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Paper:

Field Monitoring Using Sensor-Nodes with a Web Server

Tokihiro Fukatsu, and Masayuki Hirafuji

National Agricultural Research Center
3-1-1 Kannondai, Tsukuba, Ibaraki 305-8666, Japan
E-mail: fserver@zoushoku.narc.affrc.go.jp

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In order to realize field and environment monitoring over long periods, we propose remote monitoring that responds flexibly and dynamically to change. Field Servers are one of the small monitoring sensor-nodes having a Web server accessed via the Internet and using a wireless LAN to provide a high-speed transmission network differing from traditional sensor-nodes. Monitoring with Field Servers enables easy installation, monitoring field information, and remote operation in any field. By providing a Web server for all modules, we can treat them collectively via the Internet. To evaluate this monitoring, we managed numerous Field Servers in different countries using an agent program. Field experiments show the system is safe and effective for remote monitoring applications.

Keywords: sensor-node, remote monitoring, Internet, Web server, wireless LAN

1. Introduction

In the agricultural and environmental sciences, it is important to monitor crop growth and field environmental information in various places under harsh conditions over long periods, but field monitoring is difficult to perform because installation sites mostly lack infrastructure for power or networking and precision instruments must endure exposure to heat, moisture, rain, and dust. It becomes necessary to install numerous measurement devices and to change their locations and configuration according to the situation because monitoring fields are generally wide and undergo changes, unlike closed environments. In ordinary monitoring, field information has so far been acquired by collecting data periodically through a data logger; such monitoring systems produce inaccurate data and require much effort for field use.

Sensor network research enables large-scale environmental monitoring using many small sensors with radio data links. Mote [1], developed for the "Smart Dust" project, and Sensor Web [2], developed by NASA for Mars missions, are proposed as typical sensor network research. It is possible to improve measurement accuracy, acquire more useful information, and arrive at a greater understanding of each exact situation by combining data from many sensors. Research on sensor networks has focused on networks, examining issues such as routing and data transmission [3–4], or on the sensor unit, exploring position sensing, synchronization, and optimal arrangement [5–6]. There has been little research on system construction for field monitoring or long-term management.

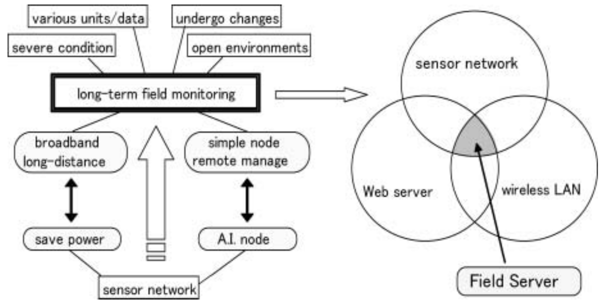


Fig. 1. Concept of the long-term field monitoring system.

In other research, measuring sensor data using Ethernet LAN technologies was proposed for sensor networks. Monitoring with Ethernet LAN gives high noise tolerance for data transmission and simplifies sensor cable wiring [7]. Thanks to these advantages, some research has been adapted in structural health monitoring [8–9]. Other reports have proposed monitoring and operating with a Web interface [10] and wireless monitoring via the Internet [11–12]. However, these systems only consider situations in which many identical specific units are arranged: for instance, monitoring the load distribution of the bridge in a closed system. Such a system is not well equipped to deal with general-purpose usage, or handling units with differing functions, and changing the operation mode according to the situation.

In the case of agriculture, measurement data is available for growth simulation of crops [13] and predicting the occurrence of disease or pest infestations [14]. Flexible and adaptable monitoring is required that utilize various type of information, change the measurement program as necessary for each growth stage, and control and operate peripheral equipment in a remote site. Large blocks of data such as images must also be treated to determine crop or livestock conditions [15].

In order to meet such needs, we propose long-term remote field monitoring consisting of a sensor network equipped with a Web server for measurement and wireless LAN for data transmission (**Fig.1**). Sensor net-

Fig. 2. A standard Field Server.

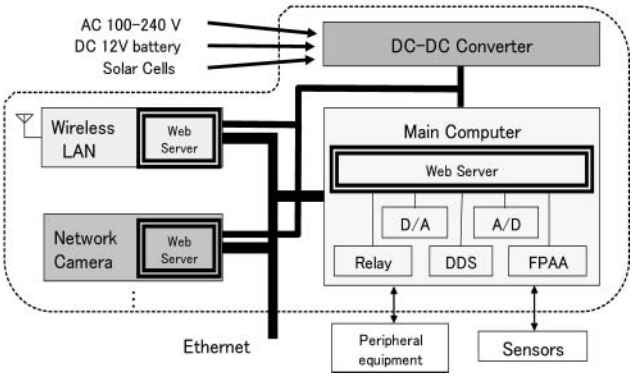


Fig. 3. System construction of the Field Server.

works conventionally use exclusive radio communication and must minimize data and communication time to save power. The wireless LAN of our proposed system slightly increases power consumption but also provides a high-speed transmission network and long-distance communication for large image files at low cost. For sensor-nodes to process measured data and cope with various situations on their own, they would have to be constructed with artificial intelligence and would require a high-performance CPU, substantial memory, and a large program file, all of which are costly and increase the risk of "bugs." In our much simpler remote system, the sensor-node is mounted on a Web server built by simple firmware and on a low-end CPU. It responds to perform various monitoring and managing complicated operations, either by remote computer or a user through a wireless LAN network. We developed a general-purpose sensor-node for fields called a "Field Server (**Fig.2**)", which is equipped with a Web server and wireless LAN to realize long-term remote field monitoring. By installing numerous Field Servers in a field, we constructed long-term remote monitoring that easily processes various data from any place at any time.

Table 1. Power consumption of the parts of Field Server.

Module	Model (Corp.)	Power consumption
Field Server	Main Computer	0.6W
	LED Light	1.2W
	Electric FAN	1.2W
Wireless LAN	WLA-G54 (BUFFALO)	3.0W
	GW-EN11H (PLANEX)	1.3W
	WRT54G (LINKSYS)	5.3W
Network Camera	CG-NCMN (Corega)	2.3W
	KX-HCM170 (Panasonic)	6.0W
	RDC-i700 (RICOH)	9.0W
Option	Halogen lamp	10.0W
	Buzzer	6.0W
	RS232C converter FA-21 (CENTURY SYSTEMS)	1.1W

2. Field Server

The Field Server, a small monitoring sensor-node, was developed so that it could easily be installed outside with a wireless LAN with broadband, and managed various sensors and peripheral equipment with a Web server housed in a small computer. **Fig.3** shows the system construction of the Field Server. Each module has a Web server and connected to other modules with Ethernet, making it is easy to exchange or add modules. For example, a Field Server is available for introducing the latest and high-performance IT module.

The standard Field Server is about $20 \times 20\text{cm}^2$ and weighs about 1kg, making it easy to install and remove. The power supply is selected from different types, such as a commercial power supply (AC100-240V), DC12V battery, and private electric generators (solar cells, etc.), based on installation conditions and purposes. Inside a Field Server, the power supply is DC12V and the proper voltage of each module is changed by a DC-DC converter. The standard power consumption is about 6W and differs by type and setting of wireless LAN, network camera, and peripheral equipment (**Table 1**). At sites without an external power supply, a Field Server requires a $1 \times 2\text{m}^2$ or larger solar cell to drive continuously; other energy-saving Field Servers that work intermittently are managed with a small solar cell (about $15 \times 15\text{cm}^2$) embedded on the roof [16].

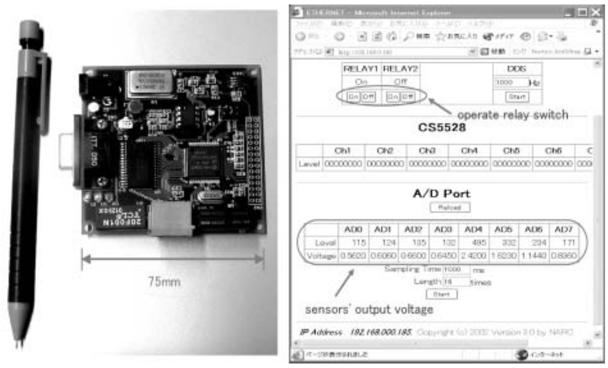
Using Field Servers for field monitoring enables much easier installation than ordinary large systems. Easy installation and removal for field monitoring is especially important for agricultural work, which varies according to the different stages of crop growth. Field Servers reduce work in long-term outdoor monitoring through the following key technologies:

2.1. Web Server

Web server software presents Web information to a client based on TCP/IP. By building a Web server into measurement equipment, we can easily access and man-

Table 2. Specification of Field Server's main computer.

	PICNIC	FS-Engine
CPU	PIC16F877	H8/3069
A/D ch (bit)	4ch (10bit, 0-5V)	16ch (24bit, 0-5V)
D/A ch	In 4ch / Out 4ch	Out 2ch with relay
Port	RS232C×1, RJ45×1	RS232C×1, RJ45×1
Option		DDS (∼70MHz) FPAA (20CABs)
Cost	US$70	US$200 (estimate)



(a) (b)

Fig. 4. (a) Field Server Engine and (b) displayed Web page in which we can monitor sensor's output voltage and operate peripheral equipment with On/Off button.

age equipment using a Web browser such as Internet Explorer, without installing exclusive software. Equipment with a Web server is simple internal firmware that responds to different monitoring and operating stably. In this way, it is possible to treat different equipment with the Web server in the same manner. We can construct a high scalability system not affected by the number of measuring devices.

Besides the Field Server, many kinds of Web-compatible equipment are beginning to spread, such as network cameras, digital cameras, and Ethernet converters making it possible to use many outdated devices with the RS232C port. Constructing a system in such a way that every unit is treated on the Web reduces legacy problems in which old measurement equipment cannot be adapted to a new system. This is important because long-term field monitoring requires much measurement equipment.

Table 2 shows the specifications for the Field Server's main monitoring computer with a Web server. The Field Server has a commercially available computer such as "PICNIC (TriState Company)" or "Field Server Engine (**Fig.4**)" developed in our previous research [17]. It has functions in which several sensors' output voltage is converted by an A/D converter and displayed on the Web, and in which peripheral equipment connected to digital output by relay circuit be operated with the CGI function of HTTP. In the Field Server Engine, various functions such

Table 3. Sensors connected to a Field Server.

	Model (Corp.)	Spec.	Cost	Output
Temperature	LM35 (National)	−55-150C±0.2C, +10.0mV/C	US$2	Direct current
Humidity	CHS-UPS (TDK)	5-95%±3%, +10.0mV/%	US$70	Direct current
Solar radiation	Embedded	0-100klx±5%, +30mV/klx	—	Direct current
CO_2	GMW22 (Vaisala)	0-5000ppm±30ppm, +2mV/ppm	US$800	Direct current
UV	G5842 (Hamamatsu)	260-400 (370) nm, 60mA/W	US$10	DC with circuit
Soil moisture	Handmade	0-70%±2% with calibration	—	Capacitance
pH	Handmade	0-14.0pH±0.1pH with calibration	—	Impedance

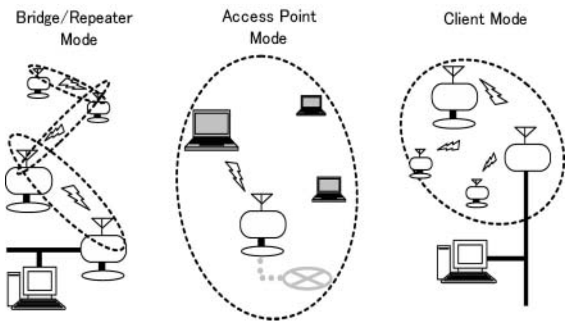


Fig. 5. Mode in wireless LAN.

as high-speed sampling A/D, DDS (Direct Digital Synthesizer), FPAA (Field Programmable Analog Array), and analog multipliers are operated on the Web. DDS generates an alternative signal up to 70MHz. FPAA constructs dynamically analog circuits such as low-pass filters using its embedded 20 CABs (Configurable Analog Block) and analog multipliers. By combining these functions, we can monitor various kinds of sensors.

Sensors connected to the Field Server monitor air temperature, relative humidity, and intensity of solar radiation by standard equipment, UV and CO2 concentration by DC output, soil moisture and pH by impedance measurement, and leaf wetness by original sensors (**Table 3**).

2.2. Wireless LAN

A wireless LAN (Wi-Fi, IEEE802.11b/g) provides high-speed transmission at low cost. Using it for the Field Server cuts the effort and the cost for laying cable and reduces communication charges. There are different features of mode (access point, bridge/repeater, and client) in the wireless LAN, and the standard Field Server uses an access point and bridge/repeater mode simultaneously (**Fig.5**).

- Access point mode

  The wireless LAN provides hotspots where it is connected to the Internet by client connections such as laptop PCs. Using this mode for the Field Server, we can only access this type of Field Server within its own hotspot, but we don't use it in cooperation with

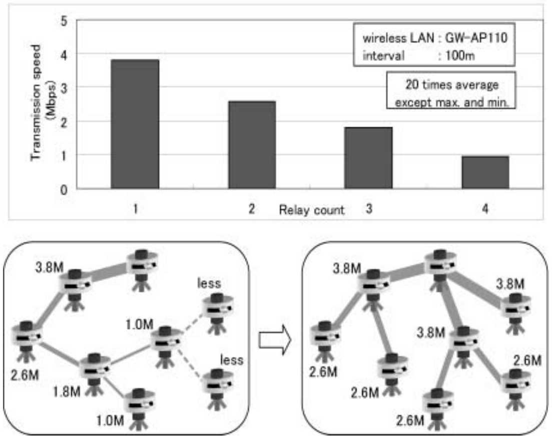


Fig. 6. Change of the transmission speed according to the relay count. By considering the network topology, the transmission speed of terminal Field Servers will be increased.

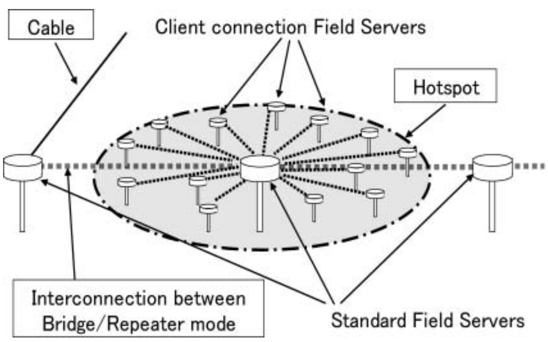


Fig. 7. Installing many Field Servers in a narrow area with client mode.

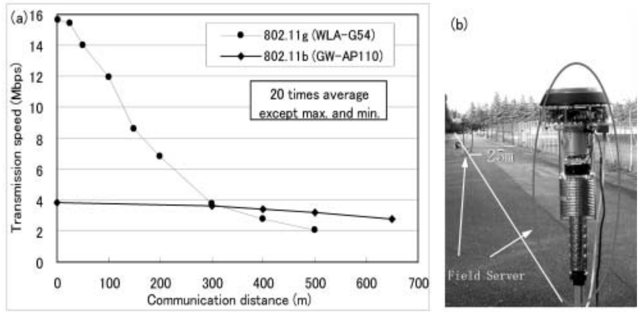


Fig. 8. (a) Relation between transmission speed and communication distance and (b) experimental aspect.

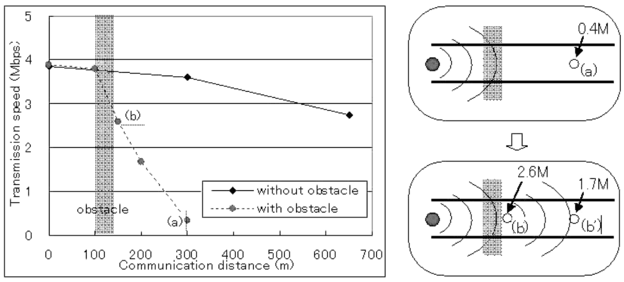


Fig. 9. Effect of the obstacle on the transmission speed. (a) It becomes too slowly when connecting through obstacles directly. (b') But by relying with more Field Server, it is kept enough.

two or more access points. Therefore, it is impossible to monitor over a long distance.

- Bridge/Repeater mode

  Identical wireless LANs connect with each other and make a network such as an Ad-Hoc network. Via this network, we can access any equipment connected to this wireless LAN from any place at any time. By constructing this mode as the backbone network for Field Servers, the monitoring area is extended to a long distance easily with relays from several Field Servers, but transmission speed decreases with the relay count (**Fig.6**). When installing numerous Field Servers in a narrow area, we must consider network topology to avoid increasing the relay count.

- Client mode

  By interfacing with the wireless LAN, also called an Ethernet converter, equipment that does not have a wireless LAN function connects to the network in hotspots. A standard Field Server is connected to the backbone in bridge/repeater mode and simultaneously provides hotspots by access point mode. Therefore, by utilizing the Field Servers with client mode, we can install many Field Servers in a narrow area without needing to consider relay count or decrease transmission speed (**Fig.7**).

The communication distance of the wireless LAN, which changes with the model, configuration, environmental conditions, antenna type, etc., generally reach the ranges where viewing takes place. **Fig.8** shows experimental results for the relation between communication distance and the transmission speed of Field Servers. In this experiment, Field Servers were equipped with wireless LAN, which is WLA-G54 (BUFFALO Inc.) for 802.11g and GW-AP110 (Planex Communications Inc.) for 802.11b. The transmission speed of the wireless LAN for 802.11g is faster than that for 802.11b at a short distance, but it rapidly decreases as distance increases, becoming the same as 802.11b at about 300m. Although 802.11b becomes slow with increasing distance, it maintains a transmission speed of 2.8Mbps (about 70% of the transmission speed in a short distance) even at 650m. This suggests sufficient performance for practical monitoring of high-resolution images (ex. 3M pixels jpeg, 1Mbytes) at field block intervals (ex. 100m/block in paddy field).

However, this distance decreases when obstacles such as windbreaks are present because of absorption and reflection of electric waves (**Fig.9**). In connecting to the network where there are obstacles, the communication performance of Field Servers is maintained by bypass-

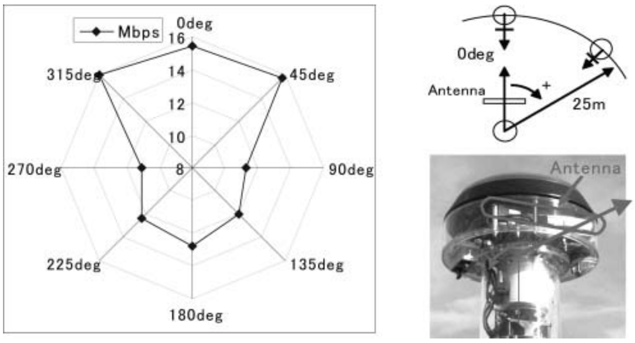


Fig. 10. Direction dependency of the transmission speed.

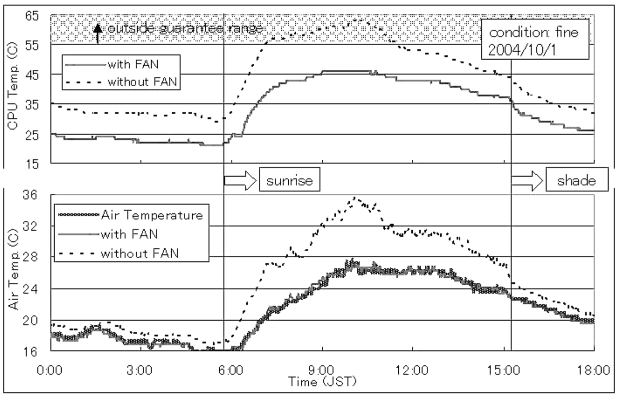


Fig. 11. Effect of the FAN on the measurement accuracy and CPU temperature.

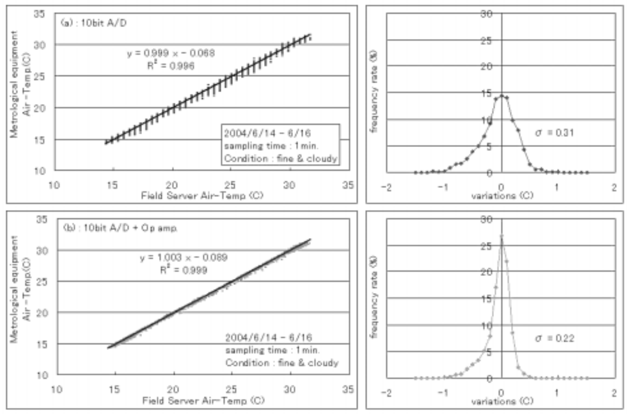


Fig. 12. Measurement accuracy of the Field Server.

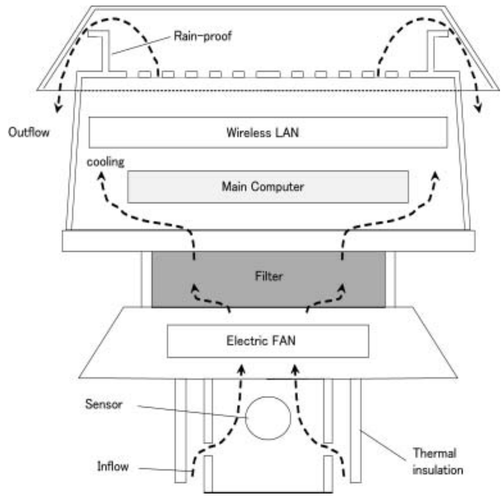


Fig. 13. Casing of the Field Server for heat-resistance, rain-proof, and dust-proof.

ing from another point or installing a Field Server in the obstacles, depending on the situation. **Fig.10** shows the direction dependence of transmission speed in the Field Servers, and shows that a sideways direction to the antenna decreases communication speed.

2.3. Hardware

For use under severe conditions over long time, Field Servers must maintain stable measuring accuracy and endure heat, moisture, rain, and dust. Especially, it is important how electronic measuring equipment that generates heat is cooled without excessive power consumption in places of severe environmental conditions. In terms of measuring accuracy, the "Assman aspirating psychrometer measure", which measures with ventilation in a sensor, was used to maintain measurement accuracy for air temperature and relative humidity. By using ventilation both for the sake of maintaining measurement accuracy and cooling electronic equipment, the Field Server solves problems of environmental exposure without excessive power consumption. **Fig.11** shows the advantageous effect of accuracy and cooling. Without an electric fan, the daytime CPU temperature increases rapidly; with a fan, CPU temperature is maintained within the guarantee range at which measurement equipment functions normally. At the same time, air temperature measurement is highly accurate because the influence of solar radiation is excluded.

In order to examine the measurement accuracy of the Field Server, we compared results of commercial metrological equipment (MS352-10, Yokogawa Weathac Co.) and Field Servers. In this experiment, (a) one Field Server was equipped with a 10 bit A/D converter and 0.5C resolution and (b) the other with a 10 bit A/D converter with 5 times Op amplifier and 0.1C resolution. Results of correlation coefficients of Field Servers with commercial equipment exceeded 0.99, and standard deviations were (a) 0.31 and (b) 0.22 (**Fig.12**), indicating sufficient accuracy for both (a) and (b) to monitor environmental data in agricultural field, and it can be further improved by raising resolution.

In addition to heat resistance, the casing of the Field Server was improved to be rain-proof by shielding air outlets with overhangs and to be dust-proof by installing a filter in the inflow (**Fig.13**). The Field Server was equipped with PoE (Power over Ethernet), which transmits electric power and information signals by one Ethernet cable.

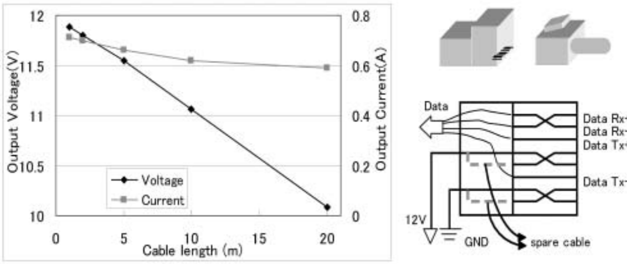


Fig. 14. Power over Ethernet of a Field Server.

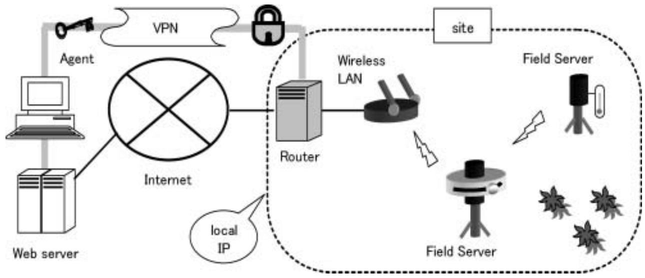


Fig. 15. Standard construction of Field Server system.

By using PoE, the difficulty of cable installation, such as power supply lines and signal lines to peripherals, can be mitigated. The PoE of a Field Server has a 12V supply unlike the PoE of IEEE802.3af standard and the lowest input voltage of DC-DC converter is 10V, so the maximum Ethernet cable is about 20m, from voltage drop and safety (**Fig.14**).

Table 4. Parts list of Field Server monitoring system.

	Model	Costs
Address	ADSL (global IP)	US$30/month∼
VPN Router	YAMAHA RT56v	US$300∼
Start Point	BUFFALO WLA-G54	US$100∼
Field Server (per 1 unit)	Main Computer	US$70∼
	Wireless LAN	US$100∼
	Sensors (standard type)	US$100∼
	Case	US$100∼
	Electronic circuits	US$50∼
	Power supply	US$20∼
Option	Network Camera	US$100∼
	LED Light	US$50∼
	ECHO sensor	US$400∼
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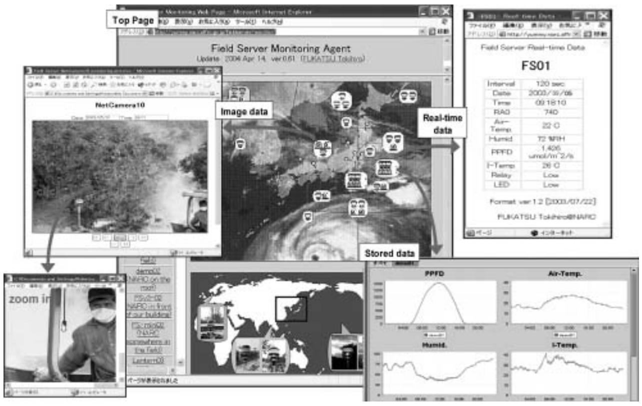

Fig. 16. Web top page of monitoring results with clickable map which is linked with real-time data, stored data, and image data page created by agent program.

3. System Architecture

We can access a Field Server easily by connecting to a computer, either fixed-line or wireless. By installing several Field Servers at different monitoring points and relay points, all Field Servers are connected to the network and each other at all times. By connecting with this network, we can easily monitor and manage all Field Servers in the network. Moreover, by connecting this network to the Internet, we have constructed a long-term Internet-based monitoring system.

In long-term monitoring using Field Servers, it is also possible to manage Field Servers by periodic local access using a local network not connected to the Internet, but such a system gives the users the burden of installing a computer, storing large amounts of data, and managing programs for each local network all day. In this research, we constructed a system that lightens the load of the users by managing different spots collectively from a remote place via the Internet.

Figure 15 shows the construction of this Field Server monitoring system, and **Table 4** shows the parts list of this system required at a site. The monitoring site has several Field Servers for monitoring and relaying, a wireless LAN as the start point, and a broadband router for safely connecting to the Internet from the local network. The start point wireless LAN and the broadband router are mainly installed in a building with a broadband line such as xDSL or CATV. To ensure security, remote access is mainly performed by a VPN (Virtual Private Network) or by the port forwarding of the router [18]. For severe network conditions such as severe security requirements or narrowband connection, alternatives such as using a HTTP post, FTP, and Mail function are being studied [19].

Using the Internet makes it easy to collect monitoring data from a remote place since all measuring equipment included in Field Servers has a built-in Web server. In our previous work, we developed a general-purpose program "Field Server Agent" that collects data automatically, and controls equipment flexibly and outputs useful information via the Internet [20]. Using this agent program, many Field Servers at several sites are managed automatically on a remote computer via the Internet. Users can acquire monitoring data easily, not only by accessing Field Servers directly from within a local network, but also by accessing Web pages created by the agent program. **Fig.16** shows an example of the Web page. The top page has a clickable map linked to data of Field Servers.

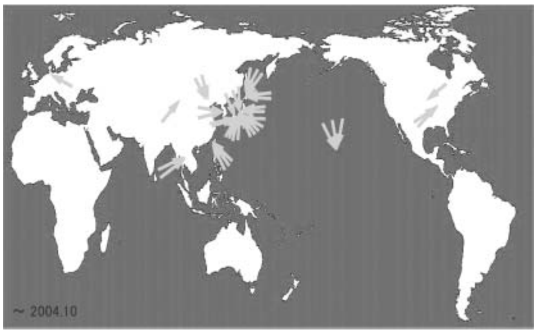

Fig. 17. Sites of Field Servers.

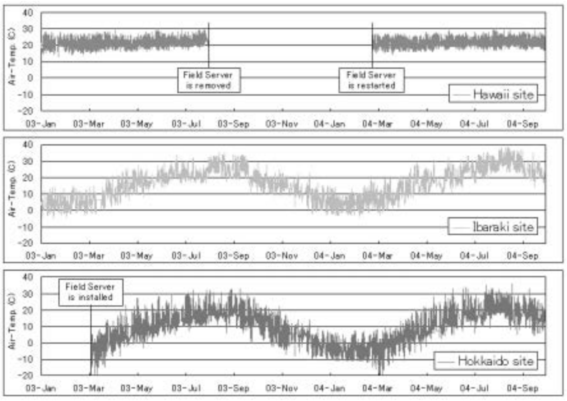

Fig. 18. Monitoring results of long-term field experiments.

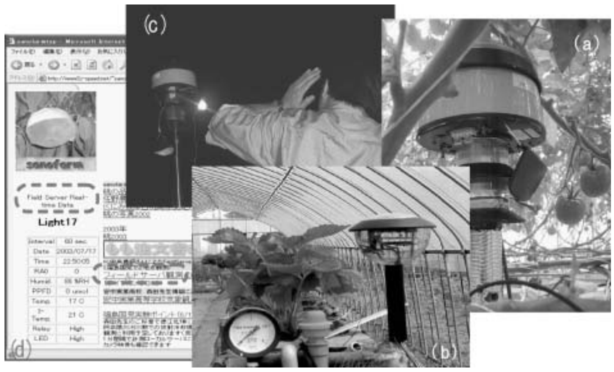

Fig. 19. Effective usage of Field Servers. (a) monitoring, (b) controlling, (c) surveillance, (d) publicity.

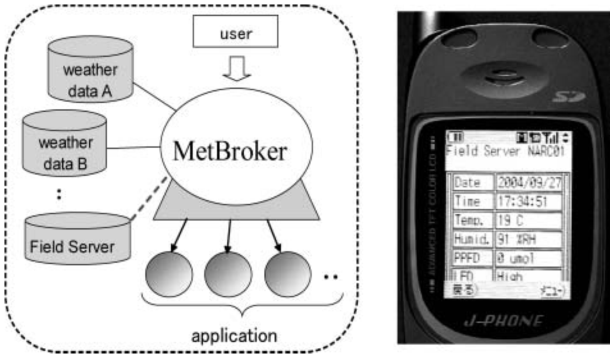

Fig. 20. Access to Field Server's database by MetBroker & cell phone.

Results of sensor data are provided by real-time data and stored data in graph form. As regards image data, this Web page displays thumbnailed animation linked to original high-resolution images.

4. Field Experiments

In order to evaluate this long-term remote field monitoring, we installed numerous Field Servers in different countries and managed them with the agent program. Approximately 40 Field Servers (as of October, 2004) are currently installed in different parts of Japan, the United States, Thailand, China, Korea, and Taiwan (**Fig.17**). Participants in these experiments include farmers, companies, universities, and research institutes. This system has performed reliably for more than two and a half years since February 2002. The agent program has been executed on the PC cluster at our laboratory (Ibaraki, Japan) and has accessed these Field Servers at intervals of 1-10 minutes depending on the network speed or the amount of data collected. Despite some sites experiencing severe environmental conditions such as extreme seasonal changes and typhoons and undergoing the addition or removal of Field Servers, it has been possible to collect data stably over a long time (**Fig.18**).

This system uses Field Servers not only for monitoring various types of weather data but also for managing greenhouses, field surveillance, and publicity (**Fig.19**). Data collected at our laboratory has been opened to the public on trial Web pages [21], and has been connected to "MetBroker [22]", middleware for weather data that provides agricultural models with consistent access to many different weather databases. MetBroker-compatible models and applications for agriculture involving on-site field information from the Field Servers' databases could prove very useful. Besides, it is easy to access real-time data by cell phone using the Internet through functions such as i-mode (**Fig.20**). Users thus benefit from this Field Server system.

5. Conclusions and Discussion

In order to realize long-term monitoring, we introduced the sensor-node with a Web server and a wireless LAN and proposed remote field monitoring in which many Field Servers are managed via the Internet. Using this system, users with only basic networking knowledge can easily install and monitor Field Servers in severe places and control and operate peripherals flexibly via the Internet.

In agricultural research, it generally seems that the robotics and mechatronics are not so important, but it becomes effective by changing the object as shown in this

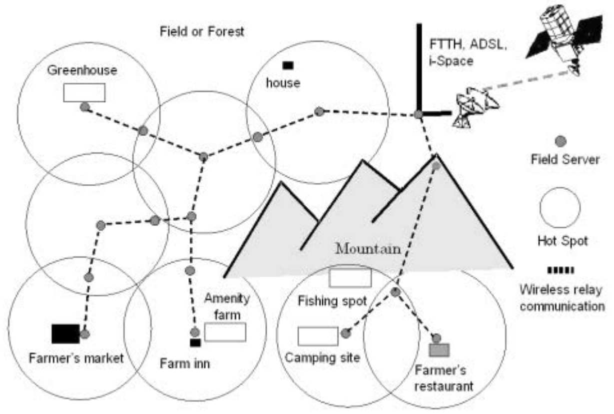

Fig. 21. Ubiquitous networking in rural area by Field Servers.

sensor network. By adapting engineering system to severe environments, open systems, and long-term operation, it becomes easy to adjust to the agricultural field. It will achieve "Field Informatics" that constructs lab-based measurement in the actual field.

In agriculture, although some monitoring and automatic management are used, it is difficult to perform a fine judgment by automatic sensor, and there is understandable anxiety about sensor error because of the possible consequences to living things [15]. In our system, sensor-nodes are constructed with a Web server and controlled via the Internet, so we can choose between management by automatic control with a remote computer or by manual operation using the user's judgment. This system also constructs a man-machine system in which users themselves can check and operate peripherals with a sense of security in the case of an important subject.

Field Servers are networked at all times with each other and provide hotspots. Since the network is connected to the Internet, this system is used as a wireless sensor network and as an infrastructure for ubiquitous networking. This ubiquitous networking solves "the last mile problem" and provides the possibility of adaptations for green tourism in rural areas (**Fig.21**) [23]. Using this network, users can also get advice, for instance, on cultivation and pest control via the Internet. With the features of concurrent access via a Web server, Field Servers are enabled to manage using several agent programs from different places, so we can distribute data storage for backup data and improve reliability. If anyone can access the monitoring data, which records the history of "who, what, when performed" in real time, this data is also used as traceability data by the general public checking as a sort of juror, so to speak.

Various kinds of equipment with a built-in Web server including Field Servers is expected to increase, and it is very important to manage this equipment appropriately. The proposed system effectively manages measurement equipment with a Web server for utilizing a remote field monitoring over long periods.

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Name:
Tokihiro Fukatsu

Affiliation:
Researcher, Department of Information Science and Technology, National Agricultural Research Center, NARO

Address:
3-1-1 Kannondai, Tsukuba, Ibaraki 305-8666, Japan

Brief Biographical History:
1998 Received M.Eng from Tokyo Institute of Technology
1998- Fujitsu Ltd.
2001- National Agricultural Research Center

Main Works:
• T. Fukatsu, and M. Hirafuji, "Development of Field Servers for a Field Monitoring System," Agricultural Information Research, Vol.12, No.1, pp. 1-12, 2003 (in Japanese).
• T. Fukatsu, and M. Hirafuji, "The Agent System for Field Monitoring Servers to Construct Smart Sensor-Network," IFAC, Proc. of Fifth International Workshop on Artificial Intelligence in Agriculture, pp. 1-5, 2004.

Membership in Learned Societies:
• The Society of Instrument and Control Engineers (SICE)
• The Japanese Society of Agricultural Informatics (JSAI)

Name:
Masayuki Hirafuji

Affiliation:
Team Leader, Computational Modeling Team, Department of Information Science and Technology, National Agricultural Research Center, NARO

Address:
3-1-1 Kannondai, Tsukuba, Ibaraki 305-8666, Japan

Brief Biographical History:
1983 Received M.Ag from University of Tokyo
1983- National Agriculture Research Center
1994- Research coordinator, Ministry of Agriculture, Forestry and Fisheries (MAFF)
1995 Received Ph.D. (Ag) from University of Tokyo
1996- National Agricultural Research Center

Main Works:
• "Bio-Expert Systems," Corona Publishing, Tokyo, 1990.
• "A global optimization algorithm based on the process of evolution in complex biological systems," Computers And Electronics In Agriculture, Vol.29, Issues 1-2, pp. 125-134, 2000.

Membership in Learned Societies:
• The Japanese Society of Environment Control in Biology (Environ. Control in Biol.)
• The Japanese Society of Agricultural Informatics (JSAI)
• The Japanese Society of High Technology in Agriculture (SHITA)
• The Society of Agricultural Meteorology of Japan (Agric. Meteorol.)
• Information Processing Society of Japan (IPSJ)
• The Society of Instrument and Control Engineers (SICE)
• The Biophysical Society of Japan (BIOPHYS)
• Japanese Society for Medical and Biological Engineering (JSMBE)
• The Japanese Society of Agricultural Machinery (JSAM)