Mobile Phone-Based Field Monitoring for Satsuma Mandarin and Its Application to Watering Advice System

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Abstract : This paper describes a mobile phone-based data logging system for monitoring the growing status of Satsuma mandarin, a type of citrus fruit, in the field. The system can provide various feedback to the farm producers with collected data, such as visualization of related data as a timeline chart or advice on the necessity of watering crops. It is important to collect information on environment conditions, plant status and product quality, to analyze it and to provide it as feedback to the farm producers to aid their operations. This paper proposes a novel framework of field monitoring and feedback for open-field farming. For field monitoring, it combines a low-cost plant status monitoring method using a simple apparatus and a Field Server for environment condition monitoring. Each field worker has a simple apparatus to measure fruit firmness and records data with a mobile phone. The logged data are stored in the database of the system on the server. The system analyzes stored data for each field and is able to show the necessity of watering to the user in five levels. The system is also able to show various stored data in timeline chart form. The user and coach can compare or analyze these data via a web interface. A test site was built at a Satsuma mandarin field at Kumano in Mie Prefecture, Japan using the framework, and farm workers monitor in the area used and evaluated the system.

Key Words : mobile phone, cultivation diagnosis, Satsuma mandarin, watering, Field Server.

1. Introduction

Recently, agricultural know-how in Japan has been fading away rapidly as farmers aging. For example, in Kumano in Mie Prefecture, Japan, Satsuma mandarin farmers’ average age is already over 60 years old. On the other hand, the frequency of abnormal weather such as excessive rainfall and/or extremely high average temperature have increased recently. In such cases, past experience and intuition are not sufficient for decision-making in farming. Therefore, the expectation of applying ICT technology to agriculture has been increasing [1], such as use of sensor technology and diagnosis systems based on sensing data.

There have already been several studies in this area. The Field Server [2] is a kind of networked weather robot that measures temperature, humidity or insulation duration at the field. By using the Field Server or a sensor network such as Crossbow’s eKo [3], data on the environmental conditions at the field can be collected automatically. Recently, various kinds of field operation logbook systems have been developed that record fertilization, pesticide usage and so on.

Nevertheless, these logging systems are mainly used for data analysis later on by researchers or for process management like Good Agriculture Practice (GAP). Thus, they are rarely used to improve product quality itself during the production process at the time data are logged.

This research aims to construct a novel cultivation method by using sensors like the Field Server, analyzing the collected data and providing it as direct feedback to field workers. This paper proposes a mobile phone-based data logging system. The field workers input their own data like fruit firmness and leaf roll on-site. The data is stored in a data management system on the server, and the users can request advice from the system about whether they need to irrigate their field. The result of the evaluation experiment at a test site is also described.

2. Mandarin Production Data and Its Applications for User Feedback

In botanical theory, the state of water deficiency for a tree is called “water stress.” It is empirically known in Satsuma mandarin farming that water stress in fruit trees increases the degree of sugar in the fruit and, as a result, improves the total quality of the fruit. Therefore, especially in summer, it is very important to control the amount and timing of watering [4].

The “Mul-Dri” method is one of the methods for controlling water stress, and has become popular in Mie Prefecture [5]. The Mul-Dri method uses mulching and water drip for controlling watering in summer. The effect of rainfall is cut by mulching, and the amount of water and fertilizer is controlled by drip tube laid on the fields. Our research target is basically the fields in which the Mul-Dri method is applied; and we focus on how to get data on fruit tree status and fruit quality at a reasonable cost, and giving feedback to the farm workers about the necessity of watering by analyzing the collected data.

There are many factors that affect the quality of Satsuma mandarin fruit. Figure 1 shows the relation of the factors that we are concerned with in the current system. Climate conditions such as temperature, humidity or insulation, and operations in the field such as watering or mulching affect the conditions of the fields, fruit trees, and the fruit itself. On top of this, the conditions of the fruit tree and fruit affect the quality of the fruit with time. Therefore, the climate conditions and operations in the field indirectly affect the quality of the fruit with time-delay.

One method for measuring climate conditions is the Auto-
mated Meteorological Data Acquisition System (AMeDAS), which is run by the Japan Meteorological Agency and covers almost the entire country. However, the number of measurement sites is only about 1,300. This means 20 to 30 locations per prefecture, which is too sparse to acquire data on subtle local climate conditions. Another method is Field Server. It covers a small area and automatically measures local climate conditions such as temperature and sends the data to the server. One of the problems with the Field Server is its cost, which is too high for each farm household to afford. Therefore, we installed one at a representative location in a Satsuma mandarin farming area.

There are several indicators to measure the water stress of fruit trees. Although the Time Domain Reflectometry (TDR) method enables measurement of soil moisture or trunk moisture of fruit trees [6], the instrument is fairly expensive, and the measurement is cumbersome and unstable. More simple ways to detect water stress are visual inspection of the fruit tree or feeling the fruit itself. For example, leaf rolling is a one indicator. The leaves of Satsuma mandarin trees roll in heavy water stress conditions. Fruit firmness is another indicator of the water content of the fruit itself; the softer the fruit, the lower the water content.

The operations in the field that affect water stress conditions are the amount and timing of watering, and the timing of mulching. The quality index of the final product, in this case Satsuma mandarins, are sugar degree, acid degree and fruit size.

It is necessary to record and manage all of these data, analyze them, and provide them to farm workers with varying technical knowledge for controlling Satsuma mandarin condition and quality.

3. Related Works

The Speaking Plant Approach (SPA) is proposed as a concept of plant cultivation diagnosis and environment control [7]. SPA targets greenhouses mainly and it first measures plant biological conditions. Then according to the condition data, it estimates cultivation conditions and stress conditions; finally, it controls the greenhouse facilities. The current SPA targets the greenhouse only, and is not for open fields. Therefore, some issues remain, especially how to collect field data, and how to adapt it to open-field Satsuma mandarin production to improve the quality of fruit for the whole area of production.

As for collecting data for production support by IT application, there are two approaches. One is the automatic data logging by robots, and the other is supporting field workers for measurement and logging by ICT.

There are many reports on the Field Server [2] and other sensors [3] that collect data on field conditions automatically. Ito [8] applied the Field Server to Satsuma mandarin fields to collect field condition data.

Mobile phones and PDAs have been used to support data logging for field workers. One of the earliest cases of applying such devices to collecting field data was as part of research on development of a database and model cooperation system funded by the Ministry of Agriculture, Forestry and Fishery. Yokoyama’s system “Cyfars Diary” [9] used a mobile phone’s web function (i-mode) and logged tasks performed by workers in the field. Otsuka et al. [10] used a PDA to log labor data to measure workers performance. Guan et al. [11] used GPS functions installed on mobile phones to ease location input of field work. Several mobile-based labor data logging systems based on these studies are already commercially available.

These studies mainly focus on how to collect data; however, they made little mention of how to use it or how to provide it as feedback to field workers.

As for the quality improvement of Satsuma mandarin production for the whole area of production by IT utilization, Sasaki started to build the Arita Satsuma-Mandarin Database in 1998 [12]. Before that, there were already some agricultural information web sites; however, they only provided general information on field work. They defined their goal as collecting data on field workers daily activity and providing analysis of the data, aiming to build a kind of real-time feedback system. The database provides various field data collected by farming consultants or farming coaches. Miyamoto [13] reported production assistance using a GIS system in Nagasaki, Kagawa and Wakayama prefectures. They introduced optical sensors to their consolidating stations in the latter half of the 90s to grade Satsuma mandarin fruit and feedback their grade data to each farm worker. They measured sugar grade and acid grade of each fruit and created a map of them using GIS. They reported that there was much positive effect in the mind of the farm producers by receiving feedback on the quality of their fruit. Both
4. Field Data Logging and Feedback System

Present research concept is basically similar to SPA in that it starts from collecting data on environment conditions, operations in the fields, and field and fruit tree status. The research goal is to improve fruit quality of the whole area of production, not only a single farm field or greenhouse because all Satsuma mandarin fruit produced in the area are assembled in the local consolidation station that is usually managed by a local farmer’s cooperative, then shipped to the market with the local area brandname. Therefore, in an area where many farmers produce Satsuma mandarins, if some of the product qualities are very low compared to the market average, the brand value may be tarnished. Therefore, the system should cover the whole production area and improve the average or lowest quality of the area.

The system aims to provide real time feedback for field workers in the area. Here, real time means that the field workers will be able to consult the system about their operations on the same day data is collected to improve their operations.

4.1 System Design Policy

While designing, developing and deploying the system, we focused on water stress as a major factor of Satsuma mandarin cultivation. We were also concerned with the practicality of the system. That is, the system installation and operation should be low-cost so that each farm producer can afford it. The system should also be able to be used on-site, and operations of the system should be simple enough to be used by the farm workers.

For data collecting methods, our system adopts both the human-support IT approach and the automatic data collection approach. We provide a simple apparatus for numeric rating of fruit firmness and a mobile phone-based data logging system for each farm producer, farm consultant and researcher in the area. A Field Server is installed at a typical location in the area. This combination provides a cost effective way to measure the entire area conditions. The field workers carry the measurement apparatus and their own mobile phones with them to the field. Fruit firmness is numerically rated from 1 to 5 by comparing with three rubber balls of different firmness [14], and the rate is inputted by the application on the mobile phone.

We conducted a study on three types of feedback methods to the user: analysis, sharing, and advice. Data analysis is the most popular standpoint of traditional IT application research for agriculture. We took a very simple approach for this point. Our system just provides a timeline chart viewer on the Web to compare various data such as climate condition collected by the Field Server, fruit firmness, sugar/acid degree or operation log in a single view. Analysis itself is performed by motivated farmers or researchers.

Data sharing is also an important viewpoint for fruit quality improvement of the area. For example, if a farm producer and a farm consultant share fruit firmness, sugar/acid degree, and TDR value of the producer’s farm, they will be able to discuss the timing of when they should water the field with concrete data. Even without a consultant, the farmer can check with other farmers that have similar field conditions and follow the behavior of the best quality producer in the area. In this way, we were able to expect the quality improvement of the whole production area. To support such data sharing and discussion, the collected data is shared in the area in our system and the time-line chart viewer provides a function to compare data from one field with that from other fields.

Finally, direct feedback of operation to each field producer is also possible by analyzing log data. However, it is still very difficult to give advice on appropriate operations by analyzing data. It requires knowledge of each crop plant; therefore, we need to extract knowledge from the expert and create rules from them. Despite the arduousness of the process, the advice based on log data will be very helpful for farm workers, especially newcomers, because they can instantly apply it to their daily operations. As a first trial of the advice function, which is one form of user feedback, we developed a watering advice system based on knowledge from Satsuma mandarin experts.

4.2 System Configuration

Figure 2 shows the current configuration of the Field Data Logging and Feedback System. AMeDAS data of the Kumano area in Mie Prefecture, which includes temperature, rainfall amount, insulation, wind speed, and wind direction, are automatically fetched from the Internet every hour and stored in the database. The Field Server and other sensors installed at a test field in Kumano also measure temperature, humidity, insulation, and soil moisture and send the data via satellite link and mobile line to the server.

“Daily App” is a logging application build on a mobile Java platform. Each field worker uses his own mobile phone and records data such as fruit firmness or TDR value measured on-site. A watering advice system is built as a web application for mobile phone and PC. The viewer application called “Neighbor Field”, which is for data analysis and sharing, is also built as a web application for PC. We assume that the viewer is used at home or at the office by field workers or consultants, not on site, because the task will take time and require large screen size.

4.3 Mobile Logging System: “Daily App”

Daily App consists of a client module on the mobile phone and a server module to store data. The client module is build as a Java application (i-appli) on NTT docomo’s Java platform (JavaME CLDC 1.1+DoJa-4.0). The server module is implemented on Linux by using a web server (Apache 2.2.3), DBMS (MySQL 5.0.77) and application framework (ColdFusion 9). The data that the user can register are operations in the field, water stress indicators and quality index of Satsuma mandarin
All data type registration is not mandatory; the field workers register only the data type they selected and measured. The input form includes only a numeric value form and a pull-down menu; therefore, the user can easily learn how to use it. The logged data is sent to the server via wireless network.

Satsuma mandarin fields in Kumano are often located in mountainous areas; therefore mobile phones sometimes cannot get a signal from mobile-phone stations. In such cases, the client applications store the measured result of the field into local storage and the user can send the data to the server after they go back to a location where the phone can get a signal.

Figure 3 shows screenshots of the client application. At first, the user logs in to the system (step 1), then chooses the item to measure (step 2). After inputting the measured value (step 3), the user sends the value to the server (step 4). If the transmission fails, the data is stored in local storage (step 5) and when the signal recovers, the user transmits the data again (step 6).

### 4.4 Watering Advice System

The authors developed a simple watering advice system as a mobile web site based on watering knowledge of Satsuma mandarin experts. On creating rules, Satsuma mandarin experts of Mie Prefecture Agricultural Research Institute help us to define four or five levels for each fruit status or fruit quality data. Basically, when one of the measured values exceeds the level 3 threshold of its criteria, the system advises the user to water the field.

The threshold values of sugar degree and acid degree vary according to the time of year because sugar degree should become higher and acid should become lower from August to September as the fruit ripen. Table 1 shows the threshold values of each level from August to September. In the current rule, the level values between explicitly shown criteria are linearly interpolated. The preference order of criteria is also changed according to the time of year. For example, fruit firmness is not a suitable criteria in September because the fruit ripens. The current rule of preference order is shown in Table 2.

The system works as follows. The user who has registered their field data by Daily App first logs in to the advice system via the mobile phone’s web function. Next, he chooses one of the registered fields and pushes the “advice” button. Then, the system checks each criteria such as fruit firmness according to the priority, and shows the judgment result of each criteria and the synthetic judgment result in five levels to the user. Figure 4 shows screenshots of each level result.

#### Table 1 Example of watering advice rule (rules for sugar).

<table>
<thead>
<tr>
<th>Level</th>
<th>Aug. 10</th>
<th>Aug. 20</th>
<th>Sep. 1</th>
<th>Sep. 10</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>–9.0%</td>
<td>–9.5%</td>
<td>–9.8%</td>
<td>~10%</td>
</tr>
<tr>
<td>2</td>
<td>9.0–10%</td>
<td>9.5–10%</td>
<td>9.8–10.5%</td>
<td>10–11%</td>
</tr>
<tr>
<td>3</td>
<td>10–11%</td>
<td>10–11%</td>
<td>10.5–11.5%</td>
<td>11–12%</td>
</tr>
<tr>
<td>4</td>
<td>11–12%</td>
<td>11–12%</td>
<td>11.5–12.5%</td>
<td>12–13%</td>
</tr>
<tr>
<td>5</td>
<td>12%—</td>
<td>12%—</td>
<td>12.5%—</td>
<td>13%—</td>
</tr>
</tbody>
</table>

#### Table 2 Priority of judgment.

<table>
<thead>
<tr>
<th>Indicator</th>
<th>July &amp; August</th>
<th>September</th>
</tr>
</thead>
<tbody>
<tr>
<td>fruit size</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>fruit firmness</td>
<td>2</td>
<td>-</td>
</tr>
<tr>
<td>sugar degree</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>leaf roll</td>
<td>4</td>
<td>2</td>
</tr>
<tr>
<td>acid degree</td>
<td>5</td>
<td>3</td>
</tr>
<tr>
<td>TDR value</td>
<td>6</td>
<td>5</td>
</tr>
</tbody>
</table>

### 4.5 Time-Line Based Viewer: “Neighbor Field”

Neighbor Field is a data viewer that shows each measurement data in timeline chart form. The system is built as a Flash application on the Web using Adobe Flex Builder to achieve intuitive operation for the users.

The system aggregates, reprocesses, and compensates logged data and displays them to the user. The data includes maximum and minimum temperature of the day, insulation amount of the day, rainfall amount of the day, mulching status, watering amount, and other data measured by the users. Fruit size is shown in both actual measured size and amount of growth per day. TDR value is compensated according to the temperature at the logged time.

The system can show the data in two ways. One is to analyze the relation between data of a specific field. The other is to compare a specific category of data with another user/field’s data. In the analysis mode, a user displays both watering timing...
data and sugar and acid value in a single timeline, he can confirm or break down the relationship of the watering and sugar and acid value changes of the field by himself. In the comparison mode, the user can compare his own data with other user’s data. Figure 5 shows sugar degree of several users including reference data made by a Satsuma mandarin expert. These data are shared between farming producer and farming consultant; therefore, if a producer logged his own field data everyday, he can confer with the consultant about his field situation via phone. Meanwhile, the producer also can check the same data via the Web using this system.

As stated in the Related Works section, there are already many reports on mobile phone-based data logging systems. For example, Yokoyama’s “Cyfers Diary” already has a similar data logging interface for the user’s task. The system also displays other user’s activity when the user logged his own data. Neighbor Field also provides other user’s activity and the user’s own activity history data in a more graphical way. The system provides not only user’s activity such as watering or mulching, but also climate conditions, water stress condition and quality of fruit in the same timeline graph. The users (farmers or researchers) are able to perform more deep analysis by checking the relations among the climate, tasks, plant condition, and fruit quality in a single system.

5. Field Test and User Evaluation

Satsuma mandarin farm producers in the Kumano area, Mie Prefecture used Daily App and Neighbor Field from June to August in 2010 as a trial use of this system. The monitors were nine persons in their 30s to 40s. Satsuma fruit experts from the Agricultural Research Institute and farm consultants in the Kumano area who are members of this project also used the system and evaluated it at the same time. They also evaluated the watering advice system.

Before the trial, the trial users had a lecture on the system outline and its usage. The mobile phones were lent out to them. Daily App was preinstalled on the phones. They used the phones to log their own field data such as fruit firmness or watering amount and timing. Their own PCs were used to view the Neighbor Field application.

During the trial, 2069 recorded data in total are logged by the monitors. That means that five data items are logged per day per

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**Fig. 4** Watering Advice System (level increases from left to right).

**Fig. 5** Neighbor Field.
Table 3 Number of collected data by “Daily App”.

<table>
<thead>
<tr>
<th>Item</th>
<th>Number of Record</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sugar</td>
<td>199</td>
</tr>
<tr>
<td>Acid</td>
<td>207</td>
</tr>
<tr>
<td>Leaf roll</td>
<td>31</td>
</tr>
<tr>
<td>Fruit softness</td>
<td>269</td>
</tr>
<tr>
<td>Fruit size</td>
<td>230</td>
</tr>
<tr>
<td>TDR value</td>
<td>927</td>
</tr>
<tr>
<td>Watering</td>
<td>194</td>
</tr>
<tr>
<td>Mulching</td>
<td>12</td>
</tr>
</tbody>
</table>

The climate data such as temperature and rainfall in the same period are also acquired from AMeDAS and Field Server and stored on the database. Table 3 shows the breakdown of the records.

The trial users were asked to fill out an anonymous questionnaire after the trial. The questionnaire includes the evaluation about the trial system itself and their daily IT usage such as what kind of Web pages they usually browse. Also, we held a group interview that some of trial users and farm consultants attended to hear detailed evaluation and requests for our system.

First, as for daily IT usage, according to the questionnaire and interview, most farm producers did not use their PCs frequently at home, and they also did not use mobile phones very much, only for calling colleagues and taking photos as reminders of their tasks. They also used the Web or e-mails on very limited occasions. Actually, they were very busy with field work during daytime hours and exhaust themselves; therefore, they did not have so much interest in IT usage, even in mobile phones. The most frequent web use from mobile phones was for weather information, especially the rainfall forecast.

As for the system’s applications, they were affirmative for the necessity and effectiveness of field monitoring. However, there are still many requests regarding the usability of Daily App. For example, the current application does not remember the status such as field ID or fruit tree ID that they used last time; therefore, they need to input them every time. Also, it was difficult to see the mobile phone display under direct sunlight.

As for Neighbor Field, they valued data sharing with consultants and the comparison function with other users fields. For example, they said that it was interesting to know when other users mulched and watered their field and how the sugar degree of their field improved. This competition became a source of encouragement. However, their PC environment is not so rich and their IT skill is not so high; Flash-based web browsing is not a very comfortable experience for them.

The watering advice system was only used by Satsuma mandarin fruit experts and consultants, and there were not enough data to evaluate the accuracy of the system. However, the experts said that the system’s judgment mostly matched their own. They valued its effectiveness because it was able to be accessed from a mobile phone on-site, and it gave direct instruction on watering to users.

In system design policy, we stated three types of feedback methods: analysis (data comparison), sharing, and advice. The user evaluation result shows that the data sharing is the most meaningful and effective feedback at least at the current moment. It seems to become the motivation for the user to log data to know what kind of operation the other users did and its result. The data sharing also activated communication among farmers or farmers and consultants. Numeric data become the common language, a common topic between them. As for the communication tool, the current Neighbor Field tool does not give real-time feedback when the user logs the data. Yokoyama’s Cylars Diary provides users activity data to the user at the time when he logged data. The proposed system should also provide such real-time feedback in the future to motivate data logging more directly. We might consider the combinational use of other communication tools such as Twitter or Facebook to build a cost-effective platform. For example, the ‘follow’ function concept of Twitter is also useful for our system to know other users activity in real-time. It may be possible to use Twitter as a platform to notify other users of data updates.

The current feedback function of our system is still in the preliminary stages. The relation between weather conditions, user tasks, fruit status and fruit quality is a kind of control system with time delay. A more precise model should be used to enhance its effectiveness. For example, more detailed parameters for each field, such as possible watering amount, timing, or the number of watering tubes at a specific field, are required. We also should incorporate forecast models of some conditions and their results. Morimoto [15] already presented a kind of prediction model of fruit quality. The authors will build a forecast model for Satsuma mandarin based on our measured information. The climate forecast such as the possibility of rainfall or temperature forecast should also be taken into account to improve advice quality. A lot of datasets in different weather conditions, activities, and results are required to make the relation clear; therefore, it might take more time to perfect.

As for usability, the result of the daily IT usage questionnaire shows that we should focus on mobile phones more than PC environments, both for data logging tools and data viewers. One of the candidates for the logging and data viewing tool is a smart phone. A recent survey predicts that more than half of mobile phones will be smart phones in a few years. The smart phone usually has a clearer and larger display and a rich user interface that help the user for logging and viewing data.

6. Conclusion

This paper described IT support for Satsuma mandarin production in Kumano, Mie Prefecture, Japan. The objective of the proposed system was the establishment of data-driven agriculture, instead of traditional experience and intuition-based agriculture. For that purpose, it is very important to analyze the collected data and provide it as feedback to the field producer to refine their operations.

As for the data logging system, we introduced a mobile phone-based logging system and simple apparatus for measuring fruit firmness because of low-cost operation for the users in terms of practicality. Three types of feedback was also proposed: analysis, sharing and advice for the user, and developed two applications: Neighbor Field and Watering Advice System.

The field test showed the validity of the system concept, especially the data sharing and comparison function between the users in the area, though many issues remain especially regarding usability.

Acknowledgments

This study was conducted as a part of a project named “Development of field server application technologies for high
quality mandarin orange production (FY2009-2010)”, which was financially supported by the Ministry of Agriculture, Forestry and Fisheries, Japan. The authors’ deepest appreciation goes to the project consortium members, including the Graduate School of Biорesources, Mie University, Kian Fruit Tree Science Branch of Mie Prefecture Agricultural Research Institute, Kisyu Regional Agriculture Extension Center and AFLAE. The authors would also like to express appreciation for anonymous referee’s valuable comments.

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