Co., Ltd.) that realized a measurement interval of 0.5 cm. Two

Communication unit

The details of the communication unit are described. The communication unit consisted of an Arduino that performed control and calculation as the main board, a Sigfox shield that performed transmission, and an original board that controlled the power supply unit. The role of the communication unit was from the measurement unit to analog values, and the purpose was to send 9 types of data (Table 1) collected by I2C communication to the Sigfox Backend Server. A Sigfox module that could be connected to the Sigfox network was connected to the transmission unit, and data was transmitted to the data Sigfox Backend Server at the transmission timing and transmission interval specified by the control unit. Table 3 shows the details of the measurement items and the details of each measurement item of the Sigfox payload.

The data transmission timing is summarized below.

- When the water level changed, it was measured every 10 minutes, and data was transmitted when the amount of water level change from the previous transmission value changed by 1 cm or more for the water level sensor and 1 step or more for the float switch.
- Regular transmission: Every 30 minutes

Table 3 Detailed information of collected data.

Byte Index	Type	Data	Details	Error	Value
0	Int16	temperature	The temperature of the sensor installed at a position approximately 1.2 m above the paddy field	-1270	275 / 27.5 ℃
1	Int8	water temperature	Paddy water temperature Decimal point truncation	-127	27 / 27 ℃
2	Int8	Substrate temperature	Substrate temperature Decimal point truncation	127	27 / 27 ℃
3	Int8	Luminance	0 - 255	-	240 / 240
4	Uint8	Internal operating voltage	Operating voltage of the main IC inside the board, rounded down to the first decimal place	-	50 / 5.0 V
5	Uint8	Barometric pressure	Atmospheric pressure on the board, Rounded down to the first decimal place	65535	10132 / 1013.2 hPa
6※7	Uint16	Humidity	Humidity on the board, Decimal point truncation	255	42 / 42 %
8	Uint8	Water level	6 levels of water level measured with a float switch	255	1 / 1
9	Uint8	Water level	25 levels of water volume measured by water sensor every 5 mm	255	3 / 1.5 cm
10	Uint8	Substrate temperature	The temperature of the sensor installed at a position about 1.2 m above the paddy field	-	-
11	empty	unused	-	-	-

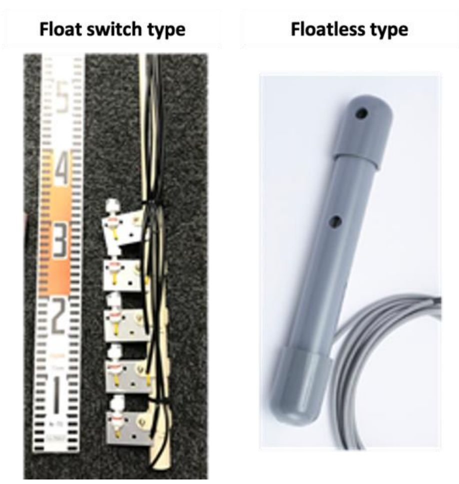

Figure 3 Appearance of two types of water level sensors.

types of sensors were used together. Figure 3 shows the appearance of the two sensors.

In this study, we designed a float sensor-type water level measurement sensor. Float sensors were installed at intervals of approximately 3 cm, and fine adjustments were made at the time of installation where the threshold value was requested. As mentioned above, the minimum value could have been adjusted to approximately 3 cm, but it was possible to register the desired interval of the user in the system. If the interval was 5 cm, the measured quantity was 0 to 20 cm. Next, Figure 4 shows the circuit diagram of the float sensor. The float sensor of S1 in the figure shows the ground side. The resistance value (SUM R1 to R5) changed by grounding in order from S1, and the design enabled identification by the input voltage.

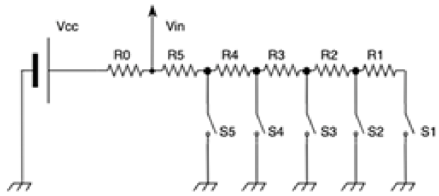

Figure 4 Float sensor input circuit diagram.

Table 4 A table of Analog voltage threshold.

	Measured value(mV)	Theoretical value(mV)	THRSD+	THRSD-
FREE	5000	5000	0	418
S1	4169	4165	418	83
S2	3998	4000	83	125
S3	3758	3750	125	208
S4	3450	3335	208	418
S5	2917	2500	418	2500
FREE	5000	5000	0	418

We collected not only the water level, but also the environmental data, such as water temperature, outside air temperature, humidity, and atmospheric pressure, as well as the state data inside the device (Table 1). The data was necessary for rice cultivation and for utilizing the internal state data of the device. A sensor (DS18B20) was used for water temperature and air temperature, and a sensor mounted on Sigfox's transmission module Una Shield (V2S2) was used for collecting humidity, atmospheric pressure, and substrate temperature data. The illuminance was converted from the input terminal of Arduino, which was capable of an analog input of 0 to 5 V, into 256 steps of 0 to 255 using a diode.

The conversion was an Arduino specification, and the resolution was 19.5 mV. Regarding the illuminance, it was assumed that the timing of sunrise and sunset and the relative shadow when compared with other days would have been used as a reference. Hence, it was not assumed that it would have been converted into a physical quantity that indicated the actual brightness of light. The internal operating voltage was the voltage that operated on the main IC in the Arduino. A voltage of 9 to 24 V was input from the battery to the Arduino, and the voltage was internally stepped down to 5 V. Since the value was the voltage collected in the main IC, 5 V was measured in principle.

Power supply part

The power supply unit used solar panels to generate electricity and a storage battery installed inside the device. It rained for 2 to 3 days after being fully charged. In addition, the solar panel should be installed at a position different from the sensor device. Table 5 showed the electrical characteristics of the solar panel used this time. Table 6 showed the electrical characteristics of the device. Figure 5 showed the appearance of the hardware.

3.4 Software

The abovementioned hardware in a paddy field collected data for paddy field monitoring, such as the water level, and visualized it with a device. The software had three functions as a web application. For example, a smartphone or PC provided an environment where the status of the paddy field could be confirmed, even from a remote location. The following points were developed for the functions of the web application.

1. Periodically collected measurement data from the Sigfox backend server
2. Displayed the measurement data on the web page on user screens
3. Sent the latest measurement data to the specified email address at the specified transmission interval

The function of item (1) was to store data from the Sigfox backend server in a data server prepared in advance. For that, we developed a webhook on the Sigfox backend server side and stored it in the prepared database. A “Webhook” was a mechanism to notify an external service by HTTP when an event was executed in a web application. When new data was stored in the Sigfox backend server, the data was sent to the database at the same time. As item (2) under this function, the DB acquired the latest data and reflected the latest data on the web page from the linked web application server. In addition, as item (3), regularly sending to e-mail would be carried out.

We built the web application server in Heroku, which is a cloud application platform, using Node.js, which is a JavaScript language. In addition, MongoDB, a document-oriented database, was used as a DB for storing measurement data, and data was linked between Heroku and this database using socket communication. In Heroku, we built a front side that presented web pages built using the JavaScript framework, Vue.js, and the CSS framework, Bootstrap. Figure 6 is implemented for the above functions. Table 3 shows the development environment.

Table 5 Characteristics of solar panel

Item	Detailed information
Normal state	12 W
Maximum output power	21.8 V
Open circuit voltage	0.73A
Short-circuit current	17.4 V
Maximum output power voltage	0.69A
Maximum load current	-

Table 6 Characteristics of electrical device.

Item	Use
Storage battery capacity	14000 (mAh)
Input voltage	9～24 (V)
Operating voltage	9 (V)
power consumption	Standby: Approximately 0.36 (W) When sending: Approximately 0.9 (W)
Operating temperature	0-40 (℃)
Storage temperature	-40-85 (℃)

Figure 5 Appearance of designed hardware and setting.

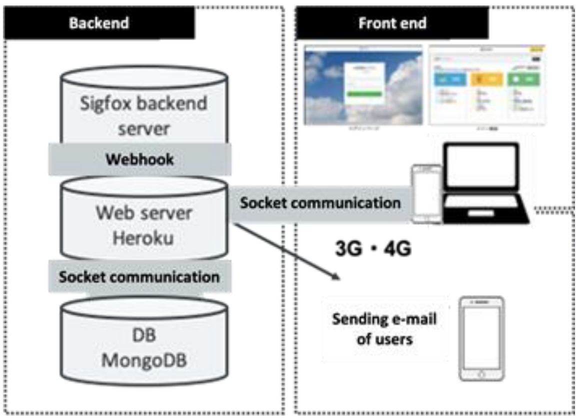

Figure 6 The overview of proposed system.

Table 7 The development environment of the software.

Object	Purpose
Development PC	Macbook
Web application server	Heroku
Data server	MongoDB
Backend and frontend development languages	Node.js
Front-end development language	Vue.js
Bootstrap	CSS framework for front-end development

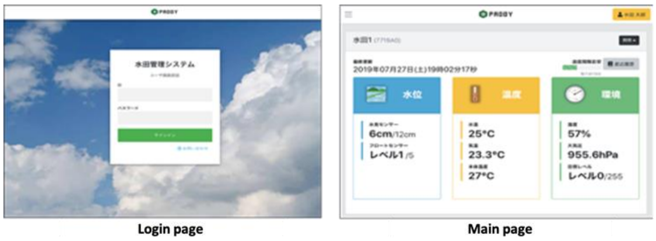

Figure 7 Screen shots of the login and main web pages.

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Figure 7 shows a screenshot of the actual web page. On the main screen, users could browse data by water level, temperature, environment and category, and the gauge on the right showed the time until new data was sent to the Sigfox backend server. The latest data was reflected on this page.

In addition, this web page design was created from interviews conducted in advance with the experiment participants who were paddy field owners. The participants had an internet environment, had no resistance to digital devices, such as personal computers, smartphones, and tablets, and were willing to use web applications, but selected the types of data to be provided (mainly water level). The water temperature was easily noticeable, and they requested push-type data provision by e-mail notification. Therefore, we implemented a simple design, as shown in Fig. 8, and an email notification function.

E-mail notification

This function inserted the latest data in the database into a premade fixed phrase at the time specified by the user and sent it to the specified e-mail address. This function was executed in Heroku and received by the user through a wide area network, such as 3G/4G.

4 EXPERIMENT

This section describes an experiment for the proposed system. The experiment was conducted in the Otari Village, the Kita-azumi District, and the Nagano Prefecture, for approximately two months from July 12 to September 20, 2019.

The experiment participants were three paddy field owners, devices were installed in each of the three paddy fields, and a total of nine devices were operated. Before and after that, we collected hearings to obtain information related to this system. The information on collaborators, including geographical information, is described Table 8.

In addition, Fig. 7 illustrates the overall positional relationship by plotted in Google Map [13]. From the north, there were the Fukahara, Mushio, and Kurokawa districts. Figure 8 shows the rice terraces in the Otari Village.

Table 8 Information of experiment participants

Number	District	Age	Experiment target paddy field
N	Fukawara	70s	Three
C	Kurokawa	40s	Three
S	Mushio	60s	Three

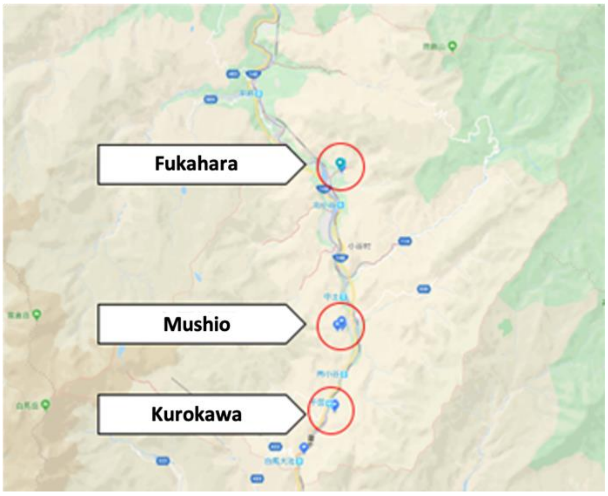


Figure 7 Places of the experiment.

Figure 8 Rice terraces in the Otari village.

5 EVALUATION

This section describes the evaluations collected from the experiments in networks, hardware, and software.

5.1 Network

This section summarizes the radio wave conditions in each area created based on the RSSI values stored in the Sigfox backend server. Figure 9 illustrates the location of the Sigfox base station and each district. Three Sigfox base stations were installed in the Otani Village, and the identification IDs of the base stations were 65B2, 65A3, and 6595. Each base station was installed near the center of the identification ID circle shown in Fig. 9 plotted by Google Map [13].

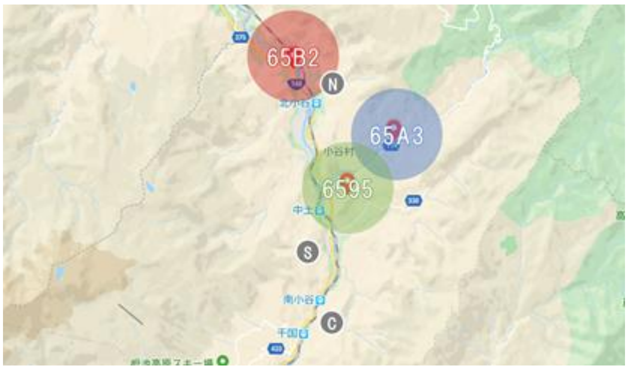


Figure 9 Location of the base stations and the experimental districts.

Although Sigfox had a domestic population coverage rate of 95% in Japan [1], a base station was set up because there were areas where radio waves did not reach the Otari village, which was a mountainous area. Since this system was the first outdoor IoT system installed in the village, this analysis was conducted with the aim of confirming whether the network was working properly. Figure 10 shows the radio field intensity data in the Fukahara area. The frequency of transmission to the base station of 65B2 was shown in the figure. The same analysis was performed in the other two districts, and we found that the frequency of transmission to neighboring base stations was high.

From this result, it was concluded that the network was stable and did not lead to system operation problems, such as data loss.

5.2 Hardware

This section mainly describes the measurement results of the water level sensor data. Figure 11 illustrates all the data measured from the float switch and the water sensor from July 11, 2019, to September 19, 2019 (70 days) in the Kurokawa district C-1. The horizontal axis represented the date, and the vertical axis represented the water level (0 to 15 cm). The amount of water in C-1 was relatively small, and the average value was close to 0. Comparing the value of the float sensor with the value of the water sensor as a reference, it could be seen that the value fluctuated according to the value of the water sensor. However, from 8/5 to 8/7, 8/11, and 8/13, there were some places where the float sensor did not move.

Figure 11 shows that two types of water level sensor's result of sensing data.

5.3 Software

Since the stable system operation was observed in the software, the results were described in the interview based on the questionnaire conducted face-to-face in this evaluation. The data obtained from this system and the usability of the web application are described below.

Data

The three collaborators browsed the web application more than three times per day and were highly interested in the measurement data. The most interesting data were the water level, followed by the air temperature and the water temperature. Since the data on the air temperature and the water temperature could not be confirmed thus far, the collaborators wondered how the data related to the growth of rice. In addition, the atmospheric pressure and the illuminance were not very helpful for cultivation.

Web application usability

The convenience of the web application was highly evaluated from the experiment participants, and the usability was also highly evaluated. However, there was a good point made that the necessary data, such as the display of the maximum and minimum temperatures of the day could be displayed, and that the flexibility of the data display function could be a future issue. In addition, the method of browsing web applications differed depending on the personal computers, tablets, and smartphones. Therefore, a

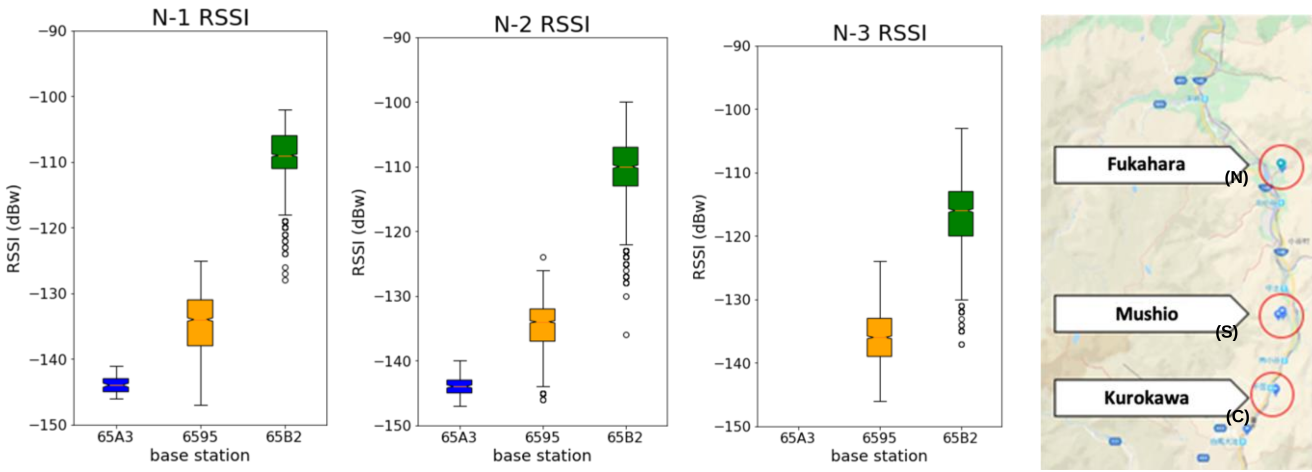
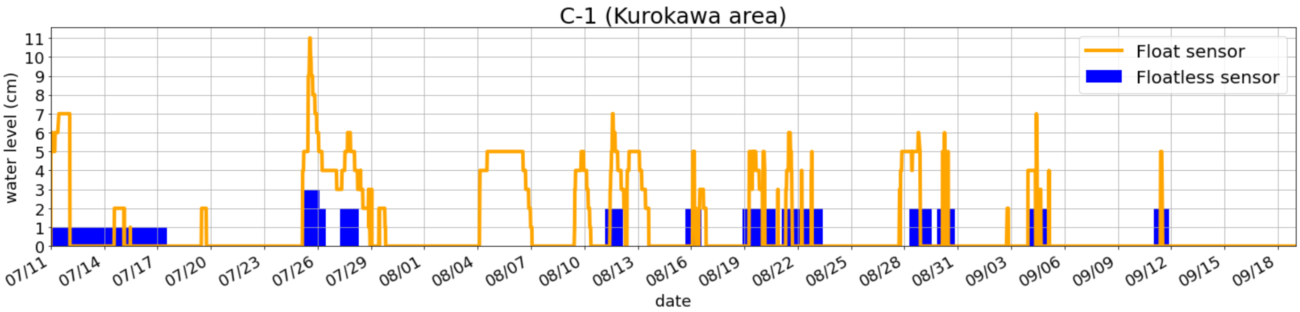


Figure 10 Graphs of RSS values.



Float sensor

Average	0.2 cm
Maximum	3.0 cm
Minimum	0.0 cm

Floatless sensor

Average	0.2 cm
Maximum	11.0 cm
Minimum	0.0 cm

Figure 11 Collected data from two types of water level sensors.

collaborator expressed that the display was small, and it was considered necessary to make the font size customizable.

Email notification function

For the e-mail notification function, we customized the paddy field managers to provide the most suitable information for each individual. It was the latest information on the three items of water level, water temperature, and temperature, but there was a collaborator who mentioned that the water level was only enough for one of the participants, and the user needed customizable management functions.

5.4 Overall

The purpose of this system was to save labor. The system can support paddy field labors in the point that it provides useful information for confirming the decisions concluded from patrols. Many collaborators expressed that they wanted to grasp the rice growing situation by looking at the state of the paddy field, and it was difficult to provide an effect that exceeded the visual inspection of the rice growing situation from the provision of information. Therefore, remotely providing paddy field information would be useful for them, and if an automatic water level management system could have been connected to our system, the number of patrols by users would have been reduced dramatically.

6 CONSIDERATION

Based on the results of the previous section, this section describes considerations in networks, hardware, and software. In addition, we considered whether the system was designed to be used by the elderly, who were the bearers of rice cultivation in the rice terraces in this study.

First, regarding the network, problems could not be found. Next, regarding hardware, we considered the water level to be the most important part of the data and focused on water level data analysis. As a result, problems were found with each of the float sensors and the water viewing sensor. If this data was unreliable, the value of the entire system would have been lost. Thus, we decided that a review was necessary. However, in this respect, the characteristics of paddy fields varied widely, making it difficult to design hardware that could handle all paddy fields. It would have been necessary to consider how to make it versatile.

In addition, two of the three participants in the experiment were elderly people, and the fact that both understood how to use this system and connected it to the paddy field patrol was useful for the purpose of this system. The evaluation was obtained. In addition, some participants were considering the use of the collected data, though we found that the collected data was expected to be used not only for patrols of paddy fields, but also for the prediction of harvest time and quality control. Therefore, it will be necessary in the future to improve the reliability of the data and organize the functions for providing simple data to farmers.

7 CONCLUSION

In this study, a demonstration experiment using a paddy field water level monitoring system was conducted in the Otari Village, the Kita-azumi District, and the Nagano Prefecture, where Sigfox, which was one of the area networks, could have been used, with the aim of saving labor in paddy field patrols by providing information. The availability of this system was confirmed from the results of the quantitative and qualitative evaluations obtained from the abovementioned demonstrated experiments and hearings.

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