Development of a System for Recording Farming Data by Using a Cellular Phone Equipped with GPS

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Abstract

In order to improve the sugarcane yield and encourage stable management, agricultural production corporations are required to manage their work systematically and efficiently. Therefore, it is necessary to accurately comprehend the work that goes on the in agricultural production corporations for the rational planning of farming operations. This study is aimed at developing a system for recording farming data with a cellular phone equipped with a GPS (Global Positioning System) function and an Internet connection. The built-in GPS function is used to produce a field map of the measured position to indicate the location of the operator. The data entered from the cellular phone are transferred to and stored on the server of the system via the Internet. The results of experiments conducted by the sugarcane-producing agricultural corporations revealed that the precision of the GPS function of the cellular phone was sufficient to identify the current working field. Using a cellular phone, a set of recorded farming data can be input in 1-2 minutes. The system is developed using low-cost hardware and software, and it has a low operating cost. This system can collect the necessary farming data such as the date, weather, working time, composition of work, and machines used in the field. Furthermore, by adopting database technology in this system, large quantities of data of the farmland that are scattered over a wide zone could be handled efficiently.

Keywords

database, sugarcane, agricultural production corporation, Geographic Information System (GIS), Internet

Introduction

In Okinawa, approximately 50% of the farmland is used for growing sugarcane, which is a major crop, and nearly 70% of the farmers are involved in its production. In recent years, some issues such as the increase in the number of aging farmers and low income have resulted in the abandonment of arable land. In order to avoid cultivation abandonment, various countermeasures have been adopted by the leaders of regional farmers; these leaders lease and consolidate the abandoned farmland and organize agricultural production corporations that manage large-scale farmland with full mechanization. At present, there are approximately 40 sugarcane-farming corporations in Okinawa, and this number is expected to increase to 80 in the future.

Despite managing large-scale farmland, the sugarcane yield per unit area of these agricultural production corporations is lower than that of conventional farmers. The present sugarcane yield of these corporations is merely approximately 4 tons per 1000 square meters; this yield is rather low as compared to the average yield of 5.8 tons per 1000 square meters in Okinawa (Agriculture, Forestry and Fisheries Planning Division, Okinawa Prefecture, 2006). The following are considered to be the major factors responsible for the low sugarcane yields of these corporations:

1. The landowners are reluctant to rent their farmland to the agricultural production corporations because of the fear of losing it permanently. Hence, the concentration of farmland becomes difficult.

2. The leased fields managed by these corporations are scattered, and the corporation workers have to move from field to field to carry out farm work. Because of the time taken to transit between the fields, the farm work becomes inefficient.

3. The farm work is poorly managed because the farmers are not accustomed to the corporation management. Thus, the farm work begins late in the season and the optimal timing is missed.

An increase in the sugarcane yield is essential for the farmers who manage the corporations in order to achieve stable management. Therefore, it is important for the corporations to develop a system for carrying out farm work in an organized and planned manner for efficient management. The first step of systematic planning to achieve efficiency is to comprehend the work performed by the agricultural production corporations accurately. Although the agricultural production corporations recognize the necessity of recording the farm work, most of the farming data have not been recorded and marshaled because of the hectic operation of farm machines by untrained employees or the poor management of the corporation by inexperienced employers. Some workers follow the traditional method of recording their work in notebooks after returning to their offices after completing their work; however, since these records are dependent on their memory, they can be inaccurate. Therefore, no data is available to plan the farm work for efficient management of farming. In order to encourage the efficient and stable farm management with regard to higher labor productivity, it is necessary to accumulate the records of cultivation management, such as the positions of the working fields, composition of work, and machines used in daily work.

Currently, IT (Information Technology) and mobile terminals have provided a great advantage in collecting farming data for cultivation management. In recent years, many researchers have studied the application of mobile terminals to logging devices in agriculture. For example, Wang *et al*. (2004) and Bange *et al*. (2004) have developed handheld PCs to collect data pertaining to forests and fields. Sugahara *et al*. (2001) have developed a system for logging farming data by using an Internet-connected cellular phone. Otuka and Sugawara (2003) have developed a labor management application by using a handheld computer. These mobile terminals may be applicable for collecting the farming data of the sugarcane-producing agricultural corporations.

The GPS (Global Positioning System) and GIS (Geographic Information System) technologies make it possible to determine and record the position of fields (Neményi *et al*. 2004). During busy times, such as the harvest season, the management of the sugarcane-producing agricultural corporations hires part-time employees who are not familiar with the cropland of the corporations. The number of fields leased by these corporations may be more than 100. Hence, they cannot clearly remember the field identifying number and the position during the farming work. A system combining GPS and GIS in a mobile terminal facilitates the understanding of the correct position by the employees. If the farmers were able to obtain a map of the adjacent areas of the current position on the display of the mobile terminal, it would be easy for them to determine the position of the working field and the work efficiency would be improved.

With regard to the farmers, the mobile terminal must satisfy the following conditions: portability, long-life battery, and low initial and running costs. The use of a handheld device such as a PDA with a GPS receiver attachment is preferred when measuring the position by using mobile terminals. This is because it can accurately measure the position by using the GIS data saved on the PDA. For example, Otuka and Yamanaka (2003) have developed an insect field survey system that employs a handheld computer and a GPS module. Breunig *et al*. (2004) have developed a route planning system by using a PDA that can support spatial database queries. However, an input cost is involved in introducing these terminals because each worker in the corporation should be provided with such a terminal. In contrast, the cellular phone, which is used as a convenient device by a wide variety of people, is considerably more suitable as a mobile terminal (Zingler *et al*. 1999, Mintsis *et al*. 2004). Especially in sugarcane-producing agricultural corporations, the workers who are working simultaneously in different farmland can manage the farming data by using their own cellular phone.

In the case of using GIS in a mobile terminal, the GIS map data can be stored in the memory of the terminal. A large system memory is required for geological data. Moreover, the farmland used for cropping by the corporations varies every year based on the lease contract of the farmland and the farm work; therefore, the GIS map of the farmland must be updated annually. The administrator of GIS map is required reinstall the renewed data on every terminal every time the map is updated. Since an unspecified number of part-time employees work in the sugarcane-producing agricultural corporations, it is difficult for the administrator of GIS map to reinstall the renewed map on every terminal. Meanwhile, the centralized GIS map management system, which stores the GIS data on a web server and distributes the GIS map from the server to a mobile terminal via the Internet, can provide the best solution for this problem. The communication cost of a PDA equipped with an Internet adapter will considerably higher than that of a cellular phone. Thus, a cellular phone equipped with the basic function of an Internet connection is suitable as a mobile terminal for the sugarcane-producing agricultural corporations.

Recently, the GPS function of the cellular phones has been applied to the land transportation system. By using cellular phones equipped with a GPS application, Sikanen *et al*. (2005) have developed a navigation assistance system for truck drivers. This system is employed in the forest fuel supply chains; it displays the exact locations of the wood fuel storage piles in the forests on the maps displayed on the mobile terminals of the truck drivers. However, the cost of developing the system hardware and software platforms is high because custom-build commercial software is used to control the procurement of forest fuel. Hence, the managers of the agricultural production corporations desire a low cost system using free software.

In the sugarcane-producing agricultural corporations, there is an emerging demand for a low-cost system that can log farming operations by using a cellular phone with a built-in GPS function as the terminal. This paper presents a system in which, instead of the conventional manual recording method, a cellular phone with a built-in GPS function was used to accumulate the farming data and provide the data necessary for further utilization in efficient work operation. The practicability of this system was verified by the sugarcane-producing agricultural corporations operating in Sashiki and Nakagusuku villages in Okinawa.

System overview

System structure

We have developed hardware and software to construct a user-friendly system based on the requirements of the sugarcane-producing agricultural corporations. A cellular phone equipped with an Internet connection and built-in GPS functions is selected as the terminal to obtain the farming data from the farmland. The web pages for collecting the farming data are obtained from the web server via the Internet and are displayed on the cellular phone screen through its built-in web browser. Fig. 1 shows the structure of the system developed in this study. <Fig.1

The system is required to handle data transfers between a database server located on a desktop PC and handheld terminals. We selected Microsoft Windows XP Professional SP2 as the suitable operating system for the desktop PC. The web server that supports CGI (Common Gateway Interface) language responds to the web requests from the cellular phone and transmits back the web pages.

In order to reduce the cost, the system utilizes some free software. Apache 1.3.27 (Win32) and PHP 4.3.3RC1 are utilized as the web server and the CGI language support platform, respectively. MySQL 4.0.13 is selected as the database server. The web pages are created in HTML (Hyper Text Markup Language) format using the CGI programs. The CGI programs are run on the web server in order to record the farming data, display the field map, address system errors, and save the data on the database server.

The CGI program enables the farmers to apply the database for the management of the agricultural production corporations. For example, the output data in the specified format are used as a report for the authorities. PHP (Hypertext Preprocessor) is used to create the program for the effective utilization of the data accumulated using the cellular phone for the management of the agricultural production corporation.

The geographical information of each data comprises its address, the latitude and longitude of the field location, and the field identifying number. The GIS, ESRI ArcView Ver.3.1, creates a map, including geographical information, of all the fields managed by the agricultural production corporations; this map is stored on the web server.

Mobile terminals

With regard to the mobile terminals, the four models listed in Table 1 can be employed as the suitable mobile terminals. <table1 If mobile terminals equipped with the GPS function are not available, cellular phones, or PDAs that support HTML with an Internet connection can be widely adopted as terminals. HTTP (Hypertext Transfer Protocol) is used to communicate across web pages via the Internet. Although the application of the abovementioned mobile terminals to this system is possible, a cellular phone with a built-in GPS function is recommended because maximum benefits can be derived from the GIS function in this system.

Software specification

Farming data entry

The complete process of recording the farming data is shown in Fig. 2. The first screen is the login page for logging into the system; <Fig.2 it authenticates the user based on the name and the password. After the menu on the second screen is selected, the program opens another screen that inputs the information on the field position from the GPS into the system. The subsequent page is for inputting the details of the farming data such as the date, weather, number of operators, working field, work description, machines used on the field, and working time. The start time of the work is automatically entered using the built-in clock of the cellular phone. After the data

have been entered, the information is transferred to and stored on the server, as shown in the fifth screen. At the end of the fieldwork, the operator clicks the “work end” button on the sixth screen; the finish time is then recorded automatically. In addition, it is possible to record the period of recess and the loss of work caused by mechanical failure. The web pages can be seen on all the Internet-enabled terminals by using any browser that supports HTML. In cases wherein the farmers forget to input the farming record, it is possible to input this record at a later stage by using a cellular phone or a computer.

Although it is inconvenient to directly input the data using the small keypad of the cellular phone, data entry is made quick and easy because of the function that retrieves information on the working field from the database server and lists this information on the pull-down menu options. Furthermore, the function that displays the GIS map using the position information obtained from the GPS function of the cellular phone is used not only for identifying the working field but also for validating whether the field identifying number for the record is correct. The two functions mentioned above enhance the verification of the validity of the data submitted from the cellular phone. The details of the web page for data entry are shown in Fig. 3. <Fig.3

Identification of the current working field by using the GPS function

In Japan, most of the cellular phones of KDDI Corporation support the GPS function; however, only certain models of the cellular phones of NTT DoCoMo and Vodafone support the GPS function. In general, the position information obtained by using the cellular phone is utilized for other services provided by the operating companies, such as road navigation or shop locator. A cellular phone does not have a built-in function to display the coordinates of the current position on the screen. In our system, the coordinates of the current position are obtained using the CGI program (Masui 2002, Siisise.net 2004). The web server is accessed when the start button located on the screen of the cellular phone is clicked to measure the position by GPS; this initiates the CGI command on the server. This command enables the cellular phone to obtain the information from GPS satellites, and the GPS data are then transferred to the web server within a period of 10-18 seconds. The CGI program, which is written in PHP, on the web server then calculates the latitude and longitude based on the GPS data obtained from the cellular phone (Geographical Survey Institute 2004, Sakai 2003).

The CGI program searches the field that corresponds to the coordinates in the GIS database. If the field is found in the database, the program will display the map of the field and its peripheral region. Considering the positioning error of the GPS, the size of the peripheral region is set to cover an area of 140 meters square. The field identifying numbers are simultaneously shown on the map; as a result, the operator can easily identify the working field and input the identifying number from the pull-down menu. If a field is not found in the database owing to the positioning error of the GPS or the inability of the cellular phone to connect to the GPS satellites because of a weak electrical signal, the CGI program will request the operator to input the field number directly by using the keypad of the cellular phone.

Fig. 4 shows the complete process of utilizing the built-in GPS function of the cellular phone. <Fig.4

Downloading the map file of the fields

The web browser of the cellular phone displays images in the PNG (Portable Network Graphics) format. Based on the position measured by the GPS function of the cellular phone, the map of the peripheral region of a field is dynamically created in PNG format on the web server.

The digitized map of all the fields managed by the agricultural production corporation is created in the shape file format from the paper maps by using ArcView, which is a GIS software package used for managing geographic data (ESRI 1998, ESRI 2004). This map is then converted into a PNG image on the web server in a specified size that is suited to the width and height of the screen of the cellular phone; the image is then transmitted to the cellular phone. The average size of this map image is approximately 400 bytes, and the maximum value of the size is 800 bytes. This size can minimize the delay in the transmission of the image file of the field map via the Internet.

Database for farming work

The farming data collected by the cellular phone is saved on the database server via the Internet. Most types of tables required for the farming database for sugarcane production are defined in advance on the database server. Thus, the farmers are not required to modify the database objects, except when they change the recording procedure of the farm work. This system allows the farmers to use cellular phones to modify the tables of the database on the server from the client side. If the farmers intend to input additional farming data that is not yet included in the database server, for example, the quantity of fertilization, they can append a new item “quantity of fertilization” from the menu on the cellular phone, as shown in Fig. 5. Once this new <Fig.5 item is appended to the database server, the main screen of the cellular phone for recording the farming data shows a new input box for accepting the data.

The collected data can be utilized by the farmers for effective work management. For example, the farming log of harvesting sugarcane on March 9, 2005, can be printed from the web site, as shown in Fig. 6. This farming log can be viewed using Internet Explorer; thus, the end user can print the farming log without having to use <Fig.6 any additional software.

Result and discussion

In this study, a KDDI cellular phone, AU-A5405SA, was selected as the experimental terminal. The battery life of this model is 210 hours. It accesses HTTP web pages via the Internet by using its built-in web browser, namely, Mobile Browser 6.2.05 (KDDI-ST23) Universal Edition. Unlike most cellular phones, a significant feature of this model is that it has a built-in GPS function.

The practicability of this system was verified by the sugarcane-producing agricultural corporations operating in Sashiki and Nakagusuku villages in Okinawa. Although the system can provide the user interface in both Japanese and English, the Japanese menu was selected for the convenience of the farmers. In the summer of 2005, the agricultural corporation in Nakagusuku village recorded the farm work for fertility management, and the agricultural corporation in Sashiki village recorded the harvesting operation throughout the harvesting period from December 20, 2005 to February 6, 2006. The validation for field identification was carried out by two agricultural corporations, and the study of the drawbacks and advantages of this system in practical use was carried out by interviewing workers in the agricultural corporation in Sashiki village. At the agricultural corporation in Nakagusuku village, the author operated a cellular phone along with the workers, and at the agricultural corporation in Sashiki village, an assisting worker operated a cellular phone along with the harvester operator.

We evaluated the GPS error of the cellular phone by conducting a statistical analysis of the GPS accuracy. The coordinates of fixed points with known positions were measured using the GPS function of the cellular phone. The actual latitude and longitude of these fixed points can be obtained from the map on the website of map navigation on the Internet. Using the built-in GPS function of the cellular phone, we measured the GPS data six times at two-minute intervals; the measurement was carried out on six different days. The result of the experiment is shown in Fig. 7. The standard deviation of the error of position measurement was 14.6 meters. Since the position errors are random and the frequency with which the errors occur follows a normal distribution, approximately 95% of the measured positions would be within +/- two standard deviations. With regard to the suitable image size on the screen of the cellular phone, the cellular phone displays the map of the field and its peripheral region within an area of 140 meters square.

<Fig.7

In the actual trial, there was no incorrect identification of the field number during the period of experiment for the agricultural corporation in Nakagusuku village. For the agricultural corporation in Sashiki village, the result was the same when receiving the satellites signals. Thus, the accuracy of positioning by using a cellular phone is sufficient for ascertaining the location of the working field.

The current farmland could not be ascertained by GPS by the agricultural corporation in Sashiki village in a few instances. This was because the satellites signals could not be detected. The assisting worker who operated the cellular phone always worked in the field outside the harvester cabin without obstructing buildings. Although the factors that led the obstruction of the satellites signals remain to be elucidated, in this case, the assisting worker inputted the number of the farmland from the keypad of the cellular phone. In Fig. 4, the figures of the field number in the map are omitted by design to reduce print for publication; the assisting worker could easily find the working field from the map and the field numbers.

The drawbacks and advantages of this system were studied by interviewing the users. The drawbacks of this system are confusion while typing on the tiny keypad and the omission of input data owing to inexperience. However, during the harvest period, there were only three omissions and one incorrect data entry.

The GPS took a period of 10-18 seconds to identify the field location, and it took approximately 1.5-2.0 minutes to enter the total data of farming operations by using the keypad of the cellular phone. There were always assisting workers operating a cellular phone during harvesting. Since it was possible for them to take time out from their busy work to enter the data, they were hardly inconvenienced by the time required for manipulating the cellular phone. However, in the case that only the machine operator works in the field, the operator should manipulate both the agricultural machine and the cellular phone. We continuously survey the merits and demerits features of this system with cooperation from the agricultural corporation in Sashiki village.

The advantages of this system are the identification of the field position, data accuracy, and elimination of the data entry work on PC. In comparison with the traditional method of manual recording on a notebook, the farmers were not required to input the data that they had recorded on the field into the computer after returning to their office. The agricultural corporations had hired subcontractors or data entry clerks to enter this data into the computer. Thus, the approaches presented in our system are cost saving.

To introduce the system to agricultural corporations, the cost should be taken into account. The cost of the system can be divided into the costs of constructing the system, developing digital maps, and operating the system. For constructing the system, only the cost for the hardware and the operating system of the server is incurred. It is possible to decrease the initial cost if a free operating system such as Linux is adopted. In the initial stage of development, we should create the GIS map of the farmland as a digital map. This work includes scanning a paper map into an image file, drawing the farmland as polygons on the image, and storing the map into the shape file format; it may require many hours to accomplish. Although we used ArcView to create the GIS map, some free GIS software packages such as TNTlite are widely used in the world at present and have good compatibility with the shape file. If the GIS maps were created by using free GIS software, the agricultural corporation can obtain the digital maps at a low cost.

In Okinawa prefecture, the digital maps of the farmland for providing information on farmland utilization are owned by some municipalities. Since the institution of directly income compensation will be applicable to sugarcane production in 2007, local municipalities have considerable interest in fostering agricultural corporations capable of stably producing sugarcane. Thus, there is a strong possibility of the active involvement of the local municipalities in the utilization of this digital map in our system. In this case, the agricultural corporation would be able to obtain the digital map at no cost.

The practical use of the system confirmed that the total data size for one field record, including the field map from the first login page to the end page, is less than 16KB. During the experimental period, the number of working fields did not exceed five fields. Assuming that five sets of records of farming data are recorded daily, the expenditure on data communication by using cellular phones is approximately 3500 yen per month; this expenditure is reasonable for the sugarcane-producing agricultural corporations or the common farmers.

Although the farming program through quantitative management encourages efficient and stable farm management, the implementation of such an approach requires a fundamental database of the farming system (Nanseki *et al*. 2003). The database technique allows us to store a large quantity of data and accumulate the user-defined data according to the regional conditions. The data structure of our database, such as field database, field map, and items to be considered during the farming operation, is applicable to the production of other crops, for example, paddy, wheat, and vegetables. With the trend of an increase in the number of cellular phone users, there is a strong possibility that this system can be applied by common farmers to compile information during the production of sugarcane and other crops.

A mathematical model of the farming operation during sugarcane production is being developed at the University of the Ryukyus (Guan *et al*. 2006). This model is based on a net model that describes the workflow of farming and will enable to the simulation and generation of an optimum farming plan. The model will optimize the sequence of farming operations and the allocation of machines and employees to each field managed by the agricultural corporations. The farming data obtained using cellular phones will be utilized in the generation and verification of an optimum farming plan.

Conclusion

Over the past several years, an increasing number of large-scale agricultural corporations have expressed the requirement for logging their farming operations at a low cost. Hence, we developed a cellular phone-based system as an alternative to the conventional paper-based recording method for collecting farming data. The technical and economic feasibility of applying cellular phones equipped with GPS technology to the system was ascertained.

The standard deviation of the error was 14.6 meters, which indicated that the precision of the GPS function of the cellular phone was sufficient to determine the current working field. It takes 1-2 minutes to input a set of records of the farming data by using a cellular phone. The expenditure on data communication is reasonable for the sugarcane-producing agricultural corporations or the common farmers. The data gathered by the system can be utilized by the agricultural production corporations to plan the optimum farm work for efficient management.

Acknowledgment

We would like to gratefully acknowledge the Yui Agricultural Production Corporation in Nakagusuku, and the Misaki Agricultural Production Corporation in Sashiki for their cooperation in the verification of our system. Thanks are also due to Mr. Takenouchi, Mr. Yasuda (Okinawa Prefectural Agricultural Experiment Station, Japan), and Dr. Norio Sakai (National Agricultural Research Center for Kyushu Okinawa Region, Japan) for their timely assistance and constructive advice.

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GPS 携帯電話による農作業データ収集システムの開発

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要旨

農業生産法人は増産や経営安定のため農作業を体系的に効率よく管理する必要がある．従って生産法人での農作業の実態を正確に把握し合理的な作業計画を立てる必要がある．本研究では全地球測位システム（GPS）機能利用とインターネット接続が可能な携帯電話を用いた農作業データを記録するシステムを開発した．GPS 機能は作業者が作業している圃場の地図を携帯画面上に表示するために用いる．携帯電話から入力されたデータはインターネットを経由しデータベースサーバーに保存される．サトウキビ生産法人において本システムを実際に使用した結果，携帯電話の GPS 機能は作業している圃場位置を計測するのに十分な精度であった．データを入力するのに要する時間は１～２分程度で農作業に支障を来すものではなかった．本システムは低コストのハードウェアとソフトウェアで構築されており，データ通信なども低料金で利用出来ることが確認された．本システムにより作業管理に必要な日付，天候，作業時間，作業内容，使用した農業機械などを記録することができる．さらに，生産法人の管理する各所にひろく散在する多数の圃場についての多量のデータを効率よく管理することも可能である．

キーワード

データベース，サトウキビ，農業生産法人，地理情報システム(GIS)，インターネット

Table 1 Mobile terminals with a GPS function

Cellular phone			Others
AU-KDDI	NTT-Docomo	Vodafone	
Most of models with built-in gpsOne chip	Some models (F505GPS, F661i, PosiseekR)	Some models (903T)	PDA with GPS receiver

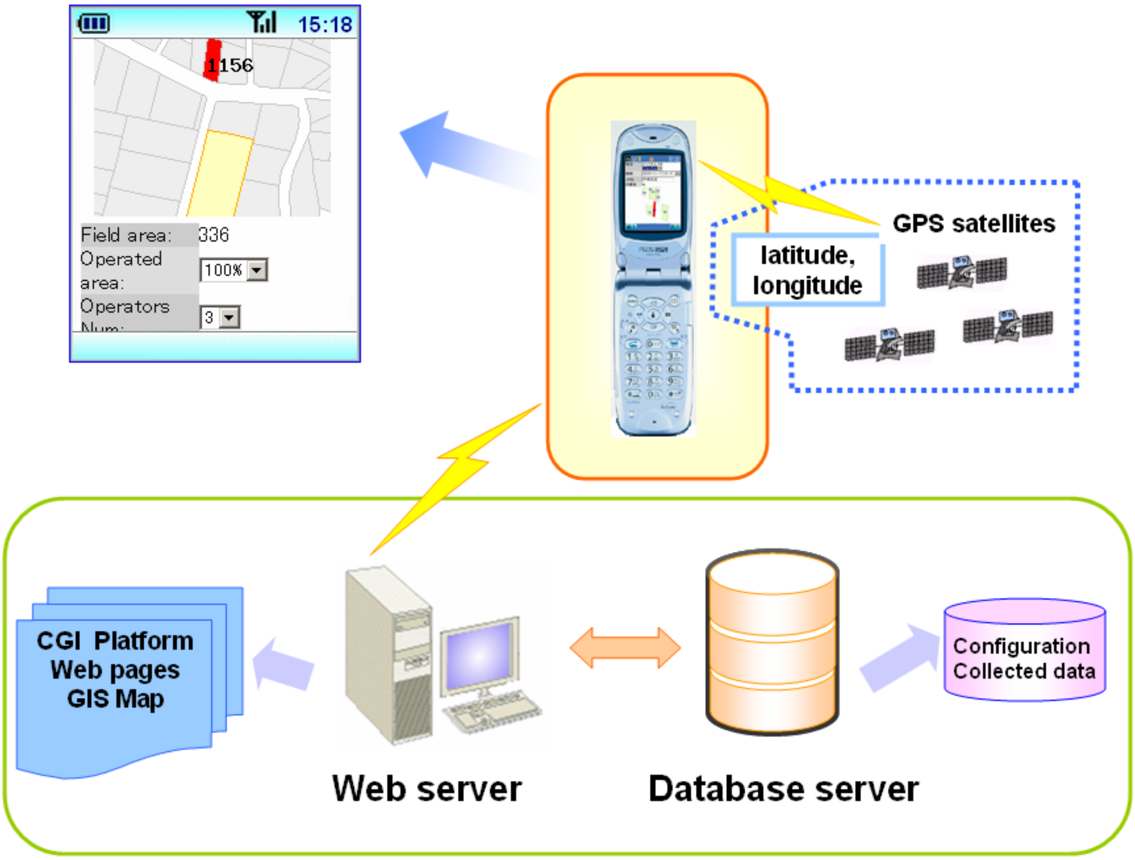

Fig. 1 System structure for recording farming data by using a cellular phone

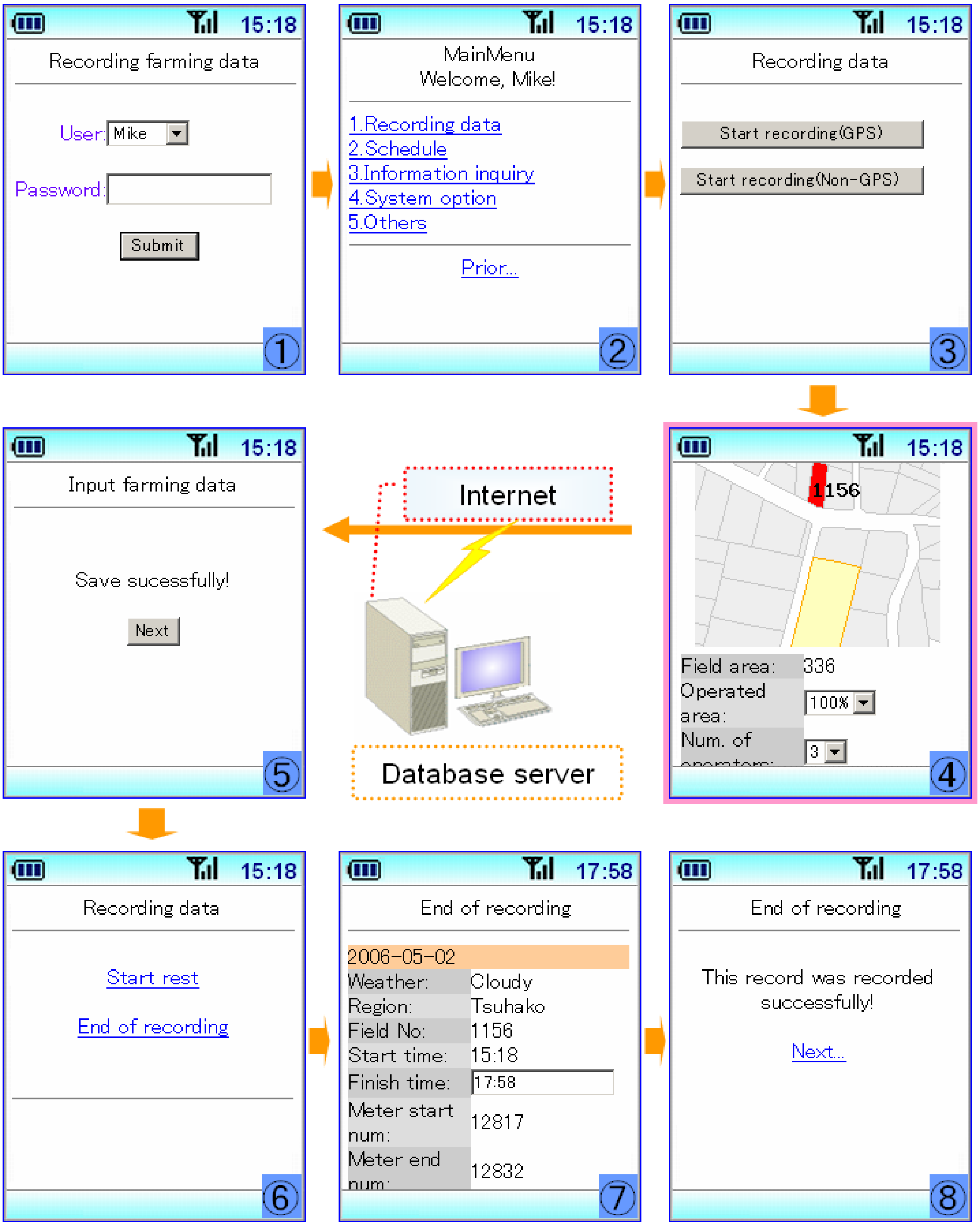

Fig. 2 Process of recording the farming data

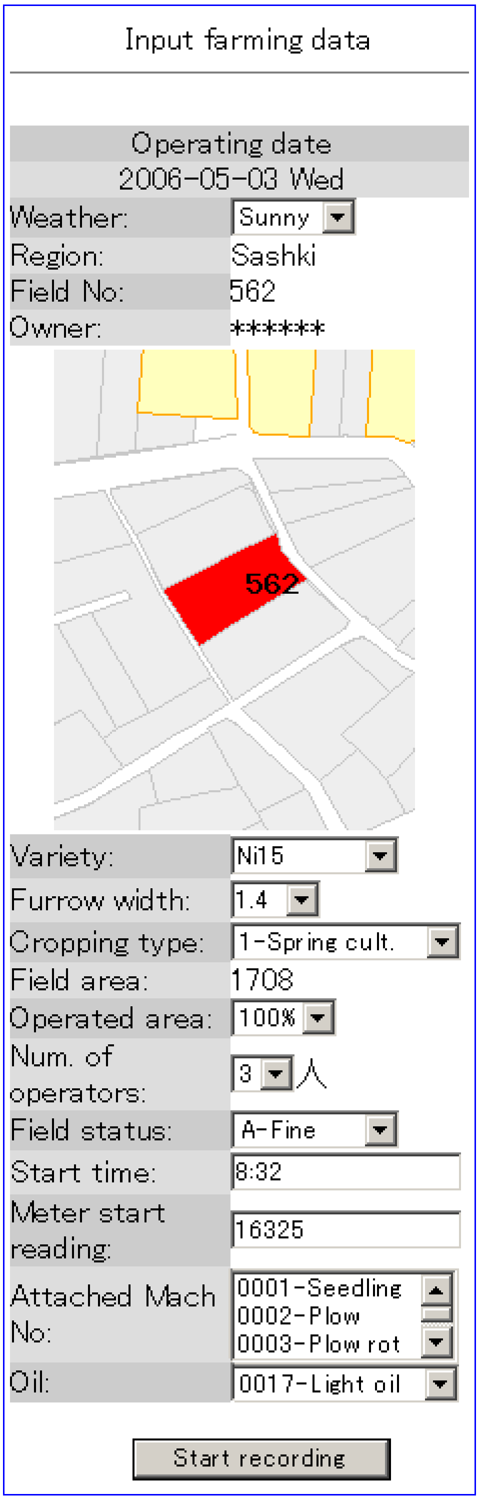

Fig. 3 Details of the web page for inputting farming data

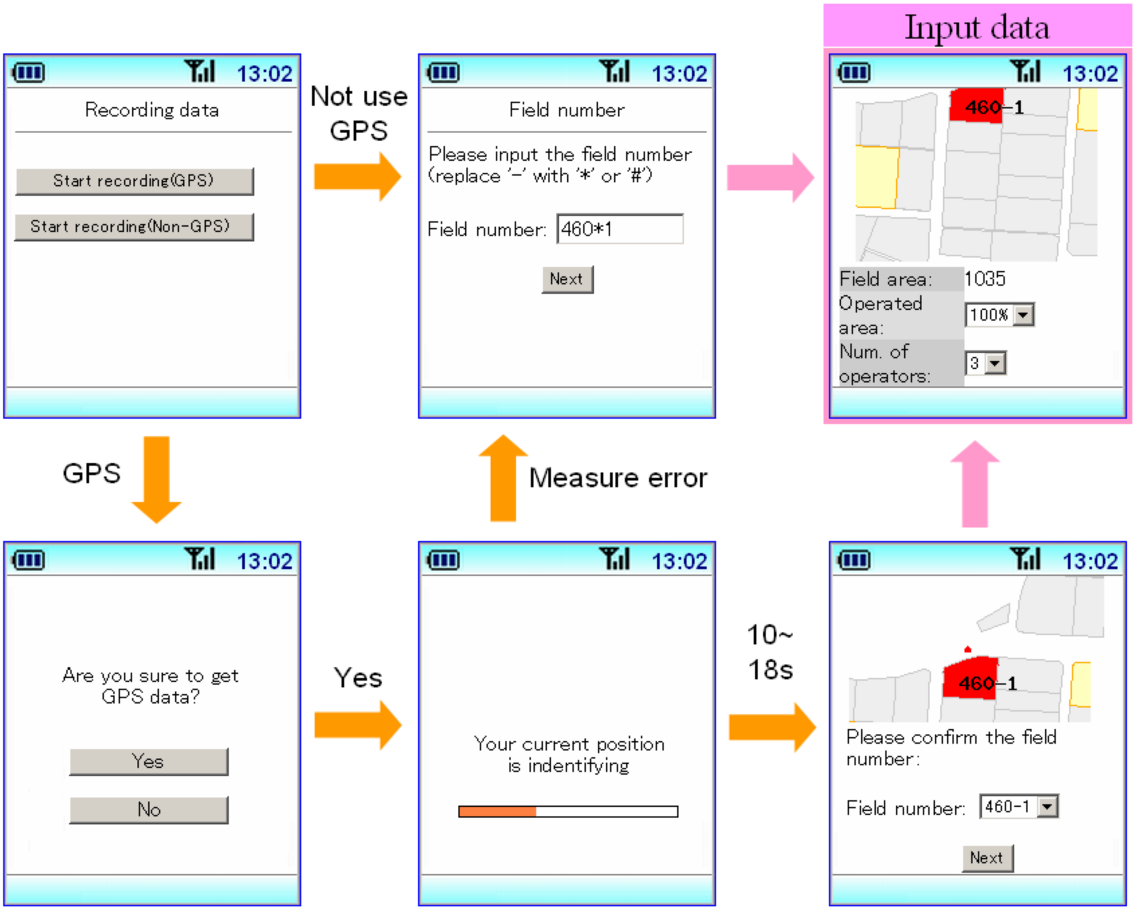

Fig. 4 Process of identification of the current working field by using the GPS function

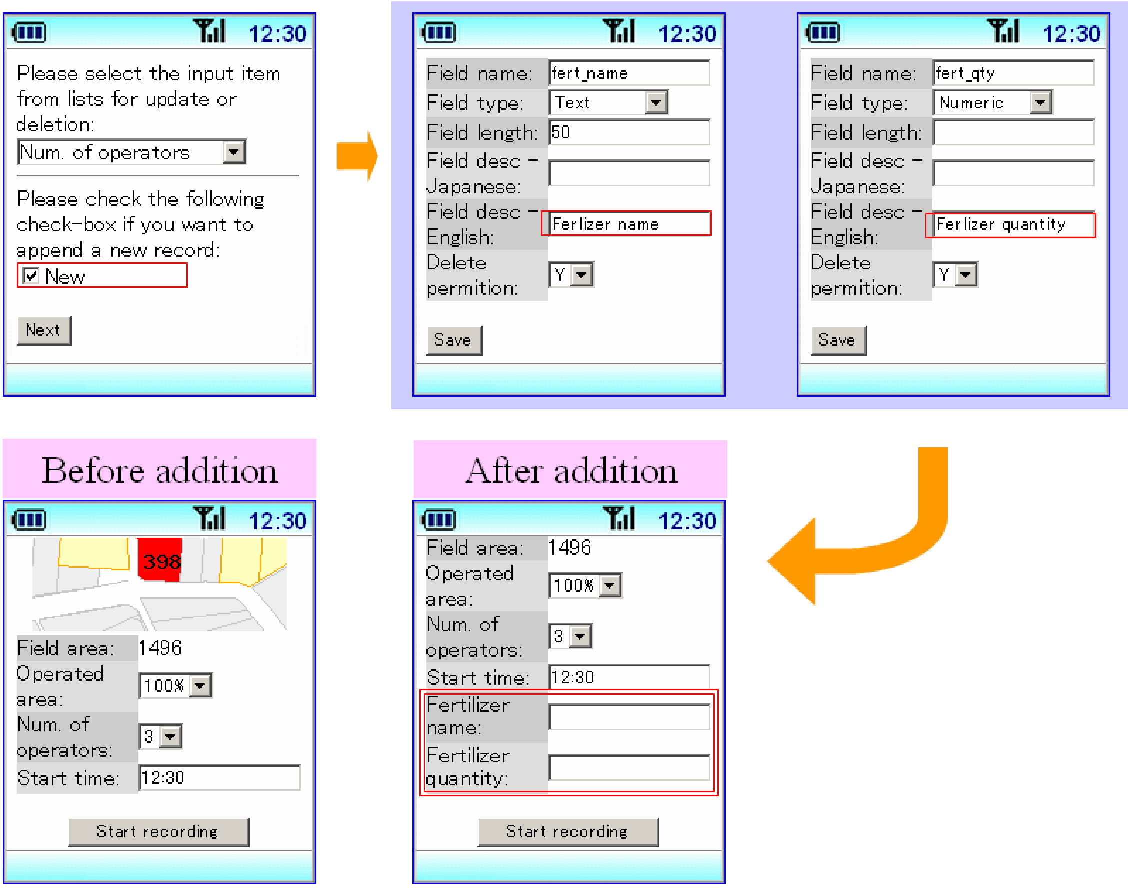

Fig. 5 Process of modifying the database tables on the server by using the cellular phone

Farming log

Date	2006-01-16 (Mon)
Weather	Sunny
Region	Fusozaki
Filed no	338
Field owner	******
Work description	Harvest
Machine name	Toft2001
Number of operators:	3
Field area	1552
Operated area	**1552**
Start time	07:55
End time	12:04
Rest time	0:11
Work time	**3:58**
Number of harvesting bags	**18**

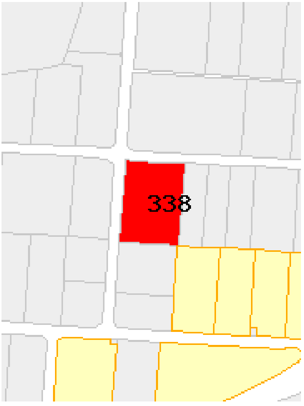

Fig. 6 Farming log of harvesting (printed from the web site)

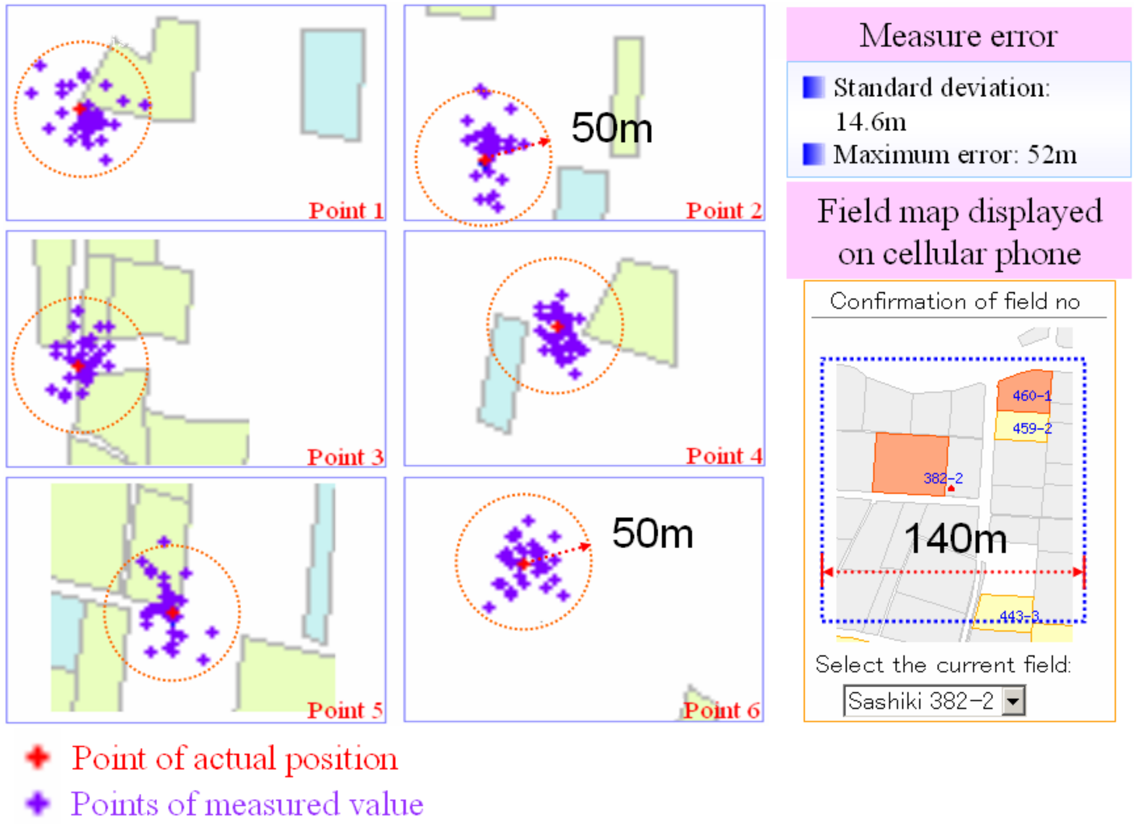

Fig. 7　Precision of the GPS function of the cellular phone

Captions of figures and tables

Table 1 Mobile terminals with a GPS function

Fig. 1 System structure for recording farming data by using a cellular phone

Fig. 2 Process of recording the farming data

Fig. 3 Details of the web page for inputting of farming data

Fig. 4 Process of identification of the current working field by using the GPS function

Fig. 5 Process of modifying the database tables on the server by using the cellular phone

Fig. 6 Farming log of harvesting (printed from the web site)

Fig. 7 Precision of the GPS function of the cellular phone