SALATA: A Web Application for Visualizing Sensor Information in Farm Fields

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Abstract: Semi-automated sensing and visualization of conditions and activities in farm fields have been actively pursued in recent years. There are three types of agricultural information: sensor information, farm work information, and plant biological information. Measuring and visualizing these agricultural information can provide valuable support to farm managers. In this study, we focus on sensor information and farm work information and develop a web application named SALATA (Sharing and AccumuLating Agricultural TAcit knowledge) that collects and shares sensor information and farm work information collected in farm fields and correlates the information in time series. SALATA need to have intuitive operation and quick response in order that people of various ages will use it on a daily basis. Therefore, there are two primary pages: the main page for visualizing simple information quickly and the analytical page for visualizing multiple pieces of information on one page. Usability evaluation experiments are performed, showing that SALATA can be operated intuitively and respond quickly.

1 INTRODUCTION

Japan is an island country surrounded by an irregular coastline. It is also a mountainous country with small flatlands. These geographical features bring diverse climates and soils to Japan. Japanese cultivation has been hindered by the increase in scale, and specialized agriculture is also practiced in various kinds of local conditions. These characteristics of Japanese cultivation make it difficult to accumulate cultivation knowledge and to automatically control farm field environments, even in a greenhouse based on cultivation know-how. Therefore, farm managers must, by themselves, acquire specialized know-how for their own farm fields.

The problem of knowledge acquisition is becoming more critical owing to the rapid ageing of the Japanese population. In mountainous farming areas, for example, 39% of farmers are over 65 years old(Ministry of Agriculture, Forestry and Fisheries, Japan, 2019). Many experienced farm managers are retiring every year due to their age. In addition, many young farm managers are leaving the farming profession owing to lack of cultivation know-how.

In recent years, rapid advances in technologies related to the Internet of Things (IoT) have made various sensor devices and their networks popular and economical. Therefore, small farmers in Japan can introduce sensor networks to their farm fields to measure and quantify cultivation know-how. The Japanese Government also promotes this movement. As a result of these circumstances, we are developing SALATA, which is a web application to facilitate the visualization of various types of farm field data, and to support farm managers in acquiring important cultivation know-how and awareness of causal relationships among field environments, farm work activities, and crop conditions.

2 RELATED WORK

There are three types of agricultural information that are of interest in this study: sensor information, farm work information, and plant biological information. Measuring and visualizing these agricultural data can

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provide valuable support to farm managers. Wjtowicz et al.(Wójtowicz et al., 2016) described the importance of sensor information, which are of three types: satellite, airborne, and ground based. These information sources contribute to the forecasting of crop yield, assessment of nutritional requirements of plants and the nutrient content in soil, and determination of plant water demand and weed control. This optimizes the profitability of crop production and improves environmental protection. In this study, we focused on sensor information and farm work information. There has been much research and many developments related to visualization of sensor information and farm work information.

For example, MIHARAS[1], developed by Nishimu Electronics Industries Co. Ltd., Agrilog[2], developed by ITKOBO-Z Co. Ltd., and SEnviro(Trilles Oliver et al., 2019) visualize sensor information. MIHARAS provides an open-field sensor unit, a weather sensor unit, and a paddy field sensor unit. The open-field sensor unit measures temperature, humidity, soil moisture, soil electrical conductivity, and soil temperature. The weather sensor unit measures wind direction, wind speed, rainfall, solar radiation, temperature, and humidity. The paddy field sensor unit measures temperature, humidity, water level, water temperature, and soil temperature. MIHARAS visualizes the information from these sensors on personal computers (PCs), smartphones, and tablets (hereinafter, referred to as user devices). Agrilog is an environmental monitoring service for greenhouses that can measure temperature, humidity, CO_2 concentration, solar radiation, soil temperature, soil moisture, and soil electrical conductivity. This sensor information is visualized by user devices, and some processed information such as an average temperature can be calculated and plotted. In addition, users can share their sensor information with each other. SEnviro can measure temperature, humidity, barometric pressure, soil moisture, wind direction, wind speed, and rainfall. This sensor information is visualized by a web application in real-time. The primary aim of SEnviro is to use disease warning models of crops in order to alert users to the danger of crop infection. Sensing and analyzing in real-time enable them to tackle the infection with the appropriate treatments.

The Priva FS Reader[3], developed by Priva Inc. and Hashimoto et al.(Hashimoto et al., 2016), provides visualization of farm work information. The Priva FS Reader is a device that can easily record farm work information. It was developed to manage a large number of laborers on a large farm field. A special tag is installed at the edge of the each ridge in the farm field, making it possible to perceive where the farm laborer worked by scanning it with a device each farm laborer wears. For example, by associating with the box ID that contains the yield, it is possible to perceive when and how many were harvested, and by whom. In addition, crop conditions, diseases, and pests can be easily registered and visualized on a map. Hashimoto et al. estimated a farm laborer's position in a greenhouse by using a smartphone and beacons placed in the greenhouse. At the same time, they estimated the farm laborer's actions to harvest based on the worker's motion as measured by smartwatches, and subsequently measured the yield. Finally, they created a harvesting map by integrating the position and action information. Using this, they can generate much detailed farm work information.

Midori Cloud[4], developed by SERAKU Co. Ltd. visualizes sensor information and farm work information on a user device by installing a sensor unit in a greenhouse. This sensor unit measures temperature, soil temperature, humidity, CO_2 concentration, and solar radiation. In addition, the Midori Cloud also has a function to record farm work information called Midori Notes. However, sensor information and farm work information are not integrated for visualization.

It is necessary to integrate and visualize sensor information and farm work information, because there are causal relationships between them. For example, if high solar radiation continues, the yield, or the harvesting work will increase, and if the greenhouse is ventilated, the CO_2 concentration will change rapidly. SALATA, our web-based application, visualizes both sensor information and farm work information such that farm managers can easily understand the causal relationships between them.

3 SHARING AND ACCUMULATING AGRICULTURAL TAcit KNOWLEDGE (SALATA)

We have developed SALATA to visualize sensor information and farm work information. We anticipate that farm managers will improve the farm field environment by using SALATA as discussed below.

1. SALATA collects sensor information and farm work information.

[1]https://www.nishimu-products.jp/miharas
[2]https://itkobo-z.jp/agrilog
[3]https://www.priva.com/us/products/fs-reader
[4]https://info.midoricloud.net

2. SALATA visualizes sensor information and farm work information.
3. Farm managers analyze and compare with the other farm field's information or the past information.
4. Farm managers improve the farm field environment based on the analysis.

Moreover, it will be easy to understand the relationship between the farm field environment and the farm manager's decisions by associating sensor information and farm work information in time series. For example, if farm manager A ventilated the greenhouse because of the increase in temperature. When Farm manager B sees only the sensor information, he can only understand that the temperature has suddenly dropped. However, if farm work information, such as ventilation changes, is posted by farm manager A in SALATA, farm manager B can understand that the temperature has suddenly dropped because farm manager A has ventilated the greenhouse.

In this paper, we focus on visualizing sensor information and indicate various functions and their evaluation results.

3.1 Sensor Information

In this study, we employ Midori Cloud developed by SERAKU Co., Ltd. for farm field sensing. The Midori Cloud sensor unit measures temperature, humidity, solar radiation, soil temperature, and CO_2 concentration every two minutes. In addition to these parameters, we deal with "humidity deficit," which is the amount of water vapor that must be added to a gas in order to achieve 100% humidity at the current temperature. Humidity deficit is one of the dominant factors affecting the rate of photosynthesis. Humidity deficit $D[g/m^3]$ is calculated from temperature $T[°C]$ and humidity $H[\%]$. The formula for calculating humidity deficit D is shown in Equation 1 below.

$$D = \frac{(100-H) \times 217 \times 6.1078 \times 10^{(7.5 \times T/(T+237.3))}}{(T+273.15) \times 100} \quad (1)$$

where H and T represent the humidity and Celsius temperature, respectively.

3.2 User Interface

SALATA must ensure intuitive operation and quick response. This is because it is assumed that people of various ages will use it on a daily basis. It seems that there are farm managers of various ages and some people are not familiar with user devices. SALATA must have a user interface that can be operated intuitively by farm managers who are not familiar with user devices. To that end, we unified SALATA's configuration. In addition, it is assumed that SALATA is used daily because farm managers usually do farm work every day. In order for farm managers to use SALATA daily, SALATA must offer a user-friendly experience. To that end, we minimized the amount of data loaded at once.

Figure 1: The main page of SALATA.

There are two primary pages displayed by SALATA: the main page and an analytical page. If the user wants simple information quickly, we recommend the use of the main page. If the user wants to view multiple pieces of information on one page, we recommend the use of the analytical page. The main page simply displays sensor information and farm work information. This page displays real-time data and dynamic graphs. On the analytical page, the user can observe sensor information. This page displays multiple-series graphs and parallel display graphs.

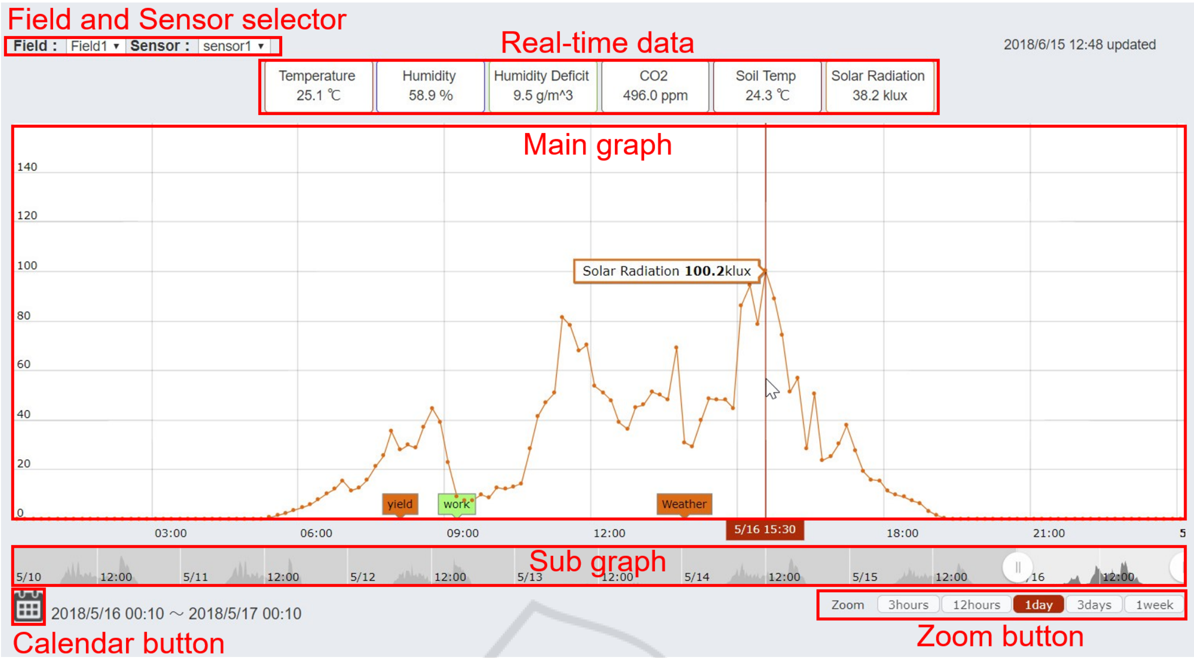

Figure 2: Dynamic graphical displays.

3.2.1 Real-time Data

The main page of SALATA is shown in Fig.1. At the top of the page, there are buttons showing the categories of sensor information; the latest data is displayed on each button. The user can change the category of the graph by clicking these buttons. For example, when the user clicks the solar radiation button, the graph switches from temperature data to solar radiation data. Moreover, the items "Field" and "Sensor" displayed above these buttons indicate the source of the sensor information displayed on the main page. The user can change the graph displayed on the main page by switching the "Field" or "Sensor" item.

3.2.2 Dynamic Graphical Displays

SALATA uses amCharts[5] for graphical displays. amCharts is a javascript-based graph creation library suitable for dynamic graphical displays. There are two graphs(Fig.2) on the main page: the graph with a white background at the top is the main graph, and the graph with a gray background at the bottom is the subgraph. If the amount of data loaded for these graph is large, the response will be slow. To avoid this, we set a loading period $T[min]$ and an interval of data subsampling as $t[min]$ $(T \geq t \geq 10)$. Then, the amount of data loaded at once is n, where n satisfies the following Equation 2.

[5] https://www.amcharts.com

$$n = \frac{T}{t} \tag{2}$$

If the data interval in the database is smaller than t, we take the average for t minutes. For example, the Midori Cloud sensor units measure every two minutes, but if $t = 10$, the amount of data will be one fifth of the total data. In this way, SALATA can respond quickly.

To provide flexible viewing of the loaded data, there are three ways to change the period displayed in the main graph: the zoom, sub graph, and calendar buttons. First, the zoom button at the bottom right of the main graph can specify the exact period. We can determine an arbitrary value of this button. In this study, we decided on values of 3 hours, 12 hours, 1 day, 3 days, and 1 week. If the user clicks the 3 hours button, the loaded data from the last 3 hours is displayed in the main graph. Second, the sub graph below main graph can flexibly change the period. The period displayed in the main graph is changed by sliding the bar on the side of the selection range in the sub-graph or by dragging the selection range. Third, the calendar button at the bottom left of the main graph can specify any day of all periods measured by the sensors. By specifying a date from this calendar button, a user can load the data for the past T minutes from the specified date and display the data from the specified date in the main graph. As a result, the user can change the period displayed in the main graph.

In addition, units, minimum values and maximum values of range, and colors have been unified under a category so that users can operate SALATA intuitively. The correspondence table is shown in Table 1. The minimum and maximum values were determined to be values that can cover all values except the outliers from the data set collected by Hashimoto et al(Hashimoto et al., 2016).

Table 1: Unit, Minimum, Maximum and Color by a Category.

Category	Unit	Min	Max	Color
Temperature	$^\circ C$	0	40	#E50000
Humidity	$\%$	0	100	#3A10F2
Humidity Deficit	g/m^3	0	20	#43B929
CO_2	ppm	350	700	#68645A
Soil Temp	$^\circ C$	0	40	#9A031E
Solar Radiation	$klux$	0	150	#FF6000

3.2.3 Multiple-series Graphs

In a multiple-series graph(Fig.3), multiple categories of multiple sensors can be displayed on a single graph. This view is suitable for investigating the relationship between categories on a time series. For example, when an anomaly is detected in a humidity deficit measurement, it is easier to determine whether it is being caused by temperature or humidity, by displaying the temperature, humidity, and humidity deficit in the multiple-series graph.

The method for creating a multiple-series graph is as follows. First, the user can transition to the analytical page by clicking ”Analyze” at the top of the main page(Fig.1). When the user clicks the ”Create a new graph” button on the analytical page, a mode selection window appears, which allows the user to enter options for the multiple-series graph. There are three options: farm field, period, and categories. When the user selects a farm field, the category field changes to the sensor information corresponding to the farm field. When the user specifies a period, the interval of data sub-sampling is automatically determined according to the period. This is done to avoid a slow response due to an excessive amount of loaded data. In this study, data are sub-sampled by the average so that the number of samples becomes 150 or less.

3.2.4 Parallel Graphical Displays

The created multiple-series graphs are shown in parallel(Fig.4). Specifically, the user can display a multiple-series graph in parallel by creating another multiple-series graph. This allows the user to compare the available information with those of other farm fields or with past data.

4 EXPERIMENT

In this experiment, we gave human subjects a set of tasks based on actual use to evaluate the usability of the dynamic display graph, the multiple-series graph, and the parallel display graph.

4.1 Experimental Method

This experiment was conducted on 14 subjects aged 19 to 26 who had previously never used SALATA. All of the subjects have operated personal computers (PCs) and smartphones with graphical user interfaces on a daily basis. The data set used in this study consists of sensor information on temperature, humidity, CO_2 concentration, soil temperature, and solar radiation observed in a tomato farm field in Fukuoka City from September 19, 2017 to February 1, 2018. In addition to these data, we also handled humidity deficit calculated from the temperature and humidity. The parameters related to the loading of data for the dynamic display graph were set to $t = 10$ and $T = 10080$ (1 week). As a result, $n = 1080$.

The 14 subjects were divided into two groups. One group was given only tasks and no lecture, and the other group was given tasks after a lecture on how to use SALATA. Subjects of both groups practiced for three minutes before doing the first task. There were three types of tasks, and we measured the time required for completing each task. Task 1 is related to the dynamic display graph on the top page, such as ”Please display the graph of solar radiation on December 13, 2018 on the top page.” Task 2 is related to the multiple-series graph and the parallel display graph on the analytical page, such as ”Please display graphs of temperature and solar radiation from December 1, 2018 to December 31, 2018, and January 1, 2019 to January 31, 2019 so that you can compare temperature and solar radiation.” Task 3 is to find an anomaly value of CO_2 assuming actual use, such as ”Normally, a CO_2 generator runs to maintain the CO_2 concentration in the greenhouse above a certain level. In this data set, there are several days when this equipment does not run.Please find a day when this equipment does not run by using the analysis page.” Both subject groups performed Task 1 and Task 2 first (first trial). After an interval of 30 or more minutes, the subjects performed Task 1 and Task 2 again (second trial). The first trial and the second trial are same except for the dates and categories. After those tasks, Task 3 was performed, and finally, we conducted a questionnaire.

The questionnaire was created based on the web usability scale (WUS)(Nakagawa et al., 2001) and

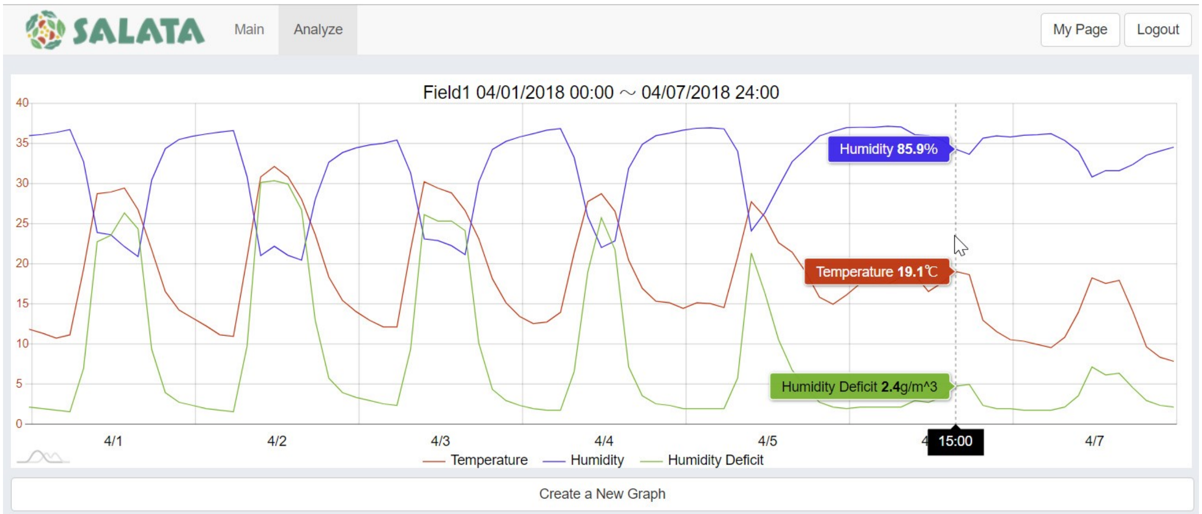

Figure 3: Multiple-series graphs.

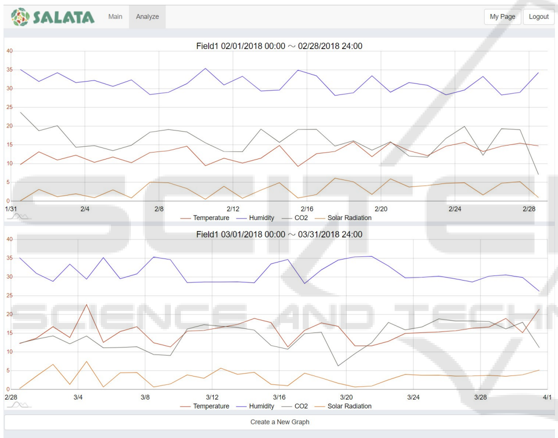

Figure 4: Parallel graphical displays.

modified for this experiment. WUS is a questionnaire to evaluate the Web Usability developed in Japanese, because the existing questionnaire (QUIS(Chin et al., 1988) and SUMI(Kirakowski and Corbett, 1993)) was developed in English and it is difficult to administer it in Japan. There are seven evaluation factors in WUS: favorability, usefulness, reliability of contents, operability, composition, visibility, and response. In this experiment, we evaluated SALATA with five factors: operability, composition, visibility, response, and functionality. There are two questions for each evaluation factor, as listed below (▽ means an invert scale).

1. Operability
   - This website is simple and easy to use.
   - I immediately understood how to use this website.
2. Composition
   - This website is consistent.
   - The structure of this website makes it is easy to understand the available content.
3. Visibility
   - The graphs and charts on this website are difficult to see. ▽
   - Using this website tires my eyes. ▽
4. Response
   - This website returns a quick response to my actions.
   - When using this website, items may not be displayed correctly. ▽
5. Functionality
   - The functionality of this website is meets expectations.
   - It took a long time to get the information I wanted. ▽

The scoring method was in accordance with WUS. Each questionnaire item was scored on a scale of one to five. In case of an inverted scale, the corrected score was achieved by subtracting the original score from six. Each factor score was calculated as the average of the scores of its two questionnaire items.

4.2 Results

Fig.5 shows the time taken to complete Task 1 in the first and second trials. In the first trial, the difference between results with and without a lecture was

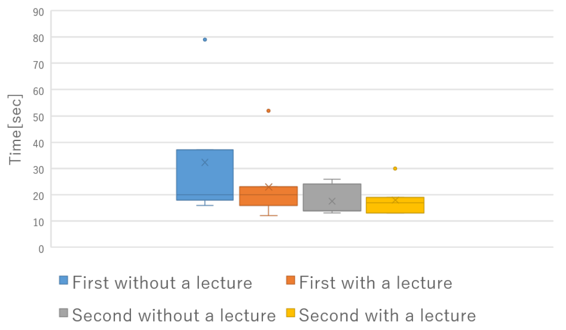

Figure 5: Result of the times to complete Task 1 in the first and second trials with and without a lecture.

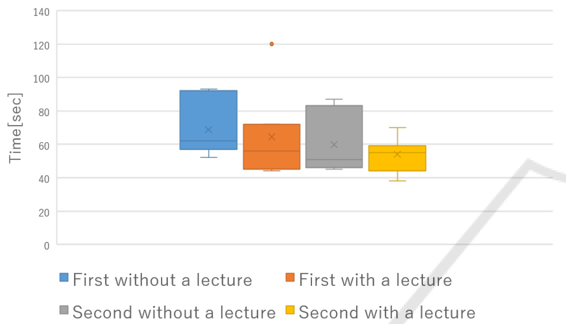

Figure 6: Result of the times to complete Task 2 in the first and second trials with and without a lecture.

remarkable. The average without a lecture is 32.3 seconds, the average with a lecture is 23.0 seconds; the difference is thus seen to be 9.3 seconds. However, in the second trial, the average was 17.6 seconds without a lecture and 18.0 seconds with a lecture, and the difference is almost negligible. Hence, the results indicate that there was little dependence on the lecture. In other words, the dynamic display graph can be operated intuitively.

Fig.6 shows the first and second trials required for completing Task 2 with and without a lecture. In Task 2, there was almost no difference between the trials with and without a lecture. The first trial is 68.7 seconds on average without a lecture and 64.4 seconds on average with a lecture. The second trial is 59.7 seconds on average without a lecture and 54.0 seconds on average with a lecture. Hence, the multiple-series graph and the parallel display graph can be operated intuitively.

For Task 3, 12 out of 14 subjects were able to answer correctly. Both subjects who could not answer correctly were in groups without a lecture. Except for those who did not answer correctly, the time required for completing Task 3 with and without a lecture is shown in Fig.7. The average completion time without a lecture was 251.4 seconds, and that with a lecture was 233.4 seconds. The answer rate of the group without a lecture was lower. The time taken to complete the task for the group was longer. This may be due to the subjects not knowing that the data interval of a multiple-series graph is automatically determined according to the specified period. In addition, as a whole, it took a long time to complete this task. From this result, we found that a system which automatically detects an anomaly from sensor information and informs farm managers is necessary.

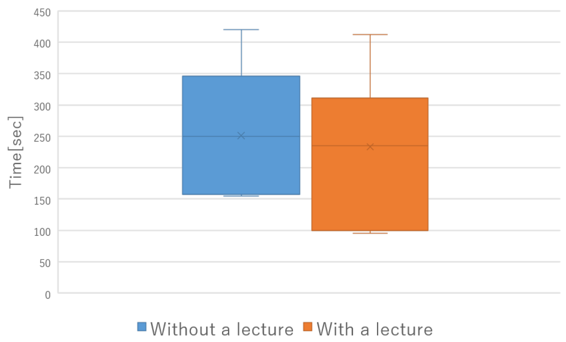

Figure 7: Result of the time to complete Task3 with and without a lecture, except for those who did not answer correctly.

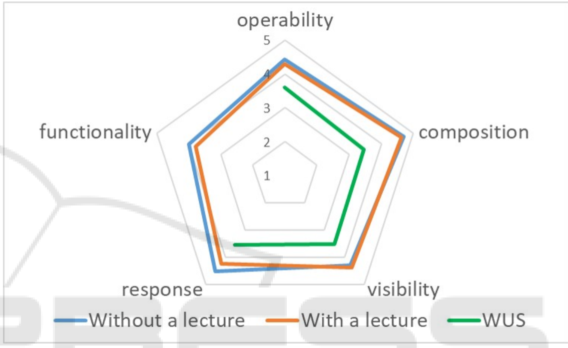

Figure 8: Result of the questionnaire and the average score of WUS.

The result of the questionnaire and the average score of WUS are shown in Fig.8. There is no average WUS score concerning functionality because functionality is our original evaluation factor. Overall, SALATA was evaluated higher than the average score for WUS, that is, the usability of SALATA is high. This may be because SALATA has an intuitive user interface, as indicated by the Task 1 and Task 2 results. In addition, since the score related to response time was high, it showed SALATA responds quickly.

5 CONCLUSION

In this study, we introduced SALATA, a web application for visualizing sensor information and farm work information in farm fields. We explained and evaluated SALATA's function of for displaying various graphs of sensor information. The experimental results showed its high usability supported by the intuitive user interface with quick response. Proposed future work includes the following:

- Development and evaluation of functions of searching, filtering, and sorting for farm work information
- Development of a function to display graphs of processed data such as cumulative temperature
- Development of a function to allow searching similar graphs

In addition, we are planning to apply SALATA to an agricultural high school to support lectures. Collecting and visualizing sensor information and farm work information can help students in finding causal relationships between them.

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