

<論文>

Cell-Phone Based Assistance for Waterworks/Sewage Plant Maintenance

Takushi Kawada[†]
Koji Nakamichi[†]
Nobuyuki Hisano[†]
Misayo Kitamura^{††}
Koji Miyahara^{†††}

Abstract

Cell-phones are now incorporating functions necessary to use them as handy mobile IT devices. In this paper, we present our results of the evaluation of cell-phones as the mobile IT device to assist the workers in industrial plants. We use a waterworks and sewage plants as an example. By employing techniques to squeeze the SCADA screen on CRT into a small cell-phone LCD, we have made it easier for a plant's field workers to access information needed for effective maintenance, regardless of location. An idea to link SCADA information and the plant facility information on the cell-phone is also presented. Should an accident or emergency situation arise, these cell-phone based IT system can efficiently deliver the latest plant information, thus the worker out in the field can respond to and resolve the emergency.

Key Words: cellular phone, industry plant systems, SCADA, facility information

1. Introduction

Industrial plant systems, especially utility like waterworks and sewage plants, are facing the reduction of skilled workers. Under requirements to lower running costs, the plants are being forced to operate with a smaller number of workers. Also, the anticipated retirement of skilled workers is expected to peak around year 2007. Fewer and usually less experienced workers are going to have to maintain the plant systems. The anxiety around proper plant maintenance is increasing.

Networked IT systems have been proposed to assist plant workers, so that fewer and unskilled plant workers can operate and maintain plant systems properly. There are mainly two types of networked IT systems used to assist the maintenance and operation of the industrial plants, which are networked facility information system and networked SCADA system. The networked facility information system accumulates design documents and maintenance records of the facilities used in plants. It serves the information needed for efficient maintenance, and help transfer knowledge from the skilled workers to the

[†] Energy and Public Infrastructure Systems Center, Mitsubishi Electric Corporation

^{††} Advanced technology R&D center, Mitsubishi Electric Corporation

^{†††} Mitsubishi Electric Research Laboratory

unskilled workers. The networked SCADAⁱ system allows operators to monitor and operate a larger number of scattered waterworks and sewage plants that are connected by the network. With these information systems, workers are able to better maintain and operate a larger number of facilities.

The reduction of the number of workers also requires the improved efficiency of the work in the field. To assist workers in the field, mobile IT systems are going to be required. Various mobile IT systems have been proposed for the workers in the field. Systems based on mobile PCs have problems such as: mobile PCs are heavy to carry; mobile PC's require space when operating; mobile PC's need both hands of an operator; and the systems tend to be expensive.

Systems based on PDAⁱⁱ devices have become successful primarily as a system to support inspection of plant systems and the operation monitoring of plant systems [5][6]. Because of the cost of PDA devices, the number of PDA devices used among plant workers is currently limited. A more convenient mobile IT device, which every plant worker can carry, is desired.

Because most the plant workers already carry cell-phones for mobile communications, work in plant systems can be improved if the same cell-phone could be used to acquire plant information. Cell-phones are incorporating functions necessary to use them as the handy mobile IT devices. Starting with the Web and Email, the most recent additions to cell-phones features are the Javaⁱⁱⁱ interpreter and the digital camera. The Web and Java have become the primary means by which applications on cell phones are constructed.

In this paper, we focus on a plant worker's need to see the SCADA screen image from wherever he might be, and we consider techniques to provide this function using cell-phones.

The users of the SCADA systems usually monitor the plant using the SCADA screen of the total plant systems, and once one of the facilities in the SCADA screen becomes the subject, then the users select the icon on the SCADA screen to see the detail of the facility. Focusing on such needs in industry applications to use the hyperlink from the graphic icons on the screen, Kitamura et al [1] proposed a mobile interface toolkit as an alternative to the Web and Java. The mobile interface toolkit is a combination of an interpreter that runs scripts, and a server that serves the script to the interpreter on the mobile device. The merit of this approach is that the size of script data transferred to show a new screen image is small; this means that the time to show screen image is fast, and the interactions on the screen can be extensible by adding functionality to the interpreter so that the interaction on the screen can meet the industrial requirements.

First, we started evaluating the use of the mobile interface toolkit to show a sample SCADA screen image of a waterworks plant on a cell-phone's LCD screen. Since it turned out that there are problems with the quality of the screen image, as well as with the performance to show the screen image, we proposed the image library extension of the mobile interface toolkit to improve the display quality and the performance to handle the SCADA screen image on the cell-phones.

2. Latest Cell-phone Technologies

Before we give the description of the use of cell-phones to assist workers in industrial plants, we will introduce the current technical status of the cell-phones. The cell-phones arena is one of the places where technological innovation is occurring very rapidly. Many advanced functions are being incorporated into cell-phones. Today, most cell-phones are equipped with WEB browsers, E-mail functions, and digital cameras. Also, the majority of them come with Java or other application engines to run users' applications.

As cell-phones are evolving from second generation to third generation (3G or IMT-2000), a bunch of IT features are being adopted. The latest cell phones have some of the following features:

- 1) Web browser: To access Web pages and to acquire information from the Web sites.
- 2) Application engines: To run application code written in Java and so on.
- 3) E-mailer: To send and receive e-mail through the Internet.
- 4) Larger LCD: Most of the latest cell phones have QVGA (320x240) size LCD screen.

- 5) Higher communication speed: Most of the 3G cell phones can download data at 384Kbps and higher. Some carrier already supports 2.4Mbps download communication speed.
- 6) Barcode reader: Two-dimensional barcode, called QR code, are becoming popular.
- 7) GPS: Some cell-phones have equipped with GPS antenna, so that the location of the holder can be detected.
- 8) Digital camera: Most of the cell-phones have digital camera function with the image resolutions around 100M pixels.
- 9) Local connections: Such as the IR and Bluetooth. The cell-phones have ways to communicate to PCs and other information systems without incurring a communication cost.

3. Needs of Showing SCADA Screen Image Using the Cell-phones

Although the quality of work in plant offices or in control rooms has been rapidly improving due to the availability of the cheap and fast computer systems and wide-area broadband network connections, assistance out in the field is not yet popular. Cell-phones, which most of the workers carry for mobile communication purposes, can be expected to provide plant information to the workers so that the workers will be able to work more efficiently. For example, by acquiring information of an incident via a cell-phone, a worker can make adequate preparations for recovery after the incident. Fig.1 shows the use of the cell-phone based assistance written in the UML use case diagram [7].

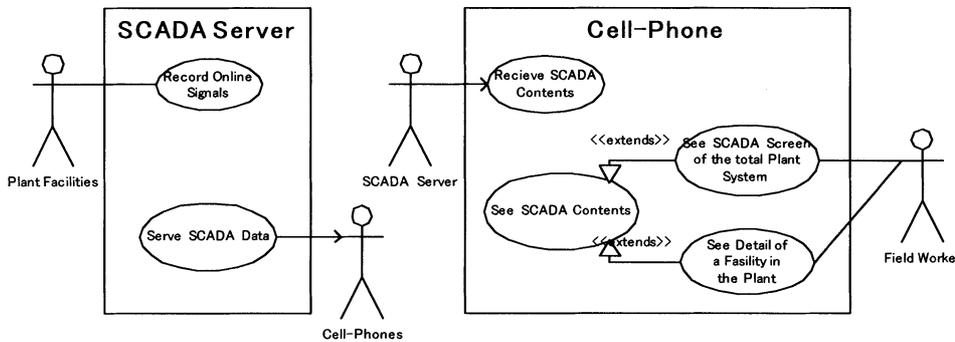


Fig.1: The use of cell-phones to assist field workers in the UML use case diagram. Cell-phones are expected to provide the field worker with the SCADA screen image of the total plant system, and with the detail of a facility in the plant.

Fig.2 shows a sample of the image of SCADA screen used in waterworks plant.

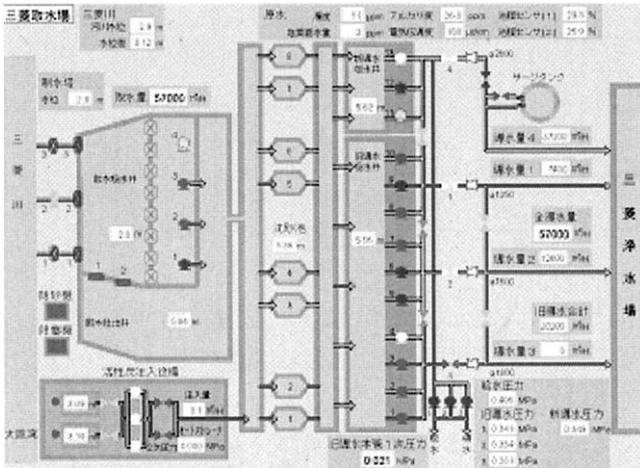


Fig.2: A sample SCADA screen of waterworks plant squeezed into 320x240 pixels, which is the resolution of cell-phone's LCD screen. The original resolution of the image is in 1024x768 pixels and the text fonts used are around 14 to 18 points. Our purpose is to make information in squeezed screen readable, and to allow user to select icons in the screen to know the detailed information possible. In this paper we use this image as the reference to study the feasibility of displaying SCADA screen image on cell-phones' small LCD.

The size of the image is squeezed to 320x240 pixels to fit into the cell-phone's LCD screen. The first requirement is that the plant workers need to see the numbers on the screen to grasp the overall operation of the plant systems. The second requirement is that the plant workers can see the detailed information of a facility, such as the list of alarms or the trend graph of signals, by selecting an icon in the screen image.

4. SCADA Monitoring Application based on the Mobile Interface Toolkit

The users of SCADA systems usually monitor the plant using the SCADA screen of the total plant systems, and once one of the facilities in the SCADA screen becomes the subject, then they select the icon on the SCADA screen to see the detail of the facility. Kitamura et al [1] pointed out the problems of constructing such industrial applications using WEB, Java and the other application development environment available on the cell-phones. They proposed the mobile interface toolkit as a way to solve these problems by providing a device independent interpreter with functions needed to construct industrial user interface applications.

4.1. The Merit of Mobile Interface Toolkit

The application constructed with the mobile interface toolkit is a combination of an interpreter that runs scripts, and a server to serve the scripts to the interpreter on the mobile device. The merits of the approach proposed by Kitamura et al. as the development environment of the SCADA monitoring application on the cell-phones are as follows.

Table 1 The Merit of the Mobile Interface Toolkit.

Interactive operation using icons:	Interactive operation that is required for the industrial applications is possible on the cell-phones screen. The hyperlink from the graphic icons on the screen is supported
Script based development of the application:	Compared to writing all functionality as the Java application, creating the application is easier. Also the size of download module is smaller, so that the time needed to transfer the script is fast. Also the behavior of the application can be modified easily by the modifying the script.
Compatibility on various devices:	By the combination of interpreter application and device independent script, dependencies of the contents to the specific mobile device can be avoided.
Extensibility of the functions:	The interactions on the screen can be extensible by adding functionality to the interpreter so that the interaction on the screen can meets the industrial requirements.

4.2. The Problems with the Mobile Interface Toolkit

We evaluated the feasibility of constructing the SCADA monitoring application based on the mobile interface toolkit using the SCADA screen image shown in Fig.2 as an example.

Fig.3a shows the block diagram of the SCADA monitoring application built with the mobile interface toolkit. One of the technical problems is that the small fonts required to draw the squeezed SCADA screen images are not available on most of cell-phones. In most of the cases, cell-phones support font glyphs larger than 12 points. Another problem is that the size of the application module to be downloaded to redraw a SCADA screen image with the latest information reaches 22Kbytes. To lower the communication latency and the communication cost, the size of application module needs to be smaller.

5. Image Library Extension of the Mobile Interface Toolkit

To resolve the problems found in the feasibility evaluation to use the mobile interface toolkit for the SCADA screen monitoring application on the cell-phone, we propose an image library extension. By using the image library extension, we aim for both the reduction of the application module size, and the utilization of small font glyphs on the cell-phones.

5.1. Image Library Extension to the Mobile Interface Toolkit

Fig.3b shows the block diagram of the SCADA monitoring application built with the mobile interface toolkit and the image data handling extension. To handle small font glyphs that are not supported by the cell-phone, small screen fonts are prepared in the image library on the server. The background images and the icons of the facilities used in the SCADA screen images are also stored in the image library. The image library on the server is downloaded to the cell-phone only once prior to the

application module. Infrared or other local communication equipped with the cell-phones can be used to download the image library, so that it doesn't affect the communication cost. The application modules are downloaded every time the user wants to see the latest information. Because the application module doesn't have to contain the image data, we expect that the size of data transferred will be considerably reduced.

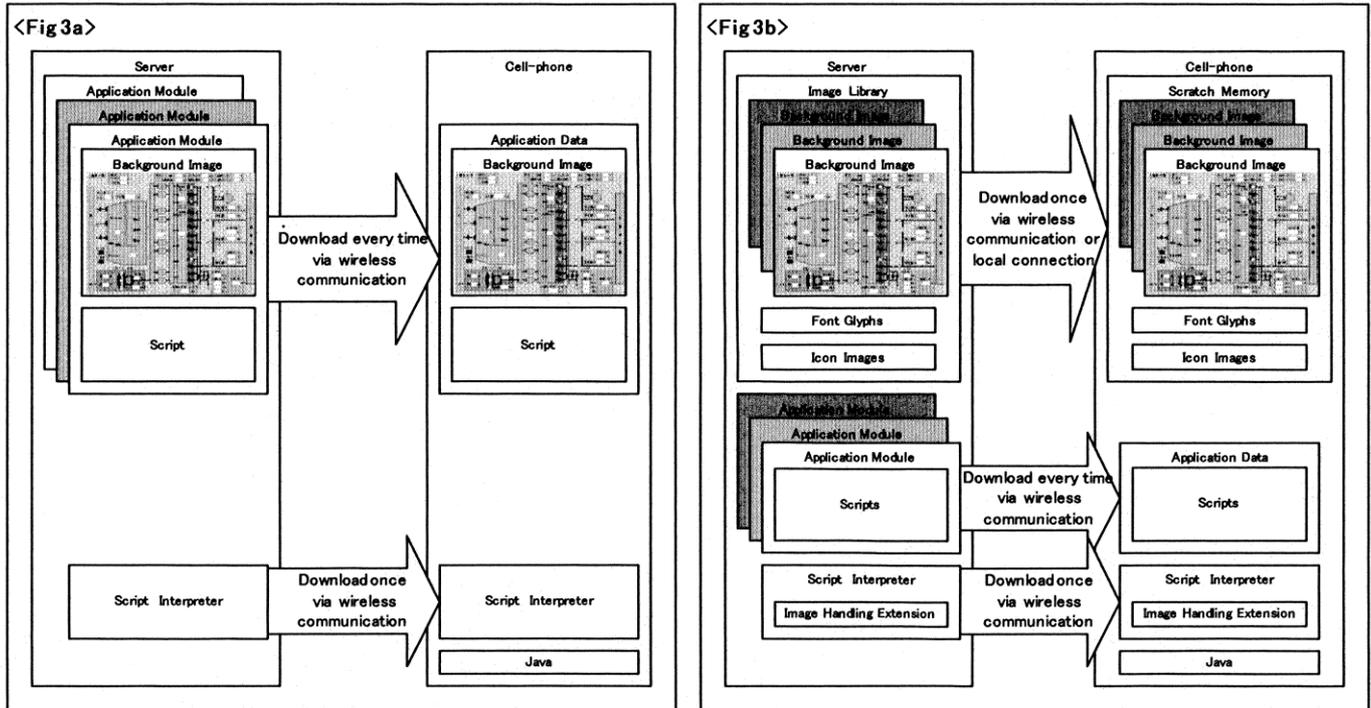


Fig.3. Block diagrams of the SCADA monitoring application built with the mobile interface toolkit. <Fig. 3a> shows the block diagram of the SCADA screen monitoring application for cell-phones built with the original mobile interface toolkit. The script interpreter of the mobile interface toolkit is a Java application to be downloaded to the cell-phone only once. The application module is composed of the background image of the SCADA screen, and the script to specify the interaction on the SCADA screen. Once the application module is downloaded to the cell-phone, the script interpreter shows the SCADA screen image on the LCD display, and allows user interaction on the display. <Fig. 3b> shows the block diagram of the same application built with the mobile interface toolkit and the image handling extension. By the use of the image handling extension, the application module can be divided into two parts: a part which is needed every time a new SCADA screen image is requested by the user, and a part which doesn't change every time. The background images, font glyphs, and icon images are in the later part, which can be downloaded to the cell-phones scratch memory prior to the use of the SCADA monitoring application.

5.2. Font Glyphs for the SCADA screen shown on the Cell-phones

On the CRT display of the SCADA systems we usually use fonts in 14 to 18 points. If the original SCADA screen image was created for XGA, which is 1024x768 resolution, the fonts that fit into squeezed SCADA screen on the cell-phone's LCD are 4.4 to 5.6 point. Using the numeric font glyphs in 5 point, most of the SCADA screen images can be displayed on the cell-phones' QVGA LCD, which is 1024x768 resolution, without a change of layout. Also, the fonts in 5 point (5x3 pixels) are the smallest that can be used if the numbers in the numeric fonts are to be distinguished.

Fig 4a shows the numeric font glyphs in 5 point with black and white pixel pattern. The numbers presented by each font in 5 point are distinguishable, but not very fine. To provide the user with fine font glyphs, we evaluated the use of font rendering

techniques. Fig 4b shows the 5 pt font glyphs generated using the ordinary font rendering techniques. The rendered outline fonts in 5 point are not distinguishable, and are not usable in the SCADA screen.

Recent work at Microsoft on Clear Type [4] utilizes the sub-pixel pattern of RGB on the LCD screen to improve the readability of the fonts. When each pixel of the LCD of the cell-phone is composed of vertical RGB sub-pixels, and when the cell-phone is held sideways up, the horizontal resolution of the LCD becomes virtually triple. Fig 4c simulates the numeric font glyphs rendered leveraging the sub-pixels of the LCD.

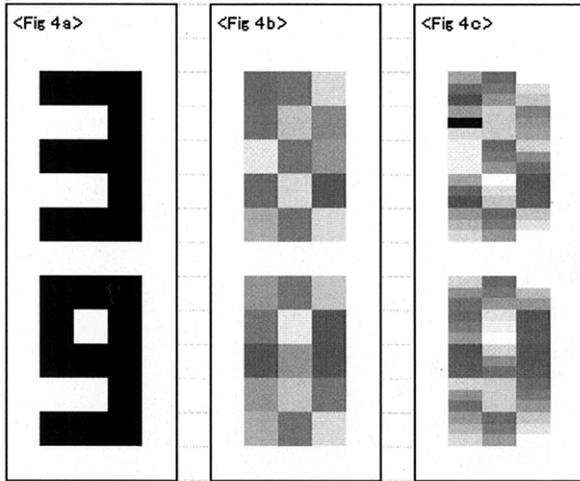


Fig. 4) Patterns of font glyphs in 5 pt. Font glyphs in <Fig 4a> are drawn with black and white dots. Font glyphs in <Fig 4b> are generated using font rendering. And font glyphs in <Fig 4c> simulate the rendered fonts generated leveraging the sub-pixel pattern of the LCD. The each sub-pixel of the font glyphs shown in <Fig 4c> are colored in red, green, and blue. The sub-pixel patterns of the LCD used for cell-phones vary among them. Some are in order of RGB and the others are in order of BGR. The font glyphs for each cell-phone have to be generated with the knowledge about the target LCD. To generate the rendered font glyphs for the cell-phones, we used the ADF proposed by Frisken et al [3].

5.3. Feasibility Evaluation of the Image Library Extension

Fig. 5 shows the sample of the SCADA screen image with the rendered fonts in 5 point that are generated leveraging sub-pixel pattern of the target LCD. The numbers on the screen are readable, and the plant worker is able to grasp the operation situation of the plant at once.

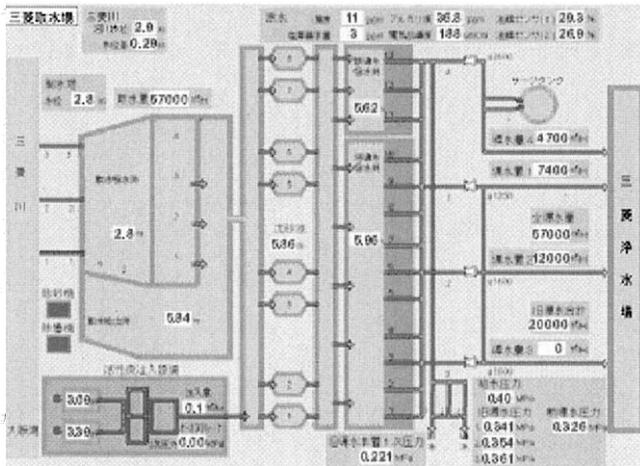


Fig. 5 Squeezed SCADA screen image generated using the mobile toolkit with the image library extension. The numeric glyphs in 5 point, generated leveraging the RGB sub-pixel pattern of the LCD, are used for better readability. If the user wants more readability of the text in the screen, we are going to use larger SCADA screen image, and allow user to scroll the larger image in the LCD. Since 12 point is the smallest font supported by ordinary cell-phones, the image library extension is valuable to draw much larger SCADA screen images, as far as the fonts needed in the screen are smaller than 12 point.

As shown in Fig.3b, by the use of image library extension, the image data needed to draw the SCADA screen is separated from the application module as the image library. The image library is only downloaded once using a local connection, such as the IR equipped with the cell-phones.

Table 2 shows comparison of the estimated performance of drawing the SCADA screen image. The original mobile interface toolkit needs to transfer approximately 22Kbytes to the cell-phone every time the user wants to know the latest information. With the image library extension, the size of the application module is 3.5Kbytes, a reduction of 83%. Reducing the size of data transferred on each request for the latest information is effective to improve both the performance and cost.

Table 2 Comparison of the data sizes.

Download Timing	Connection used	Original Mobile Interface Toolkit		Mobile Interface Toolkit with Image Library Extension	
Only once	Wireless communication	Script Interpreter	30000bytes	Script Interpreter	30000bytes
				Image Library Extension	5000bytes
Only once	Local connection or Wireless communication			Background Image	16333bytes
				Icon Images	1400bytes
				Font Images	2400bytes
	Total		30000bytes		55133bytes
Every time	Wireless communication	Script	5584bytes	Script	3549bytes
		Background Image	16333bytes		
	Total		21917bytes		3549bytes

Table 3 shows the typical response time for the request to redraw the SCADA screen image. The values shown are for reference purpose since the performance of the application on the cell-phone is influenced substantially by the communication circumstances and the performance of cell-phone devices. In our case, the speed to redraw the SCADA screen can be twice as much fast as the application based on the original mobile interface toolkit.

Table 3 Response Time of Screen Redraw Request from the Cell-phone (measured using NTT DoCoMo D900i.)

	Download		Execution		Total
	Script	Background Image	Interpret Script	Draw Screen	
Original Mobile Interface Toolkit	0.93 sec	2.72 sec	5.13 sec	0.02 sec	8.80 sec
Mobile Interface Toolkit with Image Library Extension	0.59 sec	-	3.26 sec	0.02 sec	3.87 sec

6. Additional Scenarios of Using Cell-phones for the Plant Workers

In prior sections, we presented the use of cell-phones to provide the field worker with SCADA information. In this section, we present additional scenarios that are possible through the combination of SCADA information and facility information.

This facility information includes the design documents of the plant, operation manuals of the systems, or the record of maintenance. The plant worker needs to manage the facility information to properly maintain the plant systems. We expect that if a worker will be able to see the facility information along with the online data, while he is in the field and using a cell-phone, it will be much easier for him to examine and pinpoint the source of an existing problem.

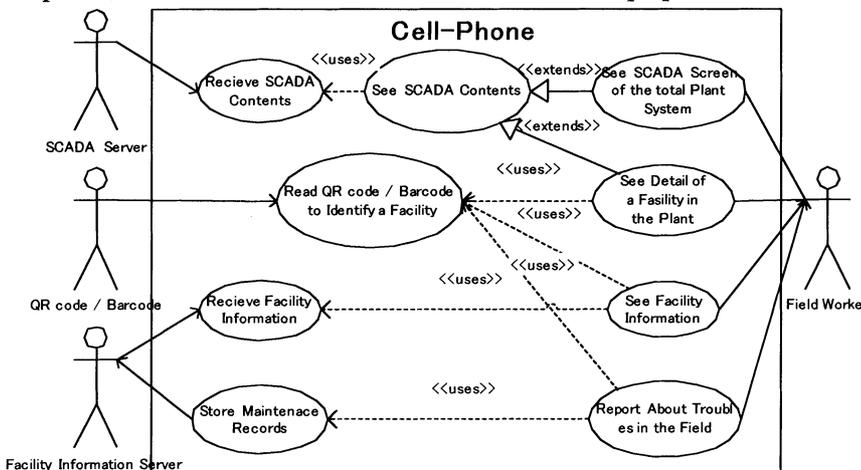


Fig.6: Various information about the plant facilities are linked together by the use of built-in QR code / Barcode reader of the cell-phone. The field worker can use QR code pasted on the target device to 1) identify facility, 2) see SCADA information, or 3) see facility information. By linking the SCADA and facility information together, the field worker can access appropriate information to deal with problems.

Fig.6 shows the UML use case diagram of an idea of the combination of the SCADA and facility information accessed using the cell-phones. In this scenario, we use the QR code to link the facility information, the SCADA information and the real plant facility. The QR code, printed out by the facility information server, is pasted on the plant facility. The worker can use the QR code to identify the facility and access related SCADA information and facility information.

7. Conclusion

To assist the maintenance workers in industrial plant systems, we focused on the technique to show the SCADA screen image on the cell-phones. Based on the mobile interface toolkit, we propose the image library extension to handle the required interaction on the screen, and to use small font glyphs for the squeezed SCADA screen image for the cell-phone's LCD.

In our evaluation using a waterworks SCADA screen sample, the size of data transferred every time the user want to redraw the screen was reduced by 83%. And it made the performance to redraw the screen twice as much fast. The reduction of the data size is effective to lower the response time to draw the screen image, and to lower the communication cost.

To make numbers in squeezed SCADA screen easier to read, we propose the use of rendered fonts generated on server as the library of font image. In our feasibility study, the size of the SCADA screen image on the cell-phone is determined to fit in QVGA so that it fits in the cell-phone LCD without scroll. This is an extreme condition where the size of screen fonts on the cell-phone LCD is as small as 5 point. The SCADA screen image and the font's glyphs can be larger if scrolling on the cell-phone LCD is allowed. Even in that case, the use of library extension to draw font glyphs on the LCD screen is effective when the required font glyphs in the SCADA screen image are less than 12 point.

We evaluated the use of the cell-phone to monitor the SCADA screen image of the waterworks and sewage plant systems. The ideas presented here can also be effective for maintenance workers in other regional plant facilities, such as utilities. By using cell-phones, plant workers can access the SCADA and facility information, regardless of location. Should an accident or emergency situation arise, these cell-phone based IT tools can efficiently deliver the latest plant information, thus providing any worker out in the field with the opportunity to respond to and resolve the emergency.

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ⁱ Supervisory Control and Data Acquisition.

ⁱⁱ Personal Digital Assistance

ⁱⁱⁱ Java is a trademark of Sun Microsystems, Inc.

Web-based information system for controlling membrane bioreactor

Jinwoo Cho, Kyu-Hong Ahn, Kyung-Guen Song, Sung Kyu Maeng

Water Environment & Remediation Research Center, Korea Institute of Science and Technology, Korea

Abstract

The web-based membrane bioreactor (MBR) system is constructed to control MBR system remotely and automatically. Applying man machine interface system to existing MBR process enables this automated system. The pressure, influent and effluent flow-rates, temperature, pH, DO and water level variation are monitored in MMI system. All these data are transferred from a local MBR to remotely located center through the web-based PC to PC networking using Internet. In this study, this system is called web-based information system, presenting very effective control of membrane fouling. While the manually operated system shows the abrupt transmembrane pressure drop and the membrane fouling.

Key Words: Membrane bioreactor, fouling, pressure, remote control, monitoring, Internet

Introduction

Membrane filtration can be efficiently coupled with a conventional activated sludge process for wastewater treatment, which eliminates the final clarifier because a membrane provides almost perfect liquid-solid separation. This is so-called membrane bioreactor (MBR). MBR has no problem in a failure of biological system due to biomass loss and/or bulking, and the biological capacity to treat organic matters and nutrients also increases (Nagaoka, 1996; Chang 1998; Fan et al., 1996).

However, membrane fouling and its control is a major issue for an economically feasible MBR system (Stephenson et al., 2000). Fouling is the process in which variety species in water are convected and deposited onto membrane surface resulting in the increasing of the hydraulic resistance as well as membrane resistance. This has been a critical obstacle to more broad application of MBR to wastewater treatment.

The objective of this study is to build up the computer aided system to control membrane fouling. It is noted that this study cannot provide an ultimate solution on membrane fouling, but proposes the way how to operate the membrane optimally in given conditions, retard the fouling, handle an emergency situation automatically, and transfer information to a remotely located operator.

Applying MMI (Man Machine Interface) to existing MBR system makes this automated system possible. The TMP, influent and effluent flow-rates, temperature, pH, DO and water level variation are monitored in MMI system. All these data are transferred from a local MBR to remotely located center through the web-based networking system. Central computer compared monitoring TMP with the critical value in real time scale and decided to adjust the influent flow-rate, permeate flux, or membrane operating cycle to decrease TMP. In this study, the operation, performed automatically using web-based remote controlling system, is compared to the manual operation in terms of the transmembrane pressure.

Materials and Methods

Lab-scale MBR system

The lab-scale MBR consists of three commercial hollow-fiber MF membrane modules (Mitsubishi Rayon, Japan). The effective filtration area is 0.2m²/module. The membrane is made of polyethylene with hydrophilic coating, and its nominal pore size is 0.4 μm. Each membrane is fully immersed and symmetrically placed in the reactor. The membrane flux is 15LMH (200L/day) and operated for 8 minutes and idled for 2 minutes. This reactor is installed in a suburban wastewater treatment plant. The municipal wastewater, which passes the screening and first-sedimentation process, is introduced. Food to microorganism ratio ranged from 0.1 to 1.0 kgCOD/kgMLVSS.

Monitoring and controlling the MBR system

In order to control and monitor MBR system automatically, a man-machine interface system (MMIs) is constructed using DAQ (Data Acquisition) board, PCI 6024E, manufactured by National Instrument, Co. This PCI board is the multifunction analogue, digital, and timing I/O boards for any personal computer. This is connected to the signal block which collects the electrical signal from the devices or delivered the output voltage.

The equipments for remote monitoring and controlling system with the web-based networking are listed in Tab. 2. The analogue output generates the voltage signal ranged from -10 to +10VDC, while analogue input detects electrical signal from any devices. Therefore, the output channels are connected to devices that an operator wants to control such as pumps. Input channels are linked to the device to be monitored such as flow meter. Operating factors such as flux, membrane filtration cycle, aeration and influent flow-rate are controlled. Among these factors, influent flow-rate, TMP, permeate volume and dissolved oxygen are monitored and recorded. All these operations are enabled in the control panel screen (Fig. 1), that is programmed using Labview 6.0i (National Instrument, Co., USA).

Tab. 2 Equipments needed for remote monitoring and controlling the lab-scale MBR system

	Item	Number	Product	Specifications
Pump	Suction	3	Pro-spense pump	0~5VDC input*
	Backwashing	1	Masterflex	1~5VDC input
	Feed	1		
Air Compressor		1	-	1.0 HP
Flow meter	Permeate	3	Mc-millian	0~5VDC output*
	Backwashing	1		
Air Flowmeter		1	AalBorg Alicat	1~5VDC output
Pressure transmitter		3	Cole-parmer	1~5VDC input
Thermal transmitter		1	Cole-parmer	4~20mA output
DO meter		1	YSI, Model 58, USA	1~5VDC output
Level sensor		2		Digital ON/OFF**
Personal computer		1	Samsung	Pentium III
PCI 6024E board		2	NI instrument	

* Input means the item can be controlled at the electrical signal and output generate the analogue signal

** Digital ON/OFF means the item provides the electrical switch

If the system faced emergency situation such as too high TMP or abnormal water level, warning signal is displayed and send this message automatically to the central computer that is located remotely. This MMI system also determines whether the permeate flux should be changed or not, automatically. Sometimes, the computer decided to halt the system and send emergency message

to the central computer waiting for the first aid of an operator. Consequently, MBR system is operated to minimize the membrane fouling and system failure.

Web based networking

In order to monitor and control lab-scale MBR system remotely, web-based networking is constructed. This concept can be embodied in real time by transferring an order in form of electrical signal through Internet. In order to transfer the data, PC-to-PC connecting software such as PCANYWHERE (version 10.0, Symantec, USA) is applied in this research. Therefore, as far as an operator can access Internet, local MBR can be controlled regardless of the time and space. Fig. 2 shows the conceptual diagram of web-based networking system.

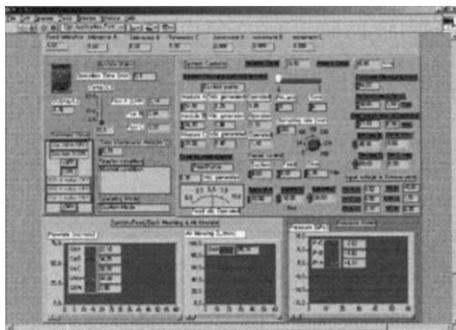


Fig. 1 Control panel programmed

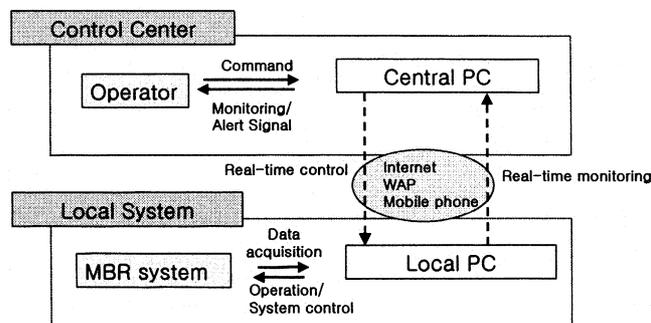


Fig. 2 Conceptual diagram of the web-based networking system

Results and Discussion

Permeate is produced at constant flux mode in lab-scale MBR process so that the TMP decreased as the membrane is fouled. Monitored TMP variation is expressed as specific flux decline curve presented in Fig. 3. Namely, the specific flux is calculated by dividing the monitored TMP into the initial TMP. Without any physical and chemical washing, the membrane could be operated for 60 days and the specific flux is maintained at about 0.7. This implied that the membrane is not fouled significantly, and still exhibited 70% of its capacity of the clean water flux. The specific flux variation for a week (circled period) is magnified in Fig. 3. The flux fluctuated like a waveform, repeating rise and fall. This pattern is attributed to the algorithm of the MBR information system. In order to find out the desirable point, at which the monitored value agreed with the simulation result, computer changed the operation factor such as suction flow-rate (permeate flux) by increasing or decreasing the signal output. For instance, if the monitored value were higher than simulated one, computer would diminish the signal output, by which the suction pump's rotation speed is controlled. Then again, newly monitored value is compared to the simulation result, and the increment or decrement of the signal output is decided. Computer repeated this procedure until the difference between the monitored and simulated value satisfied the tolerance. Therefore, in repeating this step, the specific flux fluctuated, but converged into some value. Web-based MBR system performed this iteration process automatically on behalf of an operator.

Fig. 4 presents the specific flux when the lab scale MBR is controlled manually without computer. In manual operation, TMP pressure drop is checked once per day, and membrane is operated only by operator's knowledge, intuition, and experience. As shown in Fig. 4, the operation mode could be divided into 4 periods. In first period, no washing is performed. The specific flux is maintained at around 0.5. However, it decreased rapidly to become 0.2 at the end of the first period. The membrane seemed to be fouled seriously, so that the membrane surface is physically flushed by clean water. Although physical washing, the flux decreased to 0.2 again in the second period. So, the chemical washing using 300 ppm NaOCl solution is carried out. In this cleaning step, the fouled membrane is detached from the reactor, and fully submerged into the chemical solution for 3 hours. The cleaned membrane is re-installed and operation started again (Period III).

However, as shown in the figure, the specific flux after the chemical cleaning is 0.5. This implied that the cleaning efficiency is about 50% and not good enough to recover the membrane capacity into the initial flux. The specific flux became 0.1 after 30 days operation in period III. Therefore, the more intensive cleaning is performed at the end of period III. However, at the beginning of period IV, the fouling rate is so fast that the membrane is fouled seriously only for a week.

Once a membrane is fouled too seriously, it is almost impossible to recover its capacity of filtration (Yusuf and Murray, 1993; Ueda and Hata, 1999) and the fouling rate became faster compared to the healthy membrane. The membrane filtration capacity is irreversible (Kuberkar and Davies, 2000). Fig. 4 presents this irreversible behavior of the fouled membrane, clearly (period IV). Therefore, in order to prolong the life span of a membrane, an operator should prevent the abrupt membrane fouling and sudden flux decrease or TMP increase and maintain steady state as possible. Some researchers expressed this kind of membrane operation as critical flux operation in crossflow type filtration. However, it is so difficult to operate the membrane at the critical flux by an operator manually, as shown in this experiment.

Consequently, Web-based MBR system shows the more stable transmembrane pressure, while the manually operated system shows the abrupt transmembrane pressure drop and the membrane fouling. However, there is no significant difference in the effluent quality between two systems due to the high biomass and the complete retention of the solids by the membrane filtration.

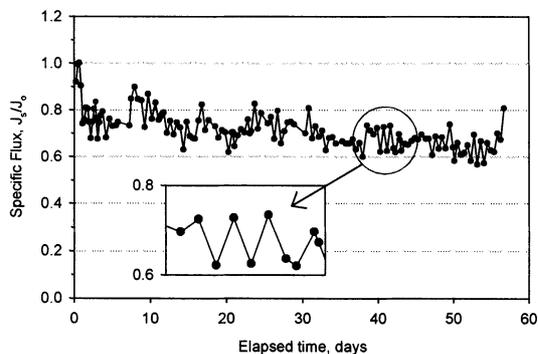


Fig. 3 Monitored TMP variation expressed as specific flux decline curve. The flux variation for a week (circled period) is magnified

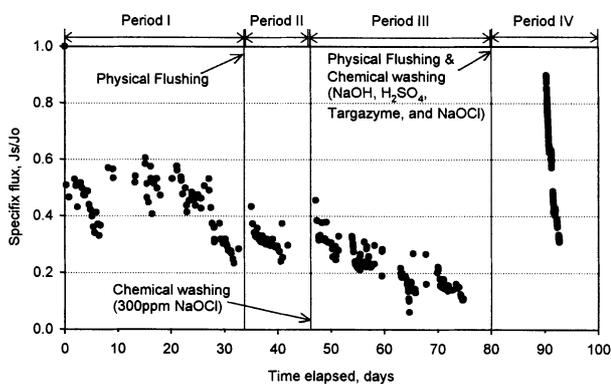


Fig. 4 Specific flux decline curve controlled by manual

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