Remote Monitoring of Building Air-Conditioners using Internet Web Server Link Communication Technology

- Improved Performance and Reliability -

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With the growing demand for energy savings, there is the need for a low-cost, maintenance-free system to monitor packaged air-conditioners in small to medium-sized office buildings using only a commercial-off-the-shelf (COTS) Web browser without installing proprietary monitoring software. Mitsubishi Heavy Industries provides Web gateway products for COTS Web browsers that utilize our Communication Protocol Interchange technology, which transforms data into monitoring data on a Web server in real time. In addition, for remote monitoring, we developed the Linked Web Server Method, which detects a change of status in the background Web gateways when multiple Web gateways are monitored. Moreover, to ensure the Internet communication quality, we developed a communication error recovery method for COTS browsers. These technologies now make it possible to provide customers with low-cost, maintenance-free, high-performance, and reliable monitoring systems for packaged air-conditioners.

1. Introduction

Recently, many control systems for monitoring packaged air-conditioners in buildings have started to use Web communication methods. The advantage of Web communication methods is that one can monitor and control packaged air-conditioners from commercial-off-the-shelf (COTS) browsers, such as Internet Explorer. In addition, remote monitoring is possible by connecting to internet protocol (IP) networks. The communication reliability of IP networks, however, differs significantly between private networks and the Internet.

There are problems to be overcome before realizing Web monitoring over the Internet, specifically, the communication performance and reliability of the networks. The communication performance over the Internet is called “best effort”, and it does not guarantee the communication packet error rate or transmission delay. However, monitoring systems for facilities in small or medium-sized office buildings require communication performance and reliability without using expensive private networks and proprietary software.

This paper introduces original technologies for our Web gateways that monitor and control packaged air-conditioners in multiple buildings located remotely using only inexpensive COTS browsers.

2. Packaged Air-conditioner Web Gateway

2.1 Building packaged air-conditioners

Figure 1 shows an overview of a building air-conditioner Web monitoring system. Packaged air-conditioners are the most common type of air-conditioning system used in small or medium-sized office buildings. A packaged air-conditioning system consists of several tens to several hundreds of indoor units embedded in the ceiling, and roughly one tenth as many outdoor units installed on the rooftop of a single building. A single refrigerant circuit module consists of one outdoor unit and approximately ten indoor units. Many refrigerant circuit modules are installed dispersed within a building.

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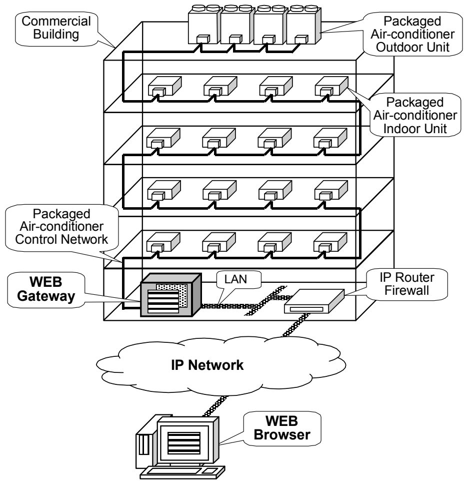

Figure 1 Web monitoring system for packaged air-conditioners in a building
The system collects operation data from packaged air-conditioners installed throughout a medium-sized building via a control network and creates real-time monitoring screen data in a Web server.

Each indoor or outdoor unit has an embedded microcomputer controller, and makes up a control network to transfer sensor data and refrigerant circuit control data. In this example of a control network, multiple refrigerant circuit modules make up a single communication channel. As shown in Figure 1, a communication line connects the indoor and outdoor units via a bus connection, and creates a single control network for the entire building.

A monitoring device for the packaged air-conditioners is connected to both the control network and a local area network (LAN), and works as a communication gateway. In Web monitoring methods, since the device functions as a communication gateway to the control network and as a Web server with an embedded server inside the gateway, we call it a Web gateway.

2.2 Our Web gateway products

The picture in the title of this paper shows the appearance of our Web gateway product, and its specifications are described in **Table 1**.

Table 1 Specifications of the Web gateway products

Item	Specification
Model	SC-WGWNA-B
External dimensions	260 × 200 × 79 mm (W × H × D)
Number of air-conditioners monitored	Maximum of 128
Embedded OS	ROM Linux
Fanless CPU	Pentium compatible (500 MHz)
Alternative to a hard disk	Compact flash ROM and RAM virtual disk
Web browser	Internet Explorer
Network security	IP address filtering Log-in user classification
Control monitoring functions	On/off, operating mode, setup temperature, room temperature, fan setting, error indication, etc.
Scheduling	Annual calendar, weekly schedule, execution schedule
Accounting feature	Total power consumption of the entire packaged air-conditioners is divided proportionally among tenants

In general, ordinary Web servers used for corporate homepages are designed to operate in a server room. However, our Web gateway is embedded in a control board under severe environments, and must operate stably without maintenance for a long period of time. The use of moving components, such as CPU cooling fans and hard disk drives, must be avoided to ensure reliability and a long lifetime. The required technology consists of a software design that creates a balanced product regardless of hardware limitations, including a fanless CPU and diskless device.

The software embedded in the device must also be able to run continuously, 24 hours a day, for years. With standard server software, administrators regularly perform maintenance as necessary, such as by restarting the operating system (OS). By contrast, the Web gateway software must run continuously without being restarted for years. For this purpose, the OS has been a type of embedded software, such as μITRON. However, to enable complicated database management, a large file-processing capability, and IP network connectivity, we developed a technology that makes it possible to employ the Linux OS for embedded systems. In this product, the Linux OS, which is recognized for its stability, is employed as the server OS.

Using this technology, our Web gateway product significantly reduces the cost of building monitoring systems, and improves the reliability and lifetime of both the hardware and software compared to existing systems.

3. Web Monitoring Screen

3.1 Overview monitoring screen

Figure 2 shows the overview monitoring screen of the Web gateway for building packaged air-conditioners. This screen allows an operator to overview the operating status of all of the air-conditioners without scrolling. In this example, the screen displays icons that indicate the on/off status and the operating mode status of each air-conditioner. To view details of a specific air-conditioner, a detailed monitoring window pops up on clicking the location name character string.

Many large buildings have sophisticated monitoring systems that can display the operating status of each packaged air-conditioner in a form of floor layout. Such systems are very expensive, since customized screens must be created for each building. For packaged air-conditioners for small or medium-sized buildings, the creation of a customized screen is difficult because of its high cost.

Other than cost, such systems cause a compatibility problem with personal computers (PCs) when customized screens are installed on each PC. Since facility monitoring systems are used for long periods, *i.e.*, more than a decade, it is essential to maintain compatibility with future PCs, OSs, and other software. To solve these problems, we developed an inexpensive Web monitoring system for small or medium-sized buildings that requires only a COTS browser, rather than customized screen software.

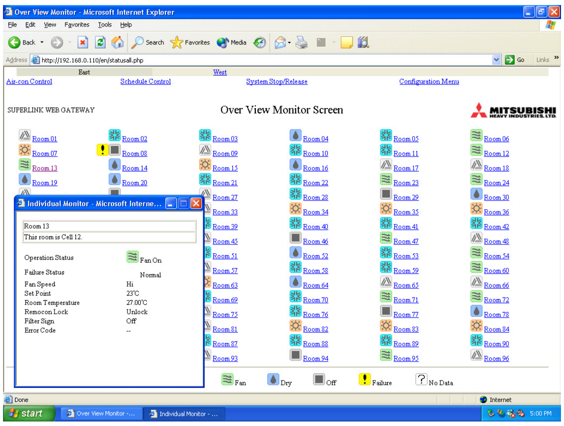

Figure 2 Overview monitoring screen of the Web gateway
This screen overviews the operating status of all of the packaged air-conditioners in a building. There is a pop-up screen for monitoring individual air-conditioners.

3.2 Architecture of Web air-conditioner monitoring

There are various methods for creating the monitoring screens in Web monitoring systems. The two main methods involve either the client side manipulating the monitoring data and rendering the monitoring screen, or the server side creating and sending the monitoring screen data. Although the former has an advantage in terms of data transmission quantity, the latter, recently called “cloud computing”, has been reconsidered because of its manageability, since it maintains all of the monitoring screen data on the server side.

In Web communication, a browser asks the server for Web monitoring screen data. For ordinary Web sites such as company's homepages, the server returns only static HTML screen data. In Web monitoring systems, the server needs to construct dynamic HTML data for the monitoring screen in real time based on the ever-changing operating status of the air-conditioners. In the cloud computing method, performance is mainly determined by the mechanism that creates HTML screen data in real time on the server side.

Figure 3 shows the architecture used for rendering the real-time monitoring screens of our Web monitoring system for building packaged air-conditioners. In the so-called synchronization mechanism, the server collects the operating status of each air-conditioner upon receiving a request from a browser to refresh the monitoring screen data. Although this method is simple, it takes time to create the monitoring screen data. The screen response may be a problem when the transmission time is on the scale of seconds, such as when connecting to the Internet, as described below. To solve this problem, we developed a mechanism in which the Web server and air-conditioner control network process operate asynchronously and independently in a Web gateway to create monitoring screen data in real time. This technology has been registered for a patent called "Communication Protocol Interchange".[1] This makes it possible for users to display the variance in the operating data of the air-conditioners in the air-conditioner control network on the client screen without delay.

In some cases, a client sends control commands to the packaged air-conditioner via a Web gateway. After the Communication Protocol Interchange converts the commands corresponding to the air-conditioner control network, the control commands are sent to indoor units through the Transmission Reserve Table (TRT) buffer arranged in parallel, as shown in Figure 3. The TRT buffer re-sorts the control commands in parallel regardless of the order received, creates communication packets by grouping the commands by the destination indoor unit according to the priority of air-conditioning, and sends them to the air-conditioner control network. This is our original technology and has been registered for a patent called "Parallel Processing Air-conditioner Control Communications Method".[2]

While the speed of Web communication has recently been improved to several tens Mbps, the speed of the air-conditioner control network is several tens kbps. This makes the transmission processing from a gateway to the air-conditioner control network a communication bottleneck. In addition, since the transmission buffer using the conventional First In First Out (FIFO) method simply sends each control command in order of arrival, the number of transmission packets sent to the air-conditioner control network is large. However, our TRT buffer method has significantly improved the transmission speed when sending control commands from a Web gateway to the air-conditioner control network.[3]

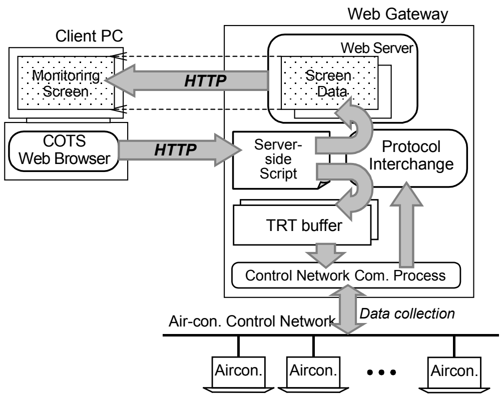

Figure 3 Architecture for rendering the real-time monitoring screens in the Web monitoring system
Our original Communication Protocol Interchange method converts the communication data in a control network for air-conditioners into monitoring screen data on a Web server in real time.

4. Linked Web Gateways

4.1 Problems of multi-Web gateways monitoring

As described above, our Web monitoring system requires only a COTS browser on the client side, and does not need special software. Instead, the browser needs to ask the server for data to refresh the monitoring screen on a certain cycle. By shortening the interval of the refresh request, it is possible to detect a change of status (CoS) of the air-conditioners that occurred on the server side.

When the system uses a single Web gateway, there are no problems, since the browser needs to accesses a single server only. By contrast, in remote monitoring using multiple Web gateways, as shown in **Figure 4**, it takes time to scan the status changes because the browser needs to access all of the Web gateways individually. In addition, when a user selects and focuses a specific monitoring screen of a Web gateway (foreground), it is impossible to detect a CoS in the other (background) Web gateways. For example, even if an air-conditioner in a background Web gateway stops abnormally, the abnormal stop alarm cannot notify the error unless the browser accesses that Web gateway. It is insufficient to simply utilize a general Web browsing method for monitoring.

Needless to say, proprietary software can be installed on the client side to scan the CoS of multiple servers. This, however, reduces the advantage of the Web monitoring method, which is that users need only a COTS Web browser already installed on a PC. Consequently, we developed the Linked Web Server Method,[4] in which a Web gateway can detect a CoSs not only for its own embedded server, but also for all of the registered linked servers in the Web gateways.

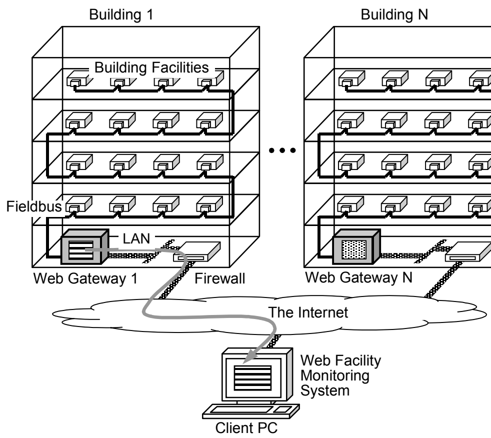

Figure 4 Remote monitoring using multiple Web gateways
Our original technology notifies the user of background changes of status (CoS) of multiple Web gateways using only a COTS browser.

4.2 Linked Web server method

Figure 5 shows the Overview Monitoring Screen for multiple Web gateways using our Linked Web Server Method. This screen notifies the user of a CoS of the background Web gateways by changing the color of the tabs used for monitoring screen switching and sounding a buzzer, even if the user is viewing the currently connected foreground Web gateway.

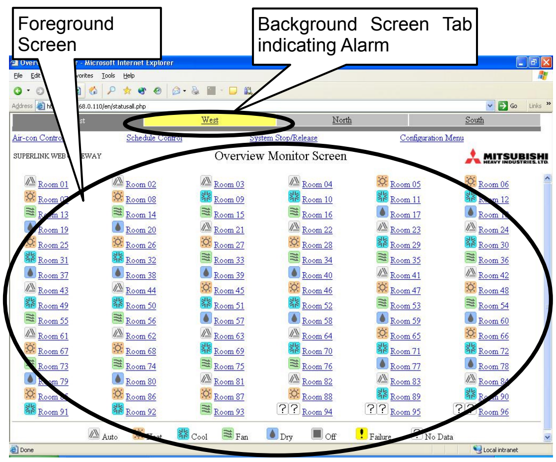

Figure 5 Overview monitoring screen for multiple Web gateways
When the status of a packaged air-conditioner changes in a background Web gateway, the color of the tab for monitoring screen switching changes and a buzzer sounds to notify users of the change.

Figure 6 shows the architecture used to realize this Linked Web Server Method. In this example, while a client communicates with the foreground server, the server-side script is used to communicate with other linked background servers simultaneously to realize communication between servers. This allows users to obtain a CoS report for the background servers not being browsed currently, without affecting the currently connected foreground screen.

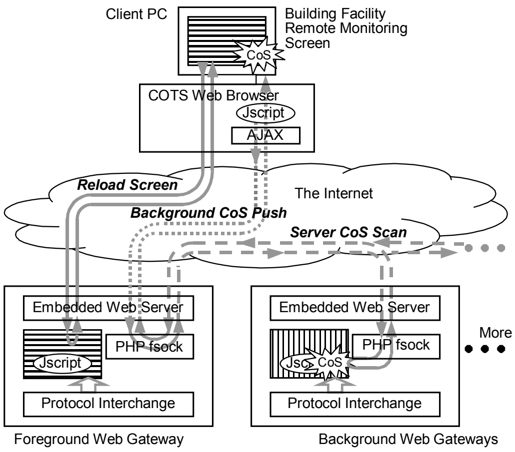

Figure 6 Architecture for realizing the Linked Web Server Method
Our original method, in which a foreground Web gateway scans and monitors the changes of status (CoS) of air-conditioners in the background Web gateways, and notifies the browser of these changes.

Figure 7 shows the communication sequences of the Linked Web Server Method. Since the foreground and background sequences are independent, loading the foreground screen is not affected. The background Web communication enables background servers to push information as a CoS Push. We have applied for a patent for our Linked Web Server Method called "Air-conditioner monitoring system with a linked Web server".

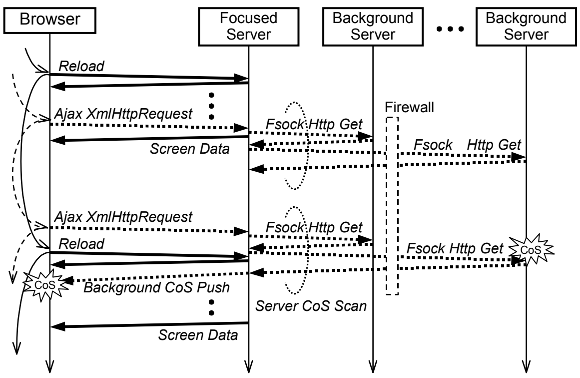

Figure 7 Communications sequences of the Linked Web Server Method
This facilitates monitoring without affecting the users' browsing operation by scanning the background Web gateways asynchronously with respect to the foreground screen.

5. Improvement in Communications Performance and Reliability

5.1 Communications performance

When monitoring a remote monitoring system via the Internet using a Web monitoring system, as described above, the reloading time of the monitoring screen can be a problem. As an example of a Web monitoring system via the Internet, **Figure 8** shows the time it takes for a browser in London to reload the monitoring screens from a Web gateway in Nagoya- in Japan.[5] Since the status of the Internet varies constantly, the Web monitoring screen was reloaded every hour for 7 days to show trends. As Figure 8 shows, the average reloading time of the monitoring screen varied widely from 1.1 to 3.4 s. Therefore, we need to consider this factor fully when assessing Web data transmission performance via the Internet.

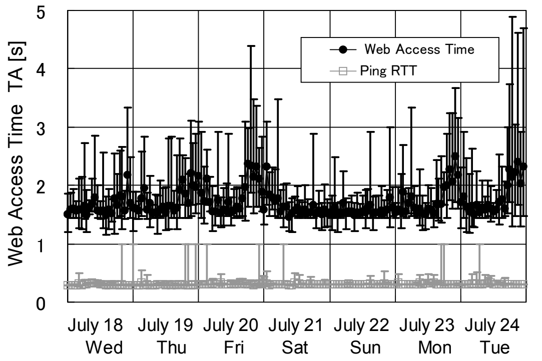

Figure 8 Field test of the intercontinental Internet communication
The measured transmission performance for overview monitoring screen data between Nagoya and London. This graph shows the transmission status changes at every moment.

Figure 9 compares the reloading time of the monitoring screen for the packaged air-conditioners Web gateway in Nagoya from browsers in several locations worldwide by taking an average for 2 days. Although our Web gateway shows high performance and can reload the monitoring screen in 0.35 s when connected to a LAN directly, it may take several seconds when the Web gateway is connected to a low-speed part of the Internet. This may cause a problem after actual operation start. In an environment that uses a low-performance wireless LAN, careful consideration is needed since the data transaction time may be extremely slow because of retransmission due to communication packet losses.

When integrating a Web monitoring system with the Internet environment, it is advisable to study the Web data transmission performance for the relevant Internet connection in the planning phase. We have been exploring ways to assess the Web communication access time using an internet communication traffic simulator[6] Although it is difficult to assess the Internet data transmission performance since the network components are unknown in most cases, it is expected that this technology will be put to practical use.

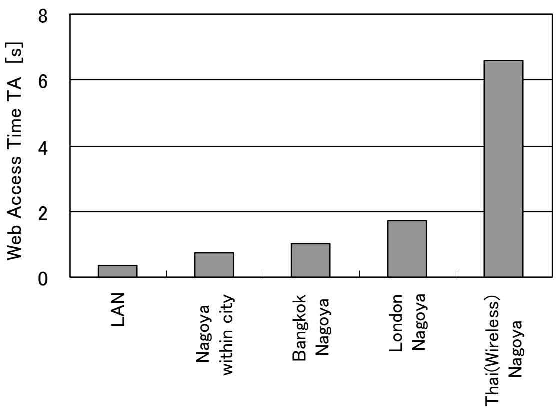

Figure 9 Assessing the transmission performance of Web monitoring screen data
This compares the transmission performance for the overview monitoring screen data by taking the averages for two weekdays. The graph shows that the data transmission time varies markedly depending on the Internet environment.

5.2 Recovery from a Web communication error

In remote monitoring with the Internet, a browser may remain stopped at the communication error screen due to communication anomalies. If an air-conditioner error occurs at this time, a fatal problem may occur, such as failure to display an alarm.

As described above, our product uses a pre-installed COTS browser because of its low cost and better operability. Nevertheless, COTS browsers assume that a user is in front of the screen browsing various Web sites. When a Web communication error occurs, the browser only prompts the user to perform manual recovery. With the Web monitoring system, since a user is not in front of the screen most of the time, manual recovery cannot be expected. Consequently, we decided to implement a mechanism that automatically recovers a COTS browser from the communication error screen.

Since the specifications of the communication error screen differ depending on the browser, we decided to implement an auto-recovery system mechanism in our Web gateway side. Specifically, we developed an original mechanism that embeds our special password character strings and a program that scans data and searches for the password in each of the transmitting Web monitoring screen data streams. The program searching for the password is coded in Java script and is embedded in the monitoring screen data.

With this mechanism, a browser on the client side finds the above Java script code by parsing the monitoring screen data, and automatically executes the script code to search for the password character strings in the current screen data. At this time, if the communication error screen is being displayed because the complete monitoring screen data cannot be obtained, the password character strings cannot be detected, even if they are embedded at the end of the monitoring screen data. In such a case, HTTP GET is sent again automatically to the Web gateway in order to reload the same monitoring screen. We have applied for a patent for this original method.

Figure 10 shows the laboratory test results for assessing the Internet communication reliability and the communication error recovery effect. Laboratory testing was employed rather than field testing because it is difficult to create extremely undesirable conditions at will. The horizontal axis indicates each communication packet loss rate. The vertical axis indicates the communication error occurrence rate while reloading the monitoring screen (solid line) and auto-recovery failure rate from the error (dashed line). The higher the communication packet loss rate is and the more averse the network conditions are, the higher the communication error rate is during the time the screen is reloading. Even with a communication packet loss rate of several tens of percent, which reflects very adverse network conditions, the auto-recovery failure rate was 0%, which means that it is possible to recover from all errors automatically, even if a communication error occurs frequently.

Using our original "Password Embedding Error Recovery Method", even in a wireless LAN or a poor Internet environment, it is possible to recover from communication errors automatically 24 hours a day. This makes it possible for us to provide users with reliable monitoring systems.

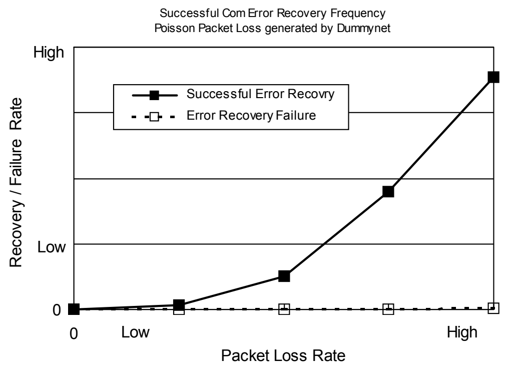

Figure 10 Web communication error auto-recovery
We assessed the communication error occurrence rate and auto-recovery failure rate from errors resulting from the network communication packet loss rate in laboratory tests.

6. Conclusion

This paper has described the technologies that support our Web system for monitoring building packaged air-conditioners via the Internet.

When monitoring packaged air-conditioners in small or medium-sized buildings, there is a demand to use only COTS browsers, instead of installing proprietary monitoring software, because of their low-cost and better maintainability. By using our Communication Protocol Interchange and Transmission Reserve Table technologies that transfer the operating data for the packaged air-conditioners into Web server screen data and vice versa in real time, we have developed Web gateway products for COTS browsers to respond to market needs. In addition, we developed a Linked Web Server Method that can detect a CoS, even in the background Web gateways when multiple Web gateways are monitored for remote monitoring. In addition, to compensate for the

Internet communication quality, we developed a communication error recovery method for COTS browsers. Utilizing these technologies, we can now provide customers with a low-cost, high-maintainability, high-performance, reliable packaged air-conditioner monitoring system.

Demand for integrated monitoring via the Internet is expected to grow. We have been developing technologies for building packaged air-conditioners to meet such customer needs.

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