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A Field Image Monitoring System Based on Embedded Linux

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Abstract Demands for the real-time field monitoring system are increasing to pass the good agricultural cultivation practices down to future generations. On-site imagery data is especially important to compensate other quantitative observed values for understanding field situation. In this study, a low cost and robust field image monitoring system was developed for acquiring real-time field condition from remote site. It was also designed to work as a starting point for the Internet connection in rural area. Inexpensive commercial USB devices such as webcam and 3G USB modem dongle were used to reduce the total cost. A USB equipped router was also utilized to exclude movable parts for improving stability. One of the famous Embedded Linux "OpenWrt" was installed to the router; original and modified packages were built to capture images with USB cameras. The system operated stably during six months field experiment including summer. It also worked as a mobile wireless router even in the large tangerine orange farm where wired network connection was not available. In addition, total cost of the system was less than 3 hundred US dollars. These evident showed that this system met most requirements for field image monitoring in agriculture.

Key words: Embedded Linux, USB, image capture, field monitoring, sensor network

1. Introduction

In Japan, there has been a decline in the area of cultivated land and such land is being increasingly abandoned. In addition, persons engaged in farming are either decreasing or aging [1]. The number of farmers working on agriculture mainly is rapidly decreasing compared to in 1998 and six out of ten farmers is aged 65 and over. Because at the most farm labor force consists of elderly farmers, it is concerned about the progress of the farm labor force weakness. The food self-sufficiency rate has witnessed a downward trend on a long-term basis in FY 2007: 40% in calories, and 66% in values. This rate is low level compared to other countries in the world. Since Japan is the world's largest importer of agricultural products, it is important to strengthen the food supply capacity and to raise the food self-sufficiency rate.

Fostering and securing of principal farmers is required for these problems, but the support system is still insufficient. One of the solutions is supposed to be transition from traditional "empirical agriculture" to the "scientific agriculture" based on theory and data. As good "empirical agriculture" has been acquired a lot of useful information for a long time, demands for the field monitoring system are increasing to pass the good agricultural cultivation practices down to future generations.

In addition, it is essential that various types of information should be provided in real time in order to prevent the occurrence of injury, pests and diseases [2]. Therefore, the field monitoring system is required to collect data from field in real-time and deliver them to remote site to analyze field condition.

2. Sensor networks in agriculture

A Field Server is one of the small monitoring sensor-nodes that are equipped with a Web server to be accessed via the Internet. It uses wireless LAN to provide a high-speed transmission network differing from traditional sensor-nodes [3]. One can measure various physical properties, such as temperature, humidity, soil moisture, and so on, with proper sensors. Observed values are stored in a server; users can easily access and get these data through the Internet. Field Server was used in many research projects, but it had not spread so much to farmers. It was mainly from its price. Although Field Server has more functions and advantages than other sensor-node systems, it is too expensive for farmers to find benefits of Field Server.

Thus, lowering cost is another potential for the field monitoring system. One approach is to simplify its function. Especially, image data is recognized as a good index; it is well-known that it involves much useful information about field condition, weather, and so on. For example, Nakamura (2006) developed an image monitoring system which enabled real-time monitoring of air temperature in a green house [4]. It captured an image including output screen of digital thermometer and transferred it to the FTP server. Reading of air temperature was recognized by image processing techniques. Although this system was simple to use and satisfied low cost, it still has problems for outdoor use; as it seems not to be so robust.

Live E! Project [5] developed a platform of wide-area sensor networking, aiming densely covers wide range of areas by many sensors with reasonable prices. They developed IP-based weather station called "digital instrument shelter" and had been monitoring meteorological conditions with more than 100 stations in 12 countries. They also developed an embedded system based weather station, but it is still expensive. Moreover, as this project consisted of researchers of ICT field, their main concerns were data communication protocols or IF specifications; utilization of stored data is still under working.

In addition, how to get the Internet connection in rural area is another serious issue in application of ICT in agriculture. For example, however the Internet coverage of Mie prefecture is said to be a hundred percent, it is not true that one can access the Internet everywhere in Mie. It just only means that people in habitation area can find a way to the Internet. Satellite communication was used in the case of ICT field experiments at a mandarin orange farm in Kumano district, because any ISP services were not almost available there. In one case, expensive initial cost was necessary for establishing wired connection; in another case, network speed rate was no enough for data transfer.

In this study, we attempt to develop a field image monitoring system based on embedded Linux that meets the following three requirements:

- low-cost (3 hundred US dollars).
- robust to endure in field installation.
- network gateway in the field.

3. Embedded Linux

An embedded system is a computer system designed to perform one or a few dedicated functions [6]. Lots of consumer electronics are based on embedded systems these days. For example, cell phone, automobile, broadband router, or even your microwave oven might be an embedded system. Since the embedded system is often adopted to reduce cost and size, it must run on a small computer with less resource compared to a general-purpose computer, such as a personal computer.

As CPUs and peripherals advanced higher and higher, embedded system became more and more complex. In some cases, real-time, multitask and multi-thread performances are also required. Such an advanced embedded system should have an Operating System (OS) to control and manage the resources of the computer system. Embedded OS should be compact and efficient to achieve designated functions properly. ITRON, VxWorks, Nucleus PLUS, QNX, Windows CE and LynxOS are popular ones. Embedded Linux is one of them. However it is tuned for small computers with less resources, it has advantages that Linux-experienced users can easily utilize their knowledge, because an embedded Linux is basically as same as general Linux distribution. Moreover, some of them are freely available on the Internet.

OpenWrt was adopted in our field image monitoring system, because it is easy to obtain and it provides not only software packages but also cross-compile environment. Although many pre-compiled binary packages are ready for OpenWrt, total amount of packages is less than general Linux distributions. In our case, we had to make some necessary packages such as image capturing software; however, it was not so difficult to build these packages, because cross-compiling environment provided by OpenWrt community needs only one makefile and some patches to make binary packages.

4. Implementation of Field Image Monitoring System

Components of the field image monitoring system are shown in Table. 1. It consists of a CPU board and some USB peripherals. These devices were put into a closed plastic box to prevent water and dust, when the system was installed in the field.

Table. 1. List of components of the system

Device	Product name	Specification
CPU board	Asus WL-500g Premium (wl-500gp)	Wireless router 2 USB 2.0 ports
USB camera	Logitech Qcam Orbit AF (Qcam)	UVC driver True 2 mega pixel
USB modem	FOMA A2502	HSDPA
USB Hub	Sanwa 225GBK	Self power, 4 ports
USB flash memory	Buffalo RUF2-K4GL	4GB ext3 and swap
USB thermo-hygrometer	Strawberry Linux USBRH-FG	usbrh driver

4.1 CPU board

A CPU board is a main equipment to control and manage the system. Ito et al. (2006) showed that the internal HDD could not survive for a long time under high temperature condition from the field experiment with a modified inexpensive small computer [7]. Therefore, WL-500gPremium (wl-500gp) was used as a CPU board in our system to improve the stability of the field monitoring system.

Wl-500gp is a consumer model of wireless broadband router produced by ASUS. It has 2 external USB ports and the OS is stored in a flash ROM. As any temperature sensitive parts like HDD are not included in wl-500gp, it is expected to be more robust than the general PCs.

In this study, OpenWrt was installed to a wl-500gp as an embedded OS, because this product is one of the recommended routers with USB ports which are supported and well documented by the OpenWrt community. Binary packages were built both for our original software and for software that was not supported by OpenWrt, such as an image capturing software (fswebcam), to compose a field image monitoring system.

4.2 USB camera

A USB webcam was used for capturing images in the field. USB camera has advantages of low price and robustness, although the resolution of a USB camera is in general lower than a digital camera or a single lens reflex camera. Evaluation of properties of the USB webcam for the image analysis is under working right now.

Logitech Qcam Orbit AF (Qcam) was adopted in our system. This model is one of the highest performance USB cameras which are sold in consumer market. It has a true 2-megapixel sensor and supports high resolution up to 1600 x 1200 pixels. Qcam is a UVC (USB Video Class) device; it is supported by the UVC driver in Linux [8]. The UVC driver implements the Video4Linux 2 (V4L2) API and support for V4L1 is not planned. As most image capturing software support only V4L1, number of V4L2 compatible software is still small and some of them are still under development. Fswebcam is image capturing software which supports both V4L1 and V4L2 devices. Unfortunately, it was not supported in OpenWrt, we had to build binary package of it and its related libraries.

After installing necessary software to capture images, it failed to obtain an image file in the highest resolution of the Qcam. It was found that the total memory of the wl-500gp was insufficient to capture in such a high resolution. Then a USB flash memory was added as a swap device to extend the working memory. In addition, rest area of the USB flash memory was utilized as an non-volatile storage.

4.3 USB modem

USB modem was used to connect the Internet by wireless in rural area. This Internet connectivity is a key issue for monitoring from remote site in real time, especially in rural area. Field experiment at a coffee farm in Hawaii Island showed that wired network was inappropriate for sensor networks in agricultural farmland [9]. Even thought wl-500gp equips IEEE 802.11g WiFi, it is not sufficient for our purpose, because WiFi needs a gateway as a starting point to the Internet. On the other hand, the more popular mobile telecommunication becomes the more the internet accessible area increase even in rural area. Many 3G USB modem dongles for laptop PCs, which connect to the Internet, are found in the market.

FOMA A2502 HIGH-SPEED (A2502) was adopted in our system. A2502 was supposed to be an OEM product of AnyDATA ADU-520C. It is a USB 3G CDMA wireless modem and it also support FOMA HIGH-SPEED services. It can connect to the Internet in the area of FOMA HIGH-SPEED and FOMA. Unfortunately the main ISP (NTT docomo) supports only MS Windows Mac OS based computers as clients. Furthermore, specific software is required to access the ISP and accessible ports are restricted. In this study, a business service provided by eAccess Ltd. (formerly ACCA mobile (D)) was chosen for the field monitoring system. We wrote some configuration and script files for OpenWrt. Finally, secure channel was established using openvpn; details are available on our Wiki pages [10].

4.4 USB thermometer

USB thermo-hygrometer (USBRH) made by Strawberry Linux Corporation Ltd. was installed to measure the working environment of the system. USBRH uses a single chip relative humidity and temperature multi sensor SHT11 of Sensiron. It is precise with the temperature accuracy of 0.4 C around 25 degrees Celsius. As mentioned above, one of the main purposes of this study was an improvement in robustness of the system. Continuous measuring of the inbox temperature and humidity was required to show the working range of these terms.

Although the vendor only provides a sample application and VB libraries for MS Windows, a user developed the driver for Linux [11]. OpenWrt package was build and installed in the system. Temperature and humidity were measured every 5 minutes by the shell script which was called from a cron daemon..

4.5 Data flow of the system

Fig 1 shows the schematic diagram of the field image monitoring system. Scripts for automated image capturing and measuring temperature and humidity values were called every designated interval. However, it's not a good idea to save all data at every time when these collecting scripts are executed, because flash memory used in USB flash drive has a limitation in the number of erase/write cycles. Hence, at first, observed data were temporary stored in the volatile region of the wl-500gp, and then another script would copy these files to the USB flash drive once an hour to reduce the number of access to the flash memory. As the capacity of volatile region was not so large, temporary files would be deleted after they were correctly saved in the USB flash drive. Finally, temporary data preserved in wl-500gp would be synchronized with the remote server through the network channel build by A2502. If it failed to synchronize with the remote server, these data was remained to be transferred at the next trial.

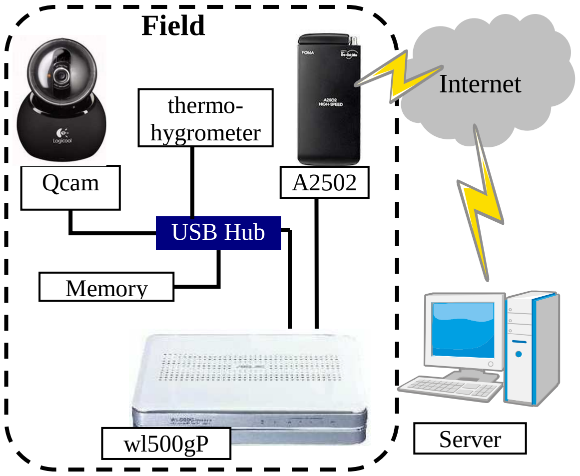

Fig. 1 The schematic diagram of the field image monitoring system

5. Result and Discussion

5.1 Field experiment

First field experiment was carried out from August 1, 2008 to January 27, 2009. Developed system was installed in the experimental farm of Mie University; it was put under the sunlight without shade to be intentionally exposed in severe condition. Stability of the system was examined at this primal run. Second experiment started in August 18, 2009 and has been continuing. In this second run, the system was improved after the results of the first one and the quality of the captured image was primarily investigated.

5.2 Cost of the system

Total cost of our field image monitoring system was estimated as shown in Table. 2. It became almost 3 hundred US dollars except for the charge of data communication. Although the charge for the mobile telecommunication seemed relatively expensive in the system, it was still cheaper than other data communication modes such as satellite communication ($600/month). Moreover, as other ISPs had started lower price mobile telecommunication services one after another, ratio of the data communication cost would be decreased in the near future.

Table. 2. Estimation of the system cost

CPU board	$100	
USB camera	$100	
USB thermo-hygrometer	$50	
Data Communication		$100/month
misc.	$50	
Total	$300	$100/month

5.3 Robust to endure in field installation

Fig. 2 shows the temperature and humidity change of the closed box for 24 hours from noon of August 19, 2009. They were measured by a USB thermo-hygrometer which was installed in the field. In this graph, red line refers the temperature change and blue line shows the humidity change respectively. This graph was drawn automatically with a help of RRDtool [12] at the remote server using measured values by the system and it was updated by scripts as soon as these data were transferred to the server. User can monitor the latest field condition on a web browser and would be easily able to detect an incidence of the system trouble from a remote site if the graph would not be updated for some time.

Fig. 2 indicates that the maximum air temperature in the closed box exceeded 50 degrees Celsius had been higher than 45 degrees until 5 PM. Daily maximum temperature of this day was 30.3 degree Celsius in Tsu city; this was almost same as the climatological normal in summer. It means that the system experiences 40 degrees Celsius or higher temperature during daytime in summer. In the first field experiment, our system had run stably for almost six months including summer, before it was withdrawn for maintenance. This fact shows that the system is robust enough to survive in the field installation.

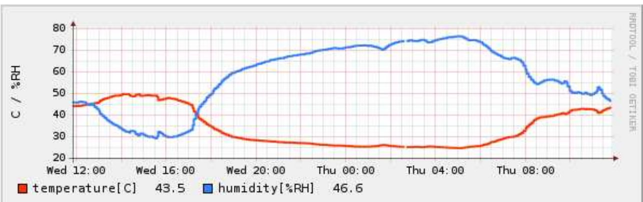

Fig. 2. Change of temperature and humidity

5.4 network gateway in the field

The field image monitoring system has multiple ways to connect a network; wired, IEEE 802.11g WiFi and 3G network provided by A2502. As we had not yet evaluated the WiFi network of wl-500gp, it would be excluded in this paper.

Once a wired connection was available, it would be the easiest way to connect our system to the Internet. Cost for the data communication would also be supposed to be the lowest in these three ways. However, as previously mentioned, there would be few farms where wired network connection was available in Japan.

When the system was installed in the area where 3G wireless network services were available, there would be no problem in network connection. Connection trial had succeeded at the mandarin orange farm in Kumano where any wired connections were not available. Speed test showed that it took 6 seconds for uploading a file of 400kB in size to the server through 3G wireless network. This rate is fast enough for transferring high resolution still image files..

Since this system has multiple ways to connect a network and it also worked as a mobile router, it would be expected as a flexible network gateway in the filed.

6.4 Image capturing

In the first field experiment, a cheap USB camera with maximum resolution of 640 x 480 pixels was used. But the captured images were almost saturated, and situation was not improved by tuning of driver's parameters.

Replacement of a webcam with Qcam solved an image quality issue. Although it has a true 2-megapixel sensor and supports high resolution up to 1600 x 1200 pixels, images were only available in low resolution at first. It was caused by the shortage of memory of a CPU board. Adding a USB flash drive as a swap partition enabled capturing high resolution images. Finally we could get a high resolution image such as Fig.3.

As resolution of 1600 x 1200 pixels is much finer than those of most popular network cameras, it is expected that captured images would be valuable of image processing. Properties of Qcam and other issues are under investigation.

Fig. 3. Example of an image in the maximum resolution

6. Conclusion

In this study, the field image monitoring system was developed using an embedded Linux based CPU board with USB ports and various USB peripherals. The total cost of this system was almost 3 hundred US dollars. And the field experiment for six month showed this monitoring system was able to endure under the severe conditions; it was proved that this system worked at the temperature of over 50 degrees Celsius at this moment. Furthermore, the system also worked as a mobile network gateway in the area where wired network connections were almost unavailable.

In conclusion, this developed system satisfied three requirements; low-cost, robust and network gateway in the field. Since the technologies used in this system are general, it would be able to apply it to not only agriculture but also many other issues including observation of ecosystem by images, monitoring in slope disaster site and so on.

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