Effectiveness and Potential of a Web-based Sensor Network System for Agricultural Applications Using Image Data

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Abstract

Image data provide useful and helpful information for agricultural use, but it is difficult to collect image data stably at field sites and to perform image analyses with the collected image data. To address these difficulties, we propose a practical image monitoring system for agricultural use with a Web-based sensor network system. The monitoring system with Internet cameras can be easily constructed by using Field Servers. For the image monitoring, we also devised a simple image analysis method that uses a combination of cropping, subtracting, and binarizing functions on the proposed system. We conducted several experiments to evaluate the monitoring system and the image analysis method in agricultural applications. The results demonstrated that practical and effective image monitoring can be realized with the proposed system.

Key words: sensor network, Field Server, image analysis, Internet camera, field monitoring

1. Introduction

Monitoring crop growth, field environments and farm operations is important in efforts to improve crop yields and quality. The recent development of sensor network systems (Akyildiz et al., 2002) has made it possible to conduct monitoring in open fields, but typical sensor networks don’t have camera devices, because the systems are designed to reduce data transmission to save power. Image data is one of the key technologies for gathering useful information for agricultural use. Many image-data methods for agriculture have been proposed, such as for checking crop conditions, estimating the influence of diseases, detecting vermin and recording farm operations (Bauchi & Rath, 2005; Boissard et al., 2008; Choi et al., 1995; Iwaya & Yamamoto, 2005; Tillett, 1991), but these methods are still at the laboratory stage. A fundamental problem is the difficulty of collecting stable target image data at field sites under harsh and varying conditions, as the image data collection in a field environment is affected by many types of disturbances (e.g., wind, rain, shadows, etc.). This makes it difficult to perform complicated image analyses without limiting the conditions or using special individual settings.

To address these problems, we propose a web-based sensor network system for image monitoring with Field Servers developed in our previous studies (Fukatsu & Hirafuji, 2005). Field Servers, one of the web-based sensor nodes, have a wireless LAN (local area network) to provide high-speed transmission and long-distance communication, a web-based monitoring unit with various meteorological sensors to perform easy management at a remote site via the Internet, and Internet cameras to collect high-resolution image data. With this system, we can easily realize stable image monitoring. The Field Servers are controlled by an autonomous management program called an “Agent System” that enables flexible data analysis with distributed web-processing modules according to users’ requirements (Fukatsu et al., 2006). Therefore, we can easily construct different types of image analyses and identify a suitable method for the raw image data collected by the system. Here we provide an introduction to the monitoring system and its use in several agricultural applications with a simple and practical analysis, and we describe its effectiveness, limitations, and potential.
2. Image Monitoring

2.1. Camera

With the continuing advances in information technology, many types of high-performance cameras are now available at reasonable prices. Image monitoring for agricultural applications has included the occasional use of smart-phones and digital cameras to record useful information when agricultural staff encounters something of note in the field. In addition, digital cameras, USB cameras and Internet cameras are used to detect a certain change or monitor the amount of crop growth for long periods at fixed point. The use of interval shooting and recording image data into a detachable memory card is a primitive technique to perform image monitoring, but someone must pick up data from the installed camera, the camera might not record important information, and the camera cannot change its target or adjust to environmental changes after deployment. Here we propose a system that does not have such limitations, as it performs real-time and interactive image monitoring with cameras.

Digital cameras provide high-quality and high-resolution image data. However, their power supplies, shutter control and data uploading functions may not be adequate. Remote control software such as “gPhoto2” improves shutter control and data uploading functions, but a small computer for the software must be added in a Field Server. Instead of the software, a wireless uploading card such as “Eye-Fi” can be easily used, because Field Servers provide Wi-Fi hotspots at field sites. The advantage of using USB cameras is their small size and weight, which enable flexible deployment to collect target image data. This method also needs a small computer installed with the device driver software, and the cable length between the computer and the USB camera is limited to less than five meters. The use of network Internet cameras is the easiest way to realize the image monitoring, because they can be controlled on a web-page via Field Servers. The only extra requirement is to connect a Power over Ethernet (PoE) cable to the nearest Field Server. Unfortunately, the resolution of the Internet cameras is inferior compared to that of the cameras mentioned above.

2.2. System

Figure 1 shows the architecture of the image monitoring system. Internet cameras are practical for farmers in the field. There are two types of Internet cameras: with and without wireless function. The average power consumption of a wireless camera is about five Watts, and more than thirty-centimetre-square solar panels are needed for collecting one image’s data (i.e., a few minutes’ running every hour), so we recommend the use of cameras that do not have a wireless function, unless a camera must be deployed without any cables. For cameras that will be deployed at field sites, it is important that their casing protects them from insects, birds, dust, rain, and so on. Sealed containers are good for the casing except when they present a heating problem, which can be solved by using Field Servers that can shut

![FIGURE 1: Architecture of the Web-based sensor network system](image-url)
down the power supply of the camera with each cycle after its collection of image data. Internet cameras with pan-/tilt-/zoom (PTZ) function are effective for multi-point monitoring and long-term monitoring, because with them the attention point can be changed depending on the growth stage of targets. Some low-cost cameras don't have an auto-focus function, and their focus should be carefully set before they are deployed.

At least one Field Server with a Wi-Fi/3G network card is usually deployed as a base unit (sink node) in a field site, and other Field Servers and cameras deployed at the same site can be accessed on the Internet via the base-unit Field Server. Image data and sensor data are periodically collected by the Agent System at remote sites, and the interval time is set depending on the network traffic, total power consumption, and countermeasures against heat generation of the camera. In cases in which the image monitoring is being used to detect a specific change, a short interval time may be required so that the target detection is not missed by the image collection, but a short interval time can result in a heavy load and a large amount of extraneous image data. Some Internet cameras have motion detection and FTP functions. By modifying the Agent System to control the cameras and collect target image data in response to uploaded image data as a trigger, our proposed system can solve the problem through the use of these functions on the cameras.

2.3. Target

For image monitoring in agricultural applications, image analyses are classified broadly into two types. One is for measuring the amount of a target change in image data by comparison with a specified standard such as scale, a color chart or a correction point. This type of image analysis is used mainly in applications such as vegetation cover rate calculations, maturity evaluations and growth diagnoses. In these scenarios, image data collection at long intervals (e.g., every hour or longer) is adequate, because the change in target plants is generally slow. However, image data collection at long intervals is easily influenced by the noise of environmental changes, making it difficult to accurately analyze differences in the image data.

The other type of image analysis is for detecting a particular event based on a difference between real-time images and reference images. This type of image analysis is used mainly in applications such as wild animal detection and farm operation recognition. In such scenarios, the system must collect image data at a high frequency or in response to a detection signal of a certain sensor, so that it will not miss the targeted image data. The sampling rate of collecting image data depends on how quickly the target appears and disappears in a frame, and how precisely the system’s users want to extract useful information from the image. For example, the detection of insects or diseases, which spread slowly, does not need very frequent collection, in contrast to wild animal detection. Frequent image data collection is not needed to judge whether a certain farm operation such as harvesting is complete, but it would be effective for gaining an understanding of how a farmer performs his operation in detail.

3. Application

3.1. Image Analysis

Many types of image analysis have been developed for agricultural image monitoring, but some complicated methods such as template matching, edge detection and optical flow are relatively ineffective for collected image data at a field site because the quality of the image data is decreased by the effects of wind, rain and shadows that cause problems such as interference of extraneous substances, image blurring, insufficient illumination, position misalignment, and so on. On the other hand, simple image analysis methods, such as cropping, subtracting and binarizing methods, are widely used for many applications as an accessible analysis for users, and they are relatively effective for analyzing the collected
image data. By using these image analysis methods, we tried to realize a large part of alternative image analyses for measuring and detecting targets. For example, it is difficult for a basic image analysis to identify the type of insects on image data, but it is possible to judge whether certain insects are on it or not. In the present study, we devised a simple and widely available image analysis method that uses a combination of basic image analysis methods, and we evaluated the utility of the image analysis method in various practical applications (Fig. 2).

We prepared three image analysis methods on the Internet, which perform cropping, subtracting, and binarizing processing to image data, as web application services for the proposed system. The cropping function cuts extraneous area from raw image data according to a specified range assigned by a given mask image to lessen the effects of disturbance in large part. The subtracting function outputs the difference between two given image data by calculating the subtraction of each pixel to detect changes. It is mainly used for background- or time-differencing techniques. The binarizing function outputs binarized image data in which each pixel of a given image is converted to black or white based on specified threshold values given by HSL, RGB, or grayscale. The total number of white pixels, whose value was in the range of the threshold value, is also calculated. The total number of white pixels is used mainly to measure the amount of plant growth and to evaluate changes from difference images.

By accessing these web application image processing services on the Internet as needed, the Agent System can realize a requested image analysis. This distributed image processing approach with Web application services enables flexible and on-demand image analyses. In this system, we only have to prepare a suitable Web application service, and various image analyses can be performed without changing or rebooting the system.

3.2. Experiments
To evaluate our proposed system that can perform useful image monitoring with a basic image analysis, we conducted several experiments with agricultural applications. First, we constructed an application that calculates vegetation cover rate from collected image data (Fig. 3). After collecting image data, the Agent System accesses the cropping Web application service with the data and a mask image to pick up the target area. Then, the result is sent to the binarizing Web application service with threshold values of HSL parameters. The vegetation cover rate is calculated based on the total number of white pixels received from the service as the processing result. The requested application worked well with the proposed system, and the accuracy of the value depended on the quality of collected image data and the parameter tuning of the threshold values.
Second, we constructed an application that detects farm operations (Fig. 4). In this experiment, we used the background difference technique with cropping, subtracting and binarizing Web application services, in that order. When the total number of white pixels calculated by the binarizing function was greater than a threshold value, the system judged that a certain farm operation was performed in the image data. However, the collected image data were affected by various disturbances, and sometimes certain farm operations were not detected in the judged image data when checked manually. To find image data with a farm operation from judged image data effectively, we also developed a browsing Web application that can display filtered image data as a motion picture. With this application, we can filter image data based on not only the total number of white pixels but also any values collected as sensor data, such as rainfall. By using the filtering function, we can reduce the time spent checking extraneous image data. For example, there were many misjudged image data without a farm operation in rainy conditions. If a user knew that farming operations were never performed in rain conditions, the browsing Web application can be altered to additionally filter judged image data in rain conditions.

Third, we constructed an application that automatically counts target insects in pheromone traps (Fig. 5). In general, insect-counting applications use 'pattern recognition' that identifies the shape of the target insect, but the collected image data at a field site makes it difficult to perform such a traditional image analysis. In contrast, our image monitoring can calculate the total number of white pixels after processing via the background difference technique with the cropping, subtracting and binarizing Web application services. With the combination of
the pheromone trap to attract target insects specifically and cropping a low-noise part of the image area to allow easy analysis, we can estimate the number of target insects in image data on the proposed system. The number of target insects can be estimated with high accuracy, and this simple image analysis worked well to reduce the labor needed for counting and to easily handle a large mass of image data (Fukatsu et al., 2012).

4. Discussion

We have proposed a practical image data monitoring system for agricultural use with Field Servers, and we tested the monitoring system with several agricultural applications to evaluate the effectiveness and potential of the system. As a practical image analysis method for image data collected at a field site, we proposed a simple image analysis method that uses a combination of basic image processing techniques (cropping, subtracting and binarizing functions). Although it is generally difficult for simple image analyses to produce detailed and accurate results, our proposed image analysis method can provide useful information, and it has the potential to be effective for various applications.

In the application for detecting farm operation, we used our image analysis method to filter extraneous image data with the browsing Web application. It has been important but difficult to manually check collected image data for detecting targets, because most of the image data were extraneous. The filtering method is effective and practical for manual checking, and it reduces user effort. In the application for counting target insects, we estimated the number of targets by simply applying the results of the background-difference technique to the part of the image data that excluded the area most susceptible to disturbance. The counting method is also flexible and applicable because it doesn’t require special individual settings and parameters.

In conclusion, we constructed a system that can be easily used by non-expert users. The monitoring system facilitates the use of varied applications for many users, and the simple image analysis method facilitates the practical use of image monitoring for various targets. The more that image monitoring comes into wide use, the more that researchers will be able to easily apply advanced image analyses for practical use, based on our system.

Reference list