THE AGENT SYSTEM FOR FIELD MONITORING SERVERS TO CONSTRUCT SMART SENSOR-NETWORK

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Abstract: In order to monitor field and environmental information under harsh conditions over long periods of time, we have developed a "Field Server Agent System" which operates sensor units uniformly through built-in Web servers. The agent system is designed on the assumption that every component can be accessed via the network. With such a system, it is possible to monitor various kinds of units, to set up parameters by the server side, and to change managing schedules dynamically according to detected conditions. Experimental use of the agent system with Field Servers has shown the validity of the Field Server Agent System.

Keywords: agents, monitoring, sensor systems, data acquisition, control, networks, information technology, databases.

1. INTRODUCTION

In agriculture, long-term monitoring of crop growth stages and field information is required in order to predict growth, predict the occurrence of pests and diseases, and improve crop traceability, among other things. In the environmental sciences, it is also necessary to monitor the environment in various places from the point of abnormal weather and global warming. The common requirement for both types of monitoring is the need to monitor under harsh environmental conditions in many places over long periods of time.

Fig. 1. A standard Field Server. Field Servers can be equipped with sensors, for example for temperature, humidity and solar radiation, and with switches for heaters, water sprinklers, etc.

Recently, sensor network research has enabled large-scale environmental monitoring using many small sensors with radio data links. In our previous work, we developed small monitoring robots called "Field Servers (Fig. 1)" which are equipped with a Web server and can use wireless LAN to provide a high-speed transmission network at a low price (Fukatsu, *et al.*, 2002; Fukatsu and Hirafuji, 2003). By building a Web server into sensor-network equipment, we can easily access and manage it using a Web browser such as Internet Explorer (He, *et al.*, 2003). It is expected that this kind of equipment will be used for remote monitoring over long periods of time.

The present paper describes the development of a "Field Server Agent System" which collectively manages these monitoring robots via their built-in Web servers and which flexibly and dynamically responds to changes in managing schedules and system parameters. We would provide the following secure services to Field Server owners: data collection and archiving; control of peripheral equipment; automated warnings; and graphic or simple display for personal digital assistants (PDAs). Centralizing the operation of the agent system greatly reduces the amount of effort and learning involved in setting up a Field Server network in a new location.

2. SENSOR AGENT

2.1 Monitoring for Agriculture

In agriculture, it is important to monitor field information, but this monitoring is difficult to perform because there is almost no infrastructure for providing power or networking capabilities, periodical maintenance and data collection are difficult to carry out at installation sites which often experience severe conditions, and the user must not only devote considerable time to monitoring, but also have access to various technologies and specialized knowledge. In the case of agriculture in particular, it is essential that various types of information be provided in real time in order to prevent the occurrence of injury, pests and diseases. The specific required information differs for every growth stage or crop, and it is therefore necessary to be able to change the measurement program as necessary for each situation. Additionally, data processing for extracting useful information from a vast quantity of collection data is highly desirable. Thus, a long-term monitoring system should be able to cope with these subjects, reduce the amount of effort required of the user, and acquire useful supporting information.

2.2 Sensor Network

Recently, sensor network research has enabled large-scale environmental monitoring using many small sensor units with radio data links. In a sensor network, 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 various sensors. Research on sensor networks to date has focussed primarily on the networks itself, examining issues such as routing and data transmission (Servetto and Barrenechea, 2002; Ye, *et al.*, 2002), or on the sensor unit, discussing position sensing, synchronization and optimal arrangement (Savvides, *et al.*, 2001; Elson and Romer, 2002). There has been little research on model application of such a system or on system construction.

In a traditional sensor network, many identical specific units are arranged so the temperature distribution of space may be measured (Umezawa, *et al.*, 2003). Such a system is not well-equipped to deal with general-purpose usage, such as identifying each unit from which a function differs, and making operation changes according to the situation. A more high-performance central processing unit (CPU), more memory and more power consumption are essential if sensor units are to be used widely. Because the control software is necessarily large, there is an increase in risks such as failure of program transmission, or bug generation within a program.

If the system is to work as desired, it must be possible for it to conduct measurements with complicated operations and conditions involving a large amount of data, including image data. Moreover, we require not only measurement but also the control and operation of equipment based on measured data. A useful sensor network in the agricultural field must be general-purpose. The proposed new agent system further extends the existing concept of a sensor network.

2.3 Smart Sensor-Network

We have already developed Field Servers which are equipped with a Web server. In the present paper, we propose an agent system which operates sensor units uniformly with these built-in Web servers (Fig. 2). The present system solves various problems which arise in a traditional sensor network.

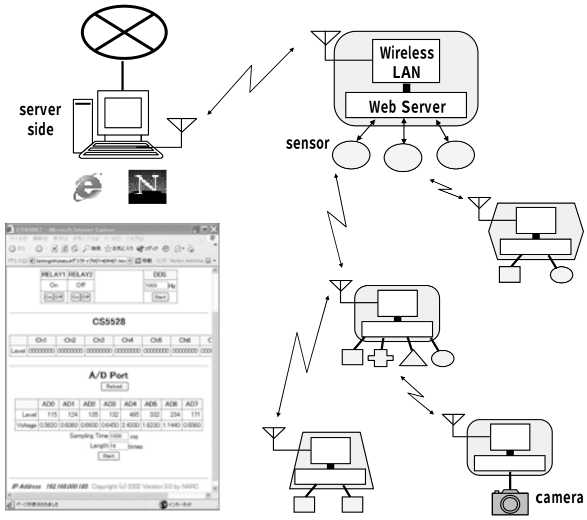

Fig. 2. Field Server Agent System. This system operates sensor units uniformly with built-in Web servers.

The measurement unit built-in Web server can be controlled from any place on a network at any time through the Web, without using exclusive software. Therefore, only by mounting small firmware on the inside, it can respond to various operations by making the server intelligent. Several kinds of units can be treated similarly on the Web and the system can respond flexibly to changes in the number of units. This provides high scalability and fewer legacy problems. Moreover, it is easy to perform set-up and change measurement timing, the operation procedure sent to the units, the method of data treatment, and system parameters by the server side. By applying our proposed agent program, which unifies sensor units and operates them efficiently, it is possible to perform dynamic changes in managing schedules, linkage with other Web servers and Web applications, and judgement of operations according to environmental and network conditions. This agent program allows us to construct an adaptable and flexible system which can perform various operations for different purposes.

3. FIELD SERVER AGENT SYSTEM

3.1 System architecture

Fig. 3 shows the system architecture of the Field Server Agent System. The Field Server Agent System is composed of an agent program, configuration files for the agent program, a database of monitoring data, and Field Servers. The agent program is written in Java, which has flexible and easy network handling, and the program is run on a computer connected to the Internet. The configuration file is in XML format, making it simple to edit, and is network accessible.

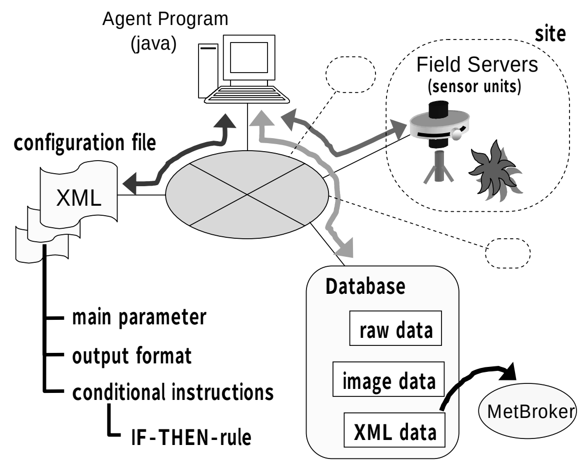

Fig. 3. Architecture of the Field Server Agent System. The system is composed of an agent program, configuration file, database, and Field Servers, managed through a computer connected to Internet.

This agent system is designed on the assumption that every component can access all others via the network. Thus, the program environment need not be located at the site at which the Field Servers are installed. Users can manage their own Field Servers from anywhere in the world by editing their own configuration file via the Internet. Additionally, a single agent program can independently handle many Field Servers and distributed measurement sites by deriving many threads. This greatly simplifies the set-up for users.

Measurement data is stored as a database in the XML format on the network. Therefore, it can easily connect to "MetBroker" (Laurenson, *et al.*, 2002), a middleware for weather data that provides agricultural models with consistent access to many different weather databases. Several MetBroker-compatible models have already been designed and many of their applications can be used for agriculture with on-site field information from the database of Field Servers.

3.2 Algorithm

Fig. 4 shows the algorithm and flow of the agent program. First, a list of one or more configuration file URLs is given to the agent program. It searches these in order for the first configuration file which can be accessed to read set-up parameters. If the agent fails to access the primary configuration file in the case of network problems, it reads a secondary one.

A configuration file contains parameters such as next configuration file URL, each Field Server's contact URL, monitoring interval, calibration parameters and output file format. The configuration file also contains conditional instructions which contain commands, such as "Get", "Put", "Post", "Read", and "Write", which can be combined so that the agent program may monitor and control the Field Servers and database. In addition to these hardware devices, Web applications also allow the agent system to communicate. Each tiny action has parameters which determine whether or not a given action is executed. This system has an IF-THEN rule which allows comparison and judgment of XML node values, such as sensor, time, and flag. It is possible in a single instruction to include two or more IF-THEN rules, and the decision to execute an action is made based on the combined result of these rules. Using this system, we can establish complicated condition judgments for remote control systems.

Figs. 5 and 6 show the XML of sample IF-THEN rules. Fig. 5 shows the conditions which cause a light on the Field Server in question to be switched on between 19:00 and 5:00. Fig. 6 shows the conditions which send a warning mail to a user if the temperature falls less than 4 degrees and another input (*e.g.* leaf-wetness sensor limit) is on. Since Field Servers can both measure and control various peripheral devices, these functions are an important aspect of the system.

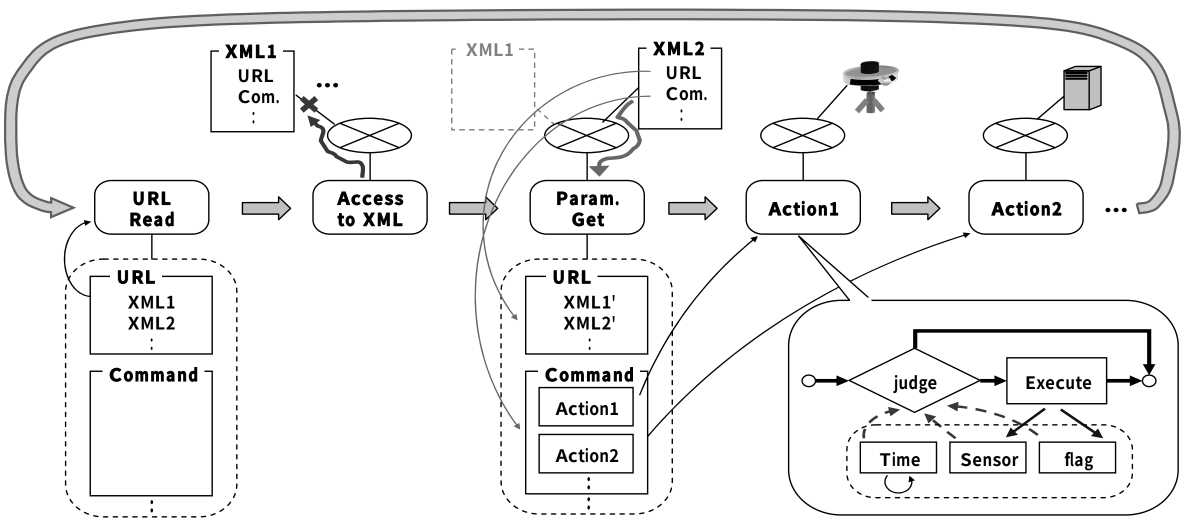

Fig. 4. Algorithm and flow of the agent program. The agent program has XML configuration files which describe its parameters and action commands with IF-THEN rule; the description of these parameters and commands is performed in conformity with the XML files.

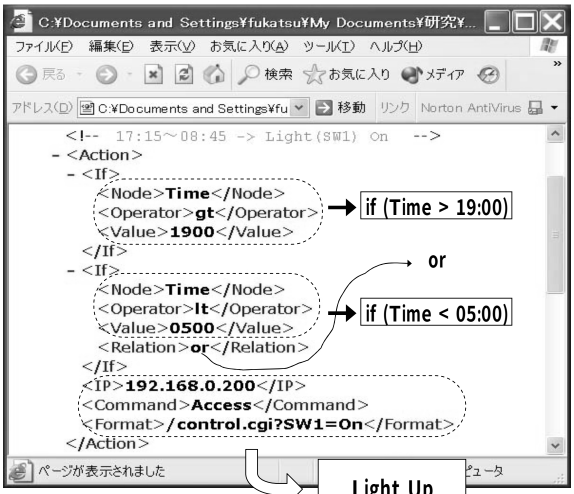

Fig. 5. XML of a sample IF-THEN rule. The XML describes the operation of turning on a light between 19:00 and 5:00.

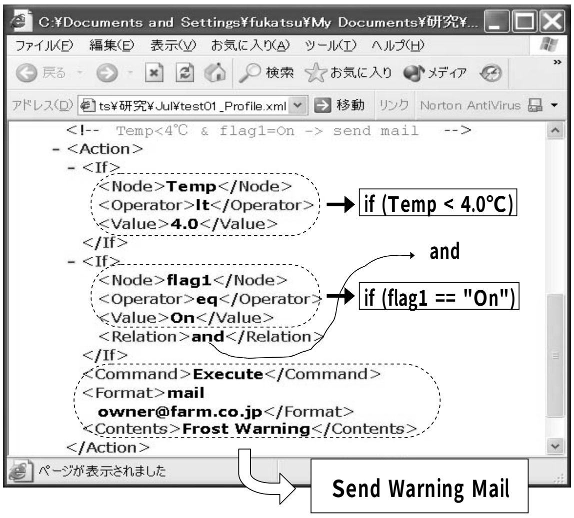

Fig. 6. XML of a sample IF-THEN rule. The XML describe the operation of sending a warning mail to a user if the temperature falls less than 4°C and Flag1 is on.

3.3 *Network Construction*

In order for this agent system to work effectively, it relies upon the design assumption that each Field Server and Web camera can be accessed via a network. The agent program must be able to access all objects satisfactorily. At sites with severe environmental conditions, it is recommended that only hardware is installed at the site itself and that the computer and database is set up on a network later. Therefore, a network allowing the agent program to access equipment installed at remotes sites is required.

For this purpose, we developed a network using Virtual Private Network (VPN) connections, such as PPTP and SSL/TSL, which enable secure access to remote places. Fig. 7 shows one of the standard VPN networks for Field Servers. Although a PPTP connection needs a fixed global IP, it is easily connectable by simply installing a PPTP router. A SSL/TSL connection does not require a global IP, and its connection is more stable than PPTP but its throughput is lower. The network has strong robustness because it can access Field Servers by using either PPTP and SSL/TSL or both. In this system, using local IP addresses at the site makes it secure and it can be accessed from elsewhere using a VPN connection only by installing hardware that has VPN functionality, such as a router or a mini-server. An agent program can access and control Field Servers safely from a remote place through the VPN router of these sites, and the identity of the Agent System is confirmed by the VPN network system.

4. RESULTS AND DISCUSSION

4.1 *Field experiments*

In order to evaluate the Field Server Agent System, it has been used to access and monitor Field Servers with sensors and Web cameras installed in various countries. Approximately 20 Field Servers are

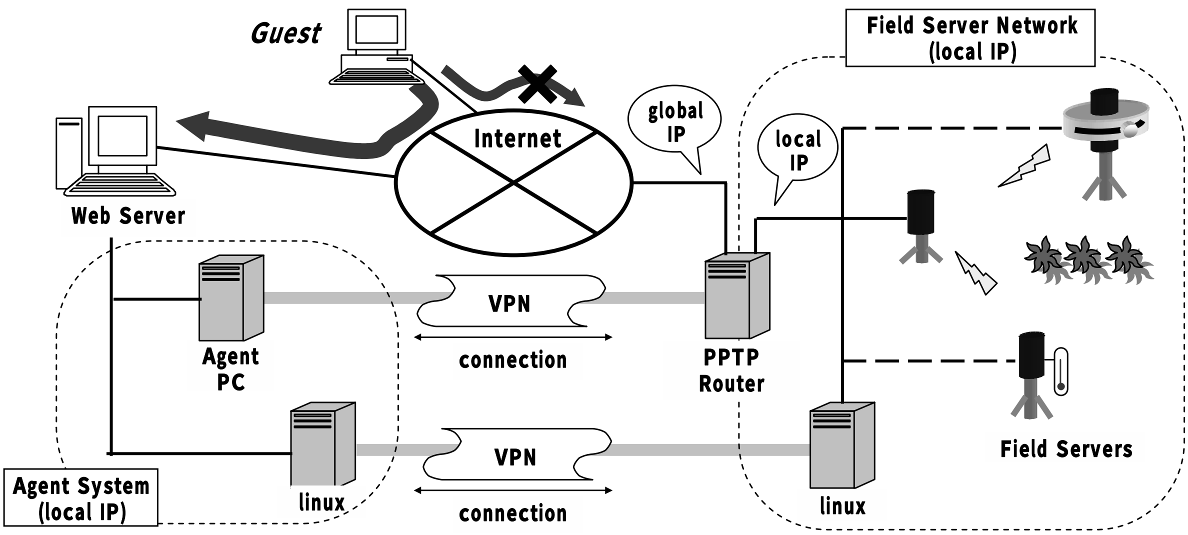

Fig. 7. A standard VPN network for Field Servers. The network has strong robustness because it can access Field Servers using either a PPTP or SSL/TSL VPN or both.

currently installed in various parts of Japan, and approximately 10 others are installed in the United States, Denmark, China and Thailand (Fig. 8). The agent system has performed reliably for more than two years since February of 2002.

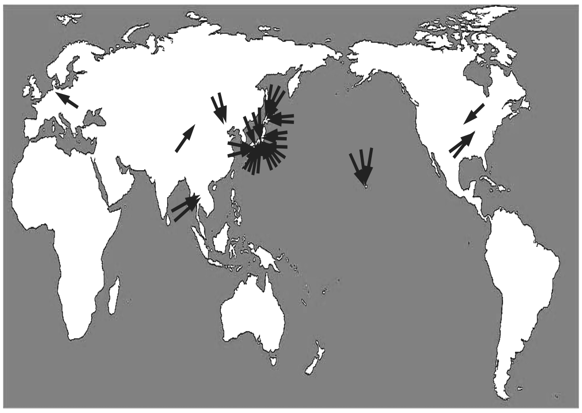

Fig. 8. Sites of Field Servers. Field Servers and Web Cameras are installed at the sites indicated by the arrows on the map.

The participants in this experiment include farmers, companies, universities and research institutes. The installation sites vary and include outdoor, indoor and greenhouse sites. The system is used for the purposes of crop management, field surveillance, and publicity of their plantation with Field Servers, network cameras, and high resolution digital cameras.

The system allows uniform monitoring and control of Field Servers under various environmental conditions. The reliability of the Field Server Agent System to date is evidence in favour of its validity and its ability to manage many Field Servers installed at various sites.

4.2 Future developments

The present paper describes a technique for a single agent in a remote place to manage many Field Servers. In practical use, many agents should be used in order to prevent an increase in network traffic and accidents, and in order to maintain reasonable costs. Given the critical importance of both safety and the accuracy of the data collected, the agent system must include simultaneous access to and interlocking of a backup agent in the event that it cannot operate normally. These subjects are easily dealt with using mobile agent and multi-agent technology. Moreover, by developing this agent system into a distributed monitoring system with these technologies, the system can become both safe and effective for long-term applications. The agent system makes a sensor measurement network with built-in Web servers a viable alternative for further research in agriculture and environmental science.

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