A Long-Term Field Monitoring System with Field Servers at a Grape Farm

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Abstract

Monitoring image data at a field site provides important and useful information concerning plant and environmental conditions for agricultural users. We propose an image monitoring system that makes it possible to work in harsh areas, collect large amounts of data in real time, and analyze the data according to users' requests. The system is constructed for use via the Internet with Web-based sensor nodes, an agent program, and Web analysis applications. Web-based sensor nodes such as Field Servers allow the monitoring of various types of sensor data, including image data, via the Internet. The agent program performs complicated operations on the sensor nodes from a remote site via the Internet; it can also analyze monitoring data easily using Web applications.

To evaluate the effectiveness of the image monitoring system, we executed a long-term field experiment at a grape farm in Obuse-town, Nagano, Japan. Four types of sensor data concerning environmental condition and 2 types of image data concerning plant detail and field overview were collected and stored at a remote site via the Internet. The image data were analyzed using a filtering approach operated by the agent program and Web applications which were used for calculations in a background subtraction model. The proposed system has worked stably since May 2006 and provided results in which approximately 84% of unnecessary image data were filtered. Due to its construction with a distributed architecture based on the Internet, this system has the advantage that non-expert users can easily obtain the monitoring data on the Web and image processing can be provided for users without changing the system architecture.

INTRODUCTION

In order to produce high quality products in agriculture, it is important to monitor information about plant and environmental conditions at field sites. With modern technology, it is both desirable and possible to monitor these data automatically and more efficiently than conventional monitoring methods, in which the farmer directly checks conditions based on his own experience. In Japan, such a monitoring system is particularly essential because environmental conditions in farming areas differ greatly with slight differences in location and the number of farmers is rapidly decreasing as the farming population ages.

One of the key technologies in field monitoring is the collection of image data concerning growth conditions and the influence of pests. Image data can also be used to examine environmental conditions, to keep products under surveillance, and to use for publicity purposes. It has recently become possible to obtain image data using digital cameras and Internet cameras, which provide high performance at a reasonable price. The main problems in developing such an image monitoring system are how to deploy this precision equipment in harsh field conditions, how to retrieve large blocks of data in real time, and how to utilize enormous sets of data effectively.

One approach to monitoring under these conditions is to use a sensor network (Khan *et al.*, 1999; Delin and Jackson, 2000) constructed of many sensor nodes made up of small sensor units with radio data links. A sensor network permits large-scale environmental monitoring with high scalability and robustness, but treats small blocks of data with a slow communication network. A new sensor network system is required to handle high resolution image data. The desired system must also be able to store enormous amounts of data with scalability for long periods in the case of monitoring image data. In addition, various image processing systems are needed in order for image data to be used effectively according to users' requests.

In this paper, we propose an image monitoring system that meets such needs. It is constructed using a Web-based sensor network based on the Internet system and information technology, and makes it possible to extend image processing with a distributed architecture. It also allows for friendly installation and easy maintenance for non-expert users at a field site. Field experiments over a long period of time confirm the accessibility of the proposed system and its effectiveness in agricultural applications.

METHODS

System Architecture

The present proposed system is constructed using Web-based sensor nodes, an agent program and Web analysis applications, and these modules are connected with each other via the Internet (Fig. 1). Web-based sensor nodes, one of which was developed as a Field Server (Fig. 2) in our previous work (Fukatsu and Hirafuji, 2005), have a wireless LAN, an Internet camera, and a monitoring unit with a Web server. A wireless LAN provides high-speed transmission and long-distance communication at low cost, and is therefore effective in monitoring image data. A sensor node equipped with a monitoring unit and an Internet camera, which can be accessed using a Web browser such as Internet Explorer, differs from traditional sensor nodes in its data handling architecture. The architecture of the Web-based sensor node is of the "pull type" (Duan *et al.*, 2005); that is, it functions in the manner of a Web page, showing information only when it is accessed. It functions interactively and performs remote management. Therefore, simply by mounting small firmware on the inside, it can be made to carry out various types of data analysis and complicated operations in the total system with an agent program and Web applications via the Internet.

In this system, each function is separate and the various functions are connected via the Internet, so users at a field site need not manage the system without deploying sensor nodes and connecting them to the Internet. The sensor nodes are controlled by the agent program at a remote site and the collected data is displayed on a Web-based database, whose storage is easily extended and which is accessible to users via the Internet. The agent program, which serves as a cornerstone of this system, accesses and controls all types of Web-based modules seamlessly on the Internet (Fukatsu *et al.*, 2006). This program operates autonomously based on parameter files (Profiles) in a XML format and it performs complicated operations on the sensor nodes using production rules. It can analyze the monitoring data by using Web applications which execute their process autonomously with input data. By preparing useful Web applications such as image analysis and signal processing, this system provides versatile and easily expansible functions without changing or rebooting the agent program and it makes it possible to distribute calculation tasks.

Image Processing

In agricultural situations, various types of image processing are required in order for data to be monitored according to its applications (Tillett, 1991). In the present study, we examined the application of our proposed system to monitoring certain kinds of events such as farm operation and insect emergence from image data. For these purposes, high frequency monitoring is essential in order not to miss critical events, but large amounts of recorded data are unnecessary because there is little variation. One sure method of identifying significant events is to check image data using human judgment because image data in a field environment shows a certain amount of disturbance due to natural phenomenon. Under this approach, great effort is required of the users in order to check the enormous amounts of data, so a filtering approach to image processing helps to reduce the workload by filtering out unnecessary data.

We constructed Web applications that execute image filtering using a background subtraction model (Pic *et al.*, 2004) and managed them using the agent program in our proposed system (Fig. 3). One Web application outputs difference image data by calculating the subtraction of each pixel from target image data to reference image data. The other Web application gives the difference image data and a threshold value in grayscale (gray threshold), calculates binarized image data in which each pixel changes to white or black, and outputs the total number of white pixels (detected pixels). To reduce filtering errors of variability over time such as background, view angle and deterioration, the reference image data are updated with the latest unnecessary data, which are defined as data in which the detected pixel is smaller than a given threshold value (binarization threshold) in this system. The agent program sequentially and automatically accesses the sensor nodes and the Web applications, and the monitoring image data are categorized based on the detected pixels.

FIELD EXPERIMENTS

Preparation

To evaluate the effectiveness of the proposed image monitoring system, we have employed it over long period of time. One Field Server was deployed at a grape farm whose area is 3000 square meters in Obuse-town, Nagano, Japan (Fig. 4). The Field Server has 4 analog sensors that measure important aspects of growth (air temperature, relative humidity, solar radiation and soil moisture), and 2 Internet cameras that monitor a view of the farm field and a detail of a grape tree in order to provide information on growth and daily activities in the field. It works with a commercial power supply to collect data at 2-minute intervals and is connected to a wireless LAN inside the farmer’s house at a distance of approximately 300 m. The wireless LAN is also connected to a broadband router, and the Field Server can be accessed via the Internet.

The agent program operated the Field Server via the Internet at our laboratory, which is located in Tsukuba, Ibaraki, Japan, approximately 180 km from the grape farm. Web applications and a Web-based database were also available via the Internet.

The proposed system depends on the Internet, and is therefore subject to potential network trouble which may cause loss of monitoring data or loss of control of the sensor nodes. At the time of writing, we have employed a backup system in which a small computer with a backup agent program cooperates with the remote agent program and manages the Field Server at a local site during network trouble. By managing the distributed system stably, users were able to obtain useful information from the monitoring data simply by accessing the database URL.

Results

The field experiment started in May, 2006, and has been working very well for 19 months (as of December 2007) despite several instances of network disconnection and electrical power failure. The collected data were successfully stored at a rate of approximately 1.6 gigabytes of data per month and all data were available to the public via the URL (http://fsds.dc.affrc.go.jp/data4/Obuse).

The image filtering system with Web applications was tested in September, 2006. For this processing, we set the gray threshold at 72, and the binarization threshold at 200. The system collected more than 99% of image data and filtered about 84% of image data during this period (Fig. 5). Based on the hourly detail, more than 90% of the views were filtered during nighttime hours (19:00 – 05:00) and half of the data around 17:00 were not filtered correctly. Based on the daily detail of views, the system filtered only 75% (σ =10%, n=14) of image data on sunny days, but filtered about 93% (σ =7%, n=16) of image data on cloudy or rainy days. This shows that the main factor of filtering error is the influence of sunbeams streaming through leaves, which causes a dynamic shadow change in the images.

The collected image data were displayed like a cutoff animation on the Web page which was automatically created by the agent program (Fig. 6). On this Web page, we can choose on site the filtering image data whose detected pixels are smaller than the threshold value given arbitrarily on the Web. Various aspects of the collected image data, such as detected pixels, sizes, timestamps and addresses are stored in a database; the database of the sensor data in a XML format is also stored. The Web page can handle each database seamlessly, so the sensor data is displayed in synchronization with the image data on the Web. Furthermore, we can also choose the filtering image data by using the sensor data. Users can obtain useful image data easily and effectively.

DISCUSSION AND FUTURE WORK

The present field experiment shows that the proposed image monitoring system is able to operate stably under severe field conditions for a long period of time. By making use of a distributed system based on the Internet, this system has the advantages that non-expert users in a farm field can obtain monitoring data on the Web without undue effort and that various types of data processing can be added simply by developing Web applications. In the present experiment, some scenes of events such as harvesting operations and the appearance of animals can be found easily because of the filtering of unnecessary image data with basic image processing (Fig. 7). A more adapted processing approach currently being researched will be employed as a Web application, and more advanced results will be provided for users without changing the system architecture.

The monitoring Web page and collected data are utilized not only as information for recording a working diary and making decisions in agricultural practice but also as a part of a production process disclosure and traceability system for consumers. The grape farmer in the present experiment has already used a net catalogue of fresh fruit (SEICA) which is a virtually identified produce system on the Internet (Sugiyama and Uda, 2003). By linking with our monitoring Web pages and the net catalogue, more information about all actual working scenes was made available to consumers. During the winter season, our proposed system was also used as a snow cover monitoring system by training the camera on a field equipped with a measuring scale, and the operation of the agent program was modified. Unfortunately, we were unable to evaluate this system because of the lack of snow, but our experiment suggests the possibility of wide applications of the proposed system by changing the type of image processing. In our ongoing research, we have developed an image monitoring for urban areas with surveillance functions such as infrared cameras and intrusion detection. We are also attempting to improve the endurance of Field Servers in order to monitor glacier melt in extremes area such as the Himalayas to observe the effects of global warming (Fig. 8). By developing not only software but also hardware, our proposed system is expected to have applications in a wide variety of situations.

ACKNOWLEDGEMENTS

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Figures

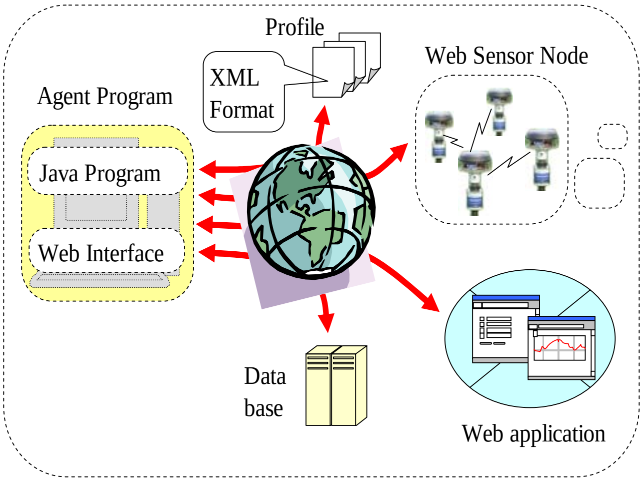


Fig. 1. Architecture of the image monitoring system.

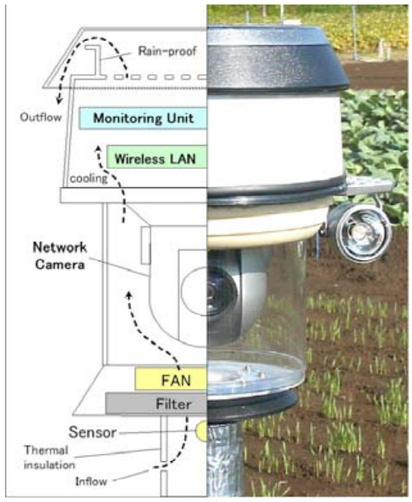


Fig. 2. Structure of a standard Field Server.

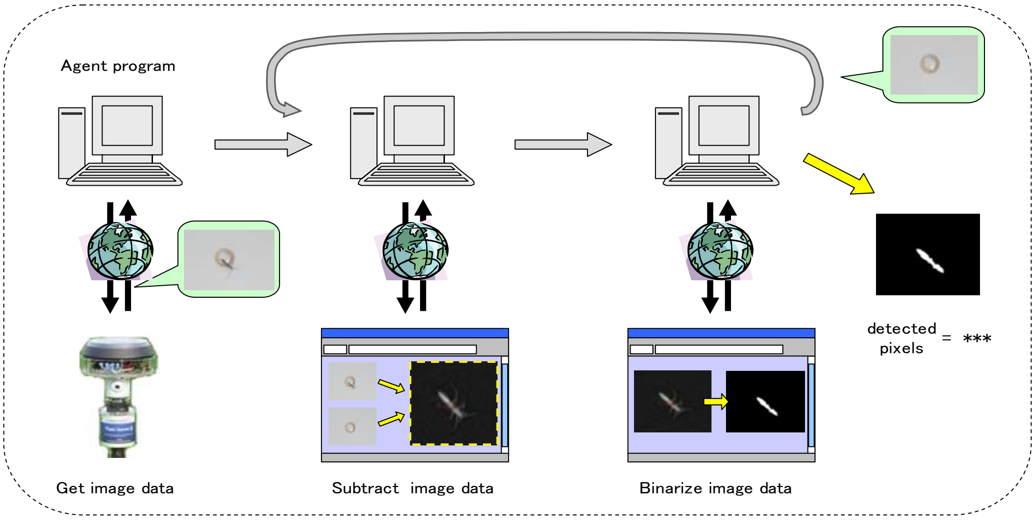


Fig. 3. Flow of image filtering using two Web applications.

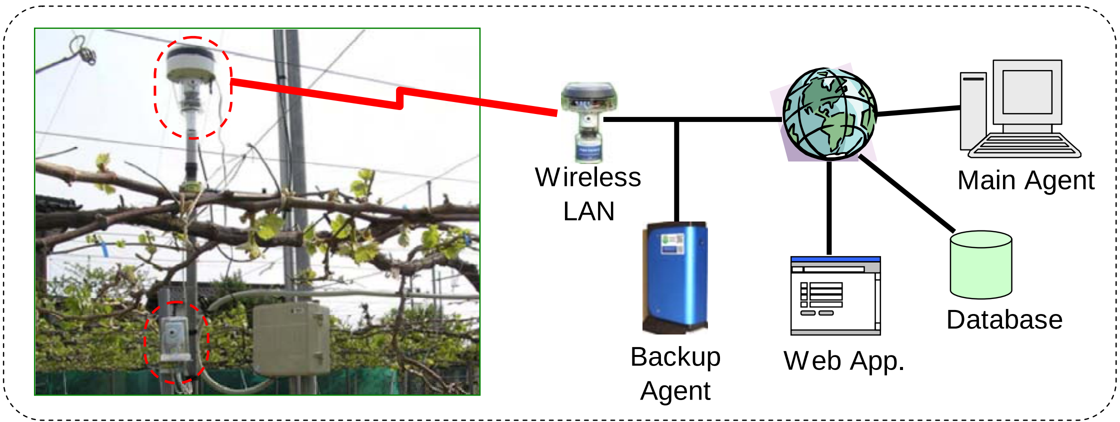
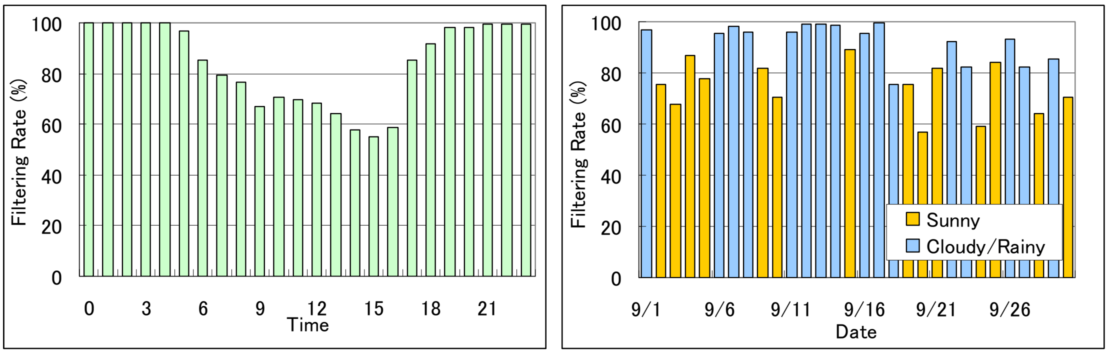


Fig. 4. Experimental site at which a Field Server was deployed at a grape farm.



a) Hourly results of filtering image data. b) Daily results of filtering image data.

Fig. 5.

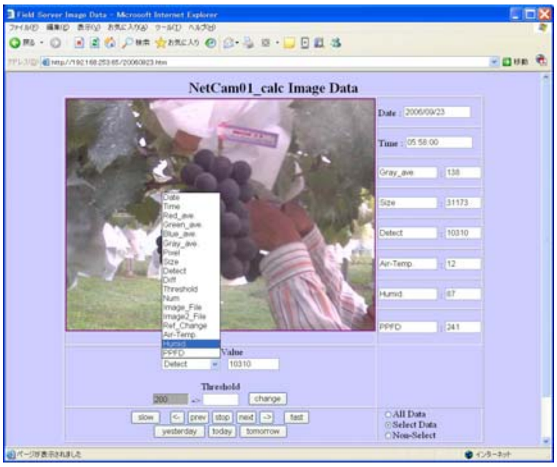


Fig. 6. Example of the Web page for browsing monitoring data.

a) Urban-type Field Server

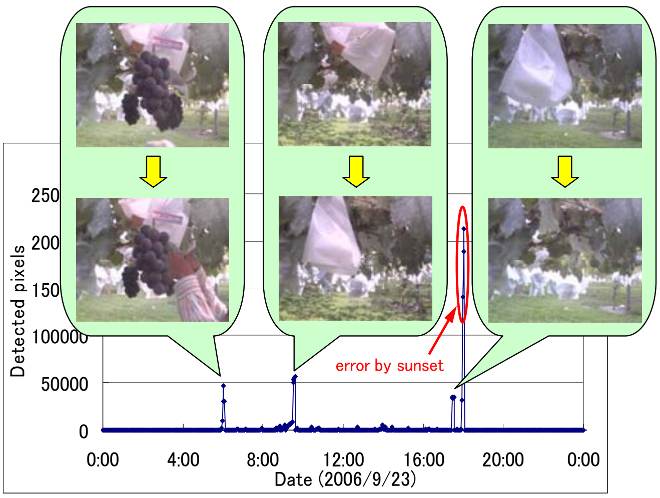


Fig. 7. Extracted scene of harvesting operations with the filtering apploach.

b) Field Server deployed in the Himalayas.

Fig. 8.